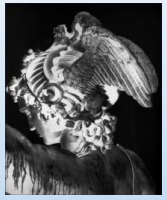
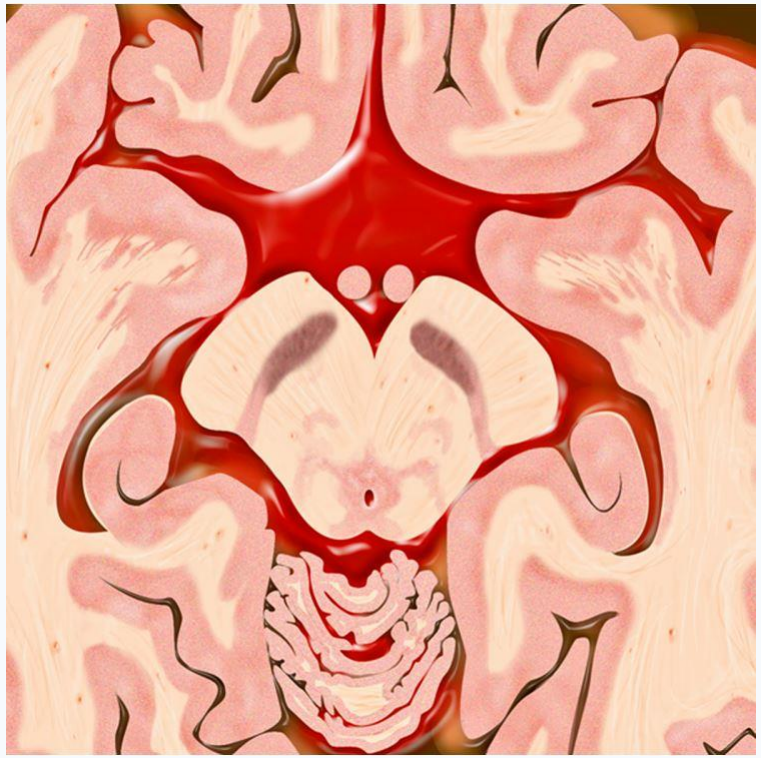
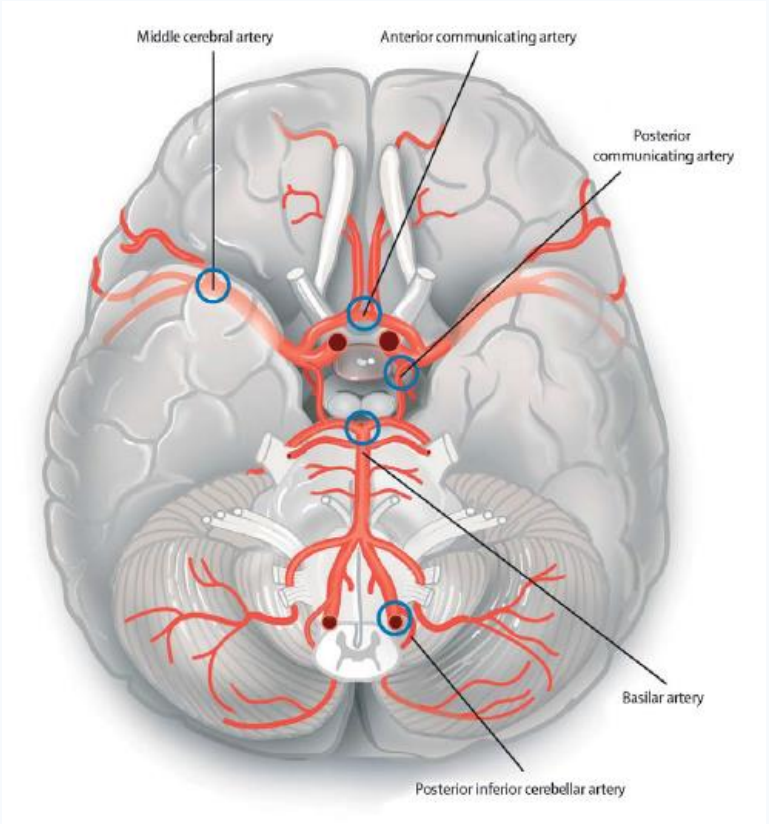
Imaging and treatment indication of subarachnoid haemorrhage and vasospasm

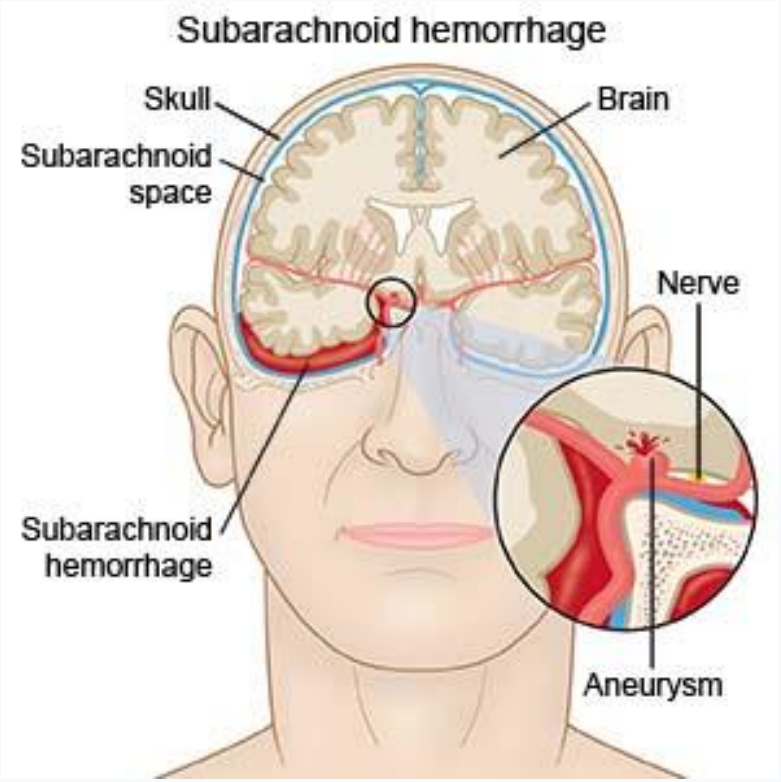


S.Nappini, E.Fainardi
AOU Careggi - Firenze

SUBARACHNOID HAEMORRAGE





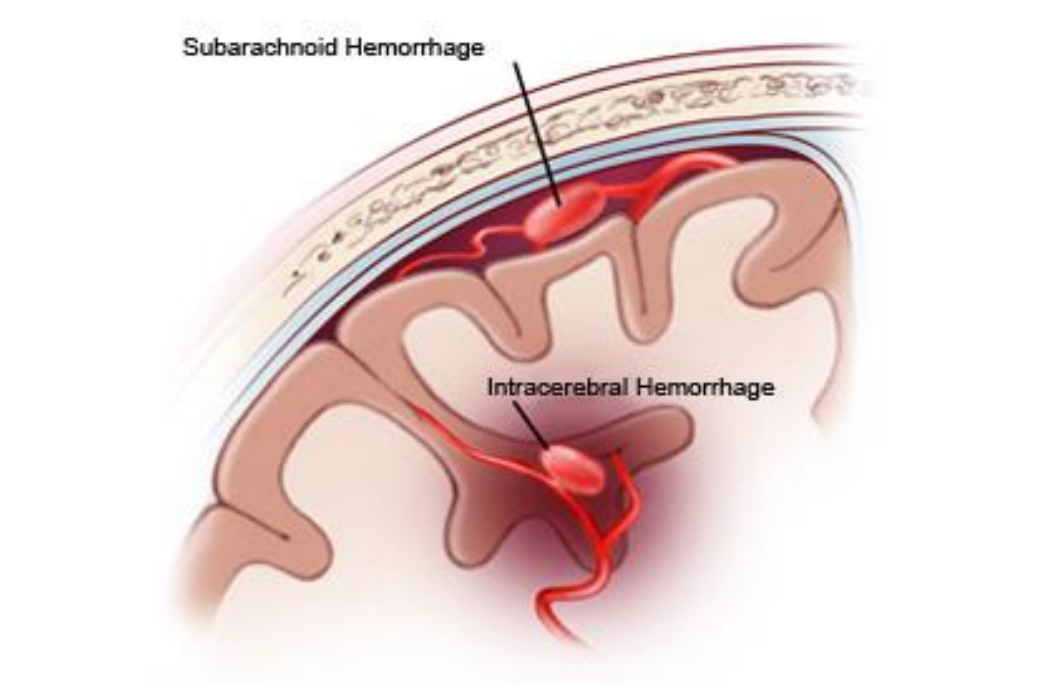


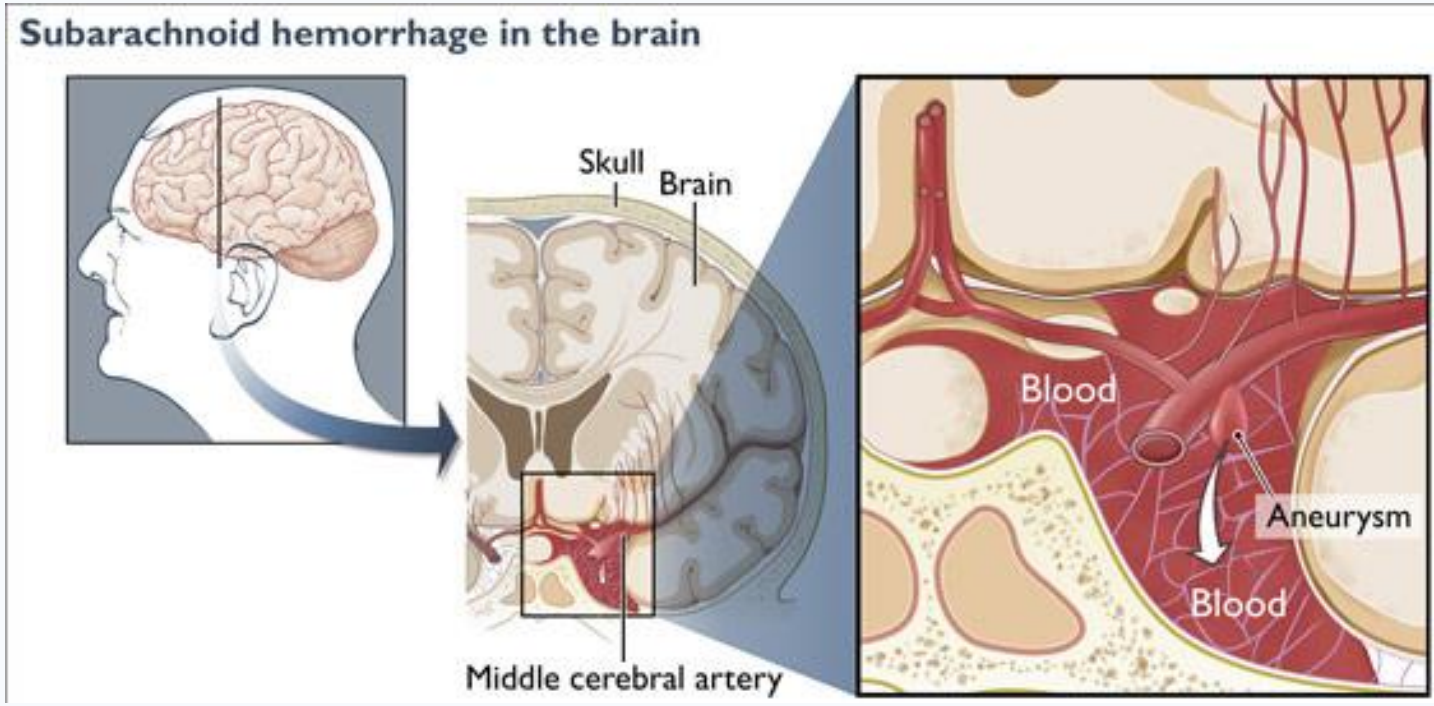
- Extravasation of blood from the intravascular compartment within the subarachnoid space between the leptomeningeal sheets (arachnoid and pia mater)

- Mainly due at the rupture of an aneurysm

Suarez JI et al. N Engl J Med 2006; 354: 387-396
Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666

ANEURYSMAL SAH



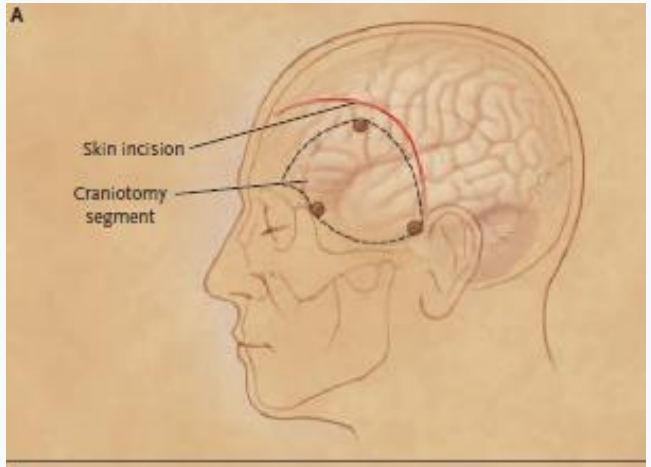


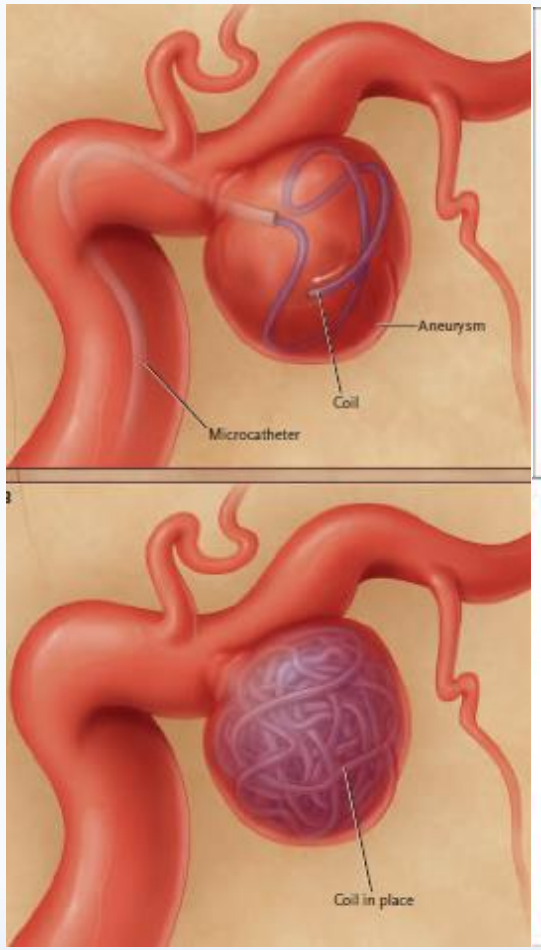
- Represents about 5-10% of all strokes and 85% of cases of spontaneous (non-traumatic) SAH

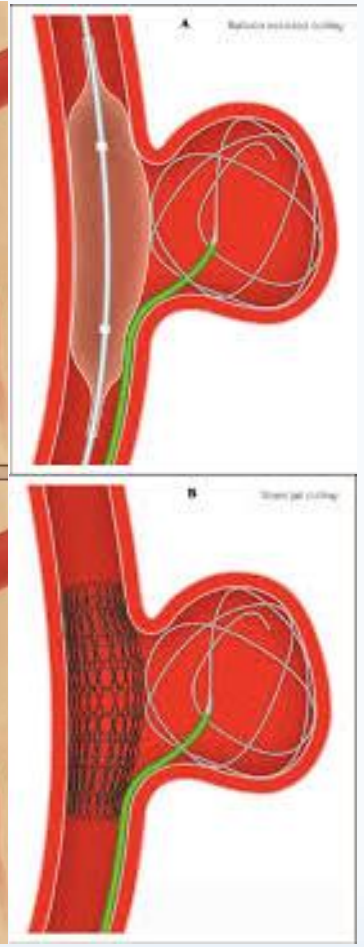
- Determines severe disability and high mortality

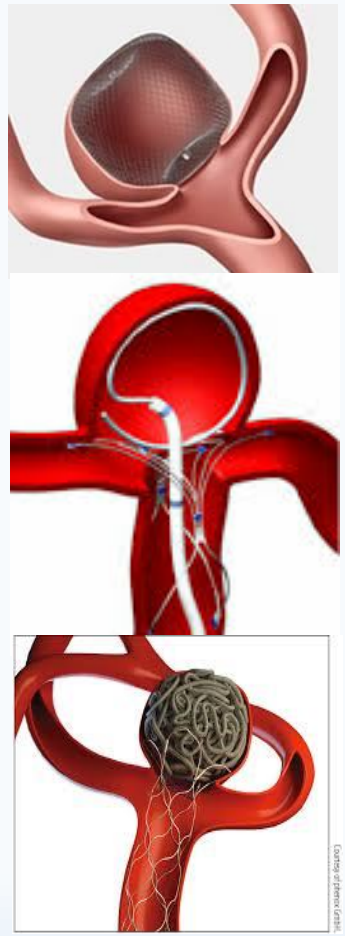
Brisman JL et al. N Engl J Med 2006; 355: 928-939
van Gijn J et al. Lancet 2007; 369: 306-318

ANEURYSMAL SAH TREATMENT (acute phase)









Clipping

Coiling

Flow-diversion

Intra/extra saccular devices

- Drastically improvement of neurological symptoms and prognosis

Colby GP et al. Neurosurg Clin N Am 2010; 21: 247-261
Pearl M et al. Neurosurg Clin N Am 2010; 21: 271-280
Rabinstein AA et al. Lancet Neurol 2010; 9: 504-519
Hacein-Bey L, Provenzale JM. AJR Am J Roentgenol 2011; 196: 32-44

THE ROLE OF NEUROIMAGING

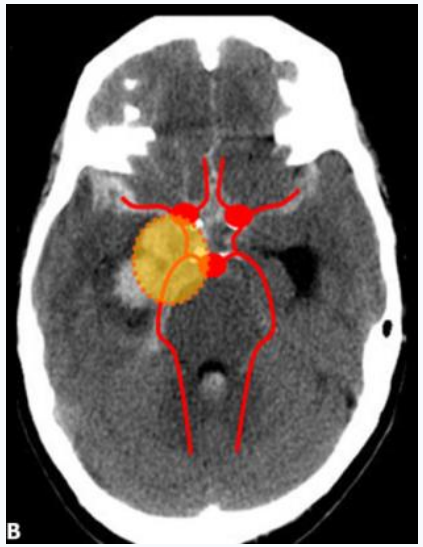
de Oliveira Manoel *et al. Critical Care* 2014, **18**:557
http://ccforum.com/content/18/6/557

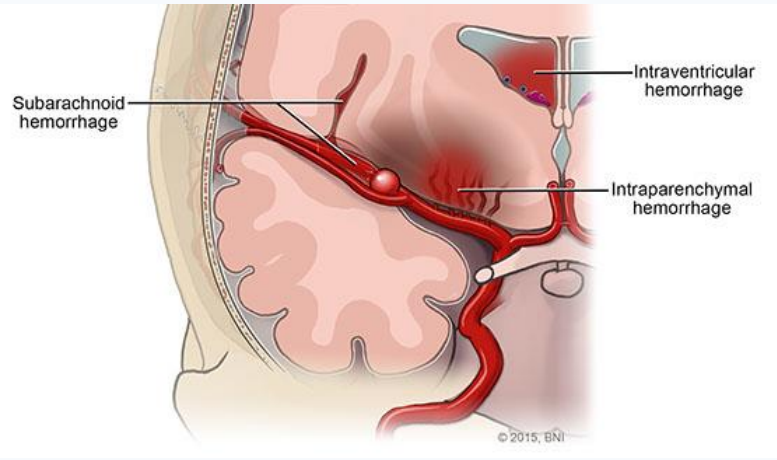
CRITICAL CARE

REVIEW

Aneurysmal subarachnoid haemorrhage from a neuroimaging perspective

Airton Leonardo de Oliveira Manoel[1,2,3*], Ann Mansur[3], Amanda Murphy[4], David Turkel-Parrella[2,5], Matt Macdonald[6], R Loch Macdonald[3,5], Walter Montanera[2,3], Thomas R Marotta[2,3], Aditya Bharatha[2,3], Khaled Effendi[2] and Tom A Schweizer[3,7]

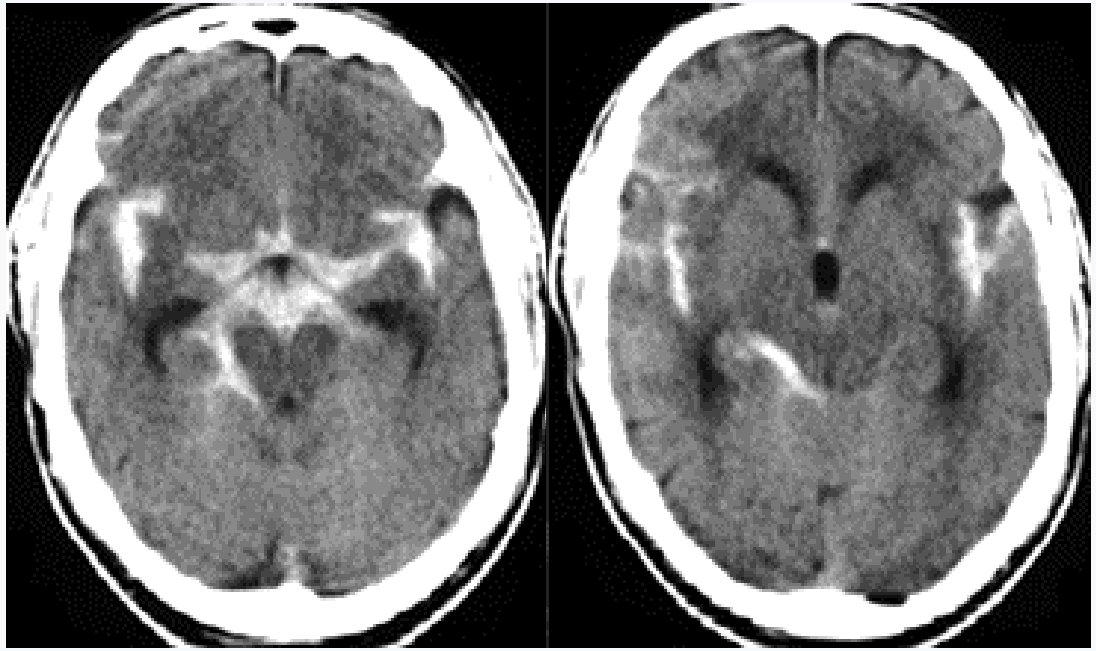


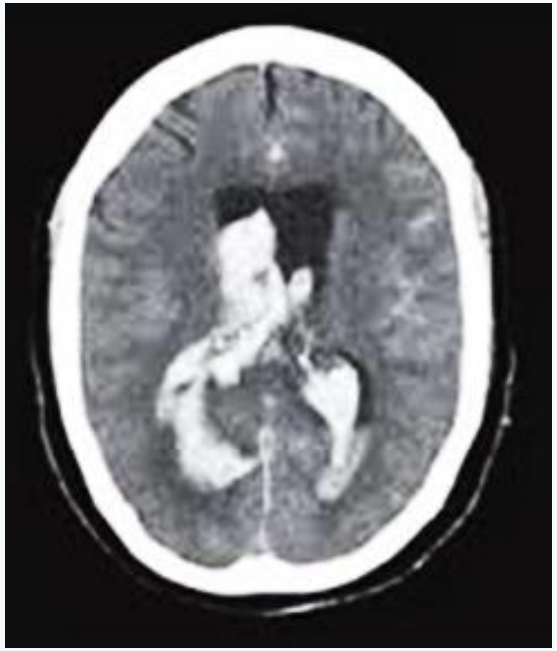


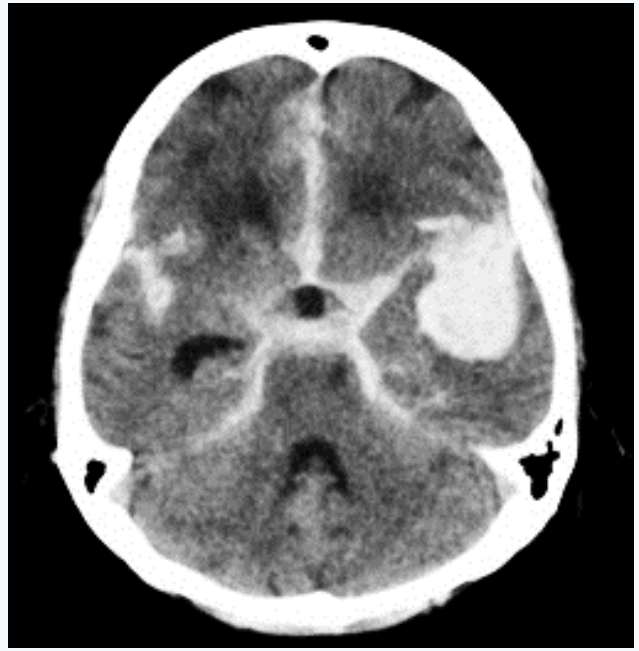
- Identify the presence and location of the subarachnoid bleeding and any associated intraparenchymal hematoma
- Identify the aneurysm responsible for SAH
- Early recognition of possible ESA complications:
  - Rebleeding
  - Hydrocephalus
  - Vasospasm
- Provide prognostic predictive parameters

Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323

THE SAH DIAGNOSIS: NECT SCAN







First choice tool for SAH diagnosing:

- Quick execution and widely available
- Low radiation dose and does not imply the administration of contrast medium
- Not contraindicated in patients wearing medical devices
- Easily recognizes the signs of SAH = presence of hyperdense material within the subarachnoid spaces (cisterns of the base, fissures, hemispherical grooves), ventricles and cerebral parenchyma

van Gijn J et al. Lancet 2007; 369: 306-318
Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323
Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666

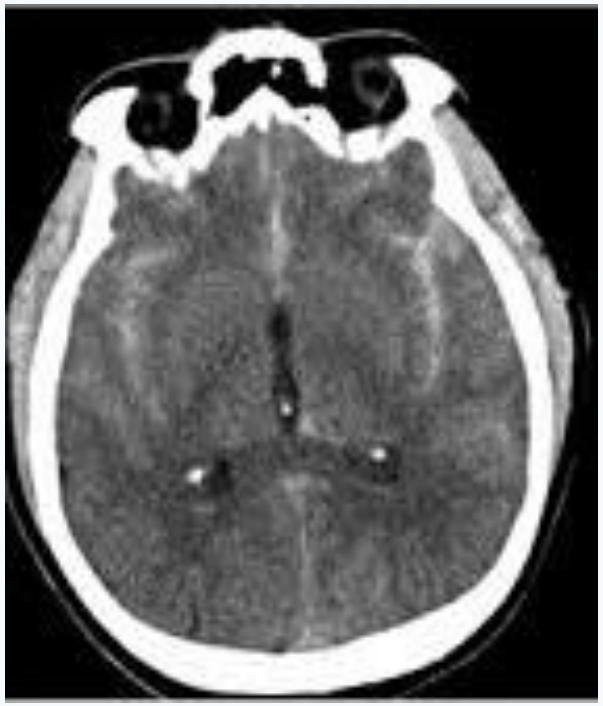
DIAGNOSTIC ACCOURACY OF NECT SCAN

Sensitivity of Early Brain Computed Tomography to Exclude Aneurysmal Subarachnoid Hemorrhage

A Systematic Review and Meta-Analysis

Nicole M. Dubosh, MD; M. Fernanda Bellolio, MD; Alejandro A. Rabinstein, MD; Jonathan A. Edlow, MD

Stroke 2016; 47: 750-755



- 95-100% sensitivity in identifying ESA in the first 12 hours from bleeding
- Reduced by about 5% if the bleeding is minimal
- Shortened to 50-60% 7 days after stroke

van Gijn J et al. Lancet 2007; 369: 306-318
Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323
de Oliveira Manoel AL et al. Crit Care 2014; 18: 557
Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666

MISSED DIAGNOSIS

Missed Diagnosis of Subarachnoid Hemorrhage in the Emergency Department

Marian J. Vermeulen, MHSc; Michael J. Schull, MD, MSc, FRCPC

Stroke 2007; 38: 1216-1221

Initial Misdiagnosis and Outcome After Subarachnoid Hemorrhage

Kowalski RG et al. JAMA 2004; 291: 866-869

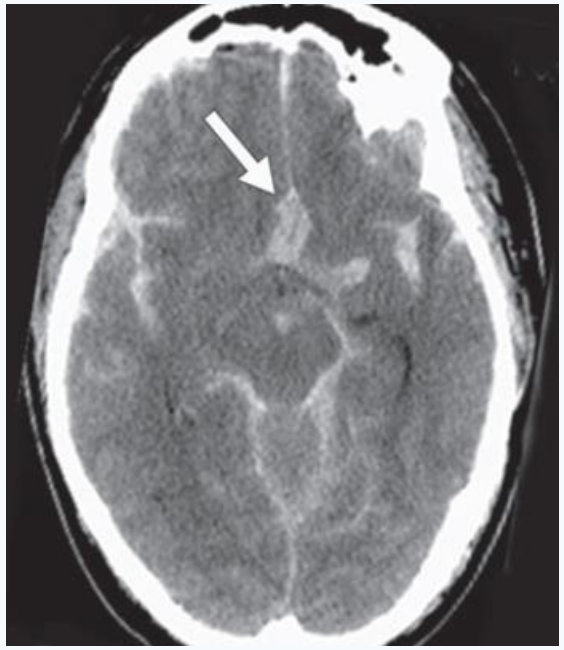
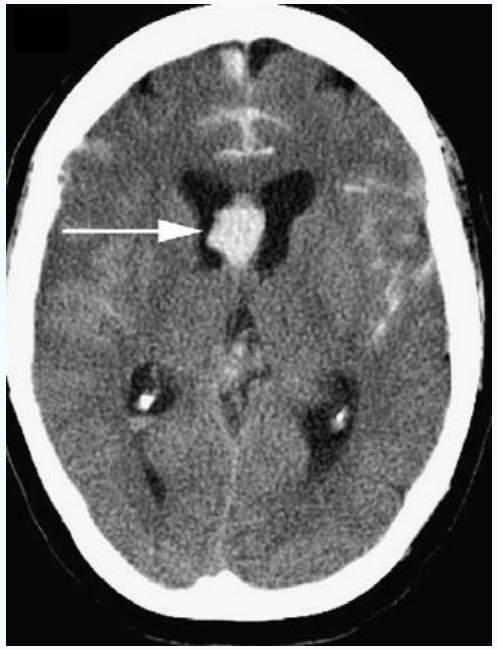
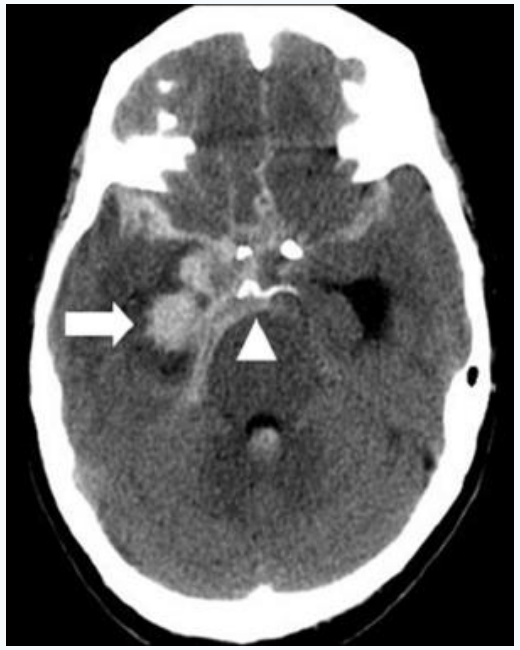
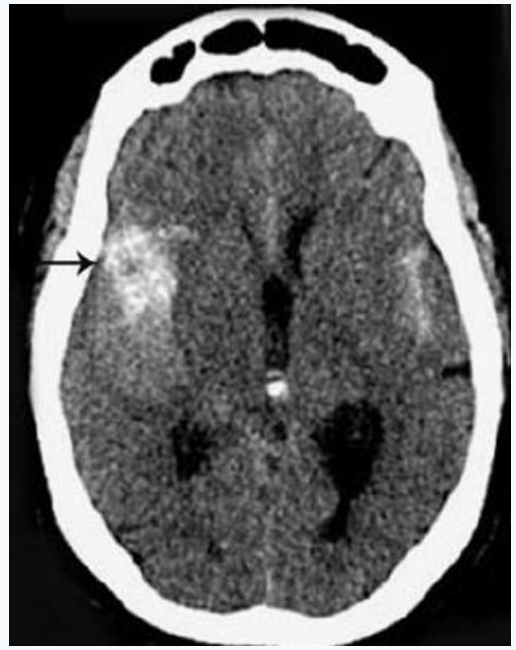
About 5-12% of patients with ESA are not correctly diagnosed:

- Failure to perform emergency CT scan to incorrect clinical diagnosis

- Lack of recognition of the SAH to the CT for the low subarachnoid bleeding and / or execution of the investigation after 48 hours from the onset

Provenzale JM, Hacein-Bey L. Emerg Radiol 2009; 16: 441-451

ABILITY TO LOCALIZE ANEURYSMS

- The distribution of subarachnoid bleeding
- The presence of a clot thicker than the remaining subarachnoid haemorrhagic effusion
- The appearance of a hypodense focal zone in the context of subarachnoid hemorrhagic suffusion

help to understand the possible location of the aneurysm even if reliability remains relative

van Gijn J et al. Lancet 2007; 369: 306-318; Provenzale JM, Hacein-Bey L. Emerg Radiol 2009; 16: 441-451;
Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323 ; Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666

PROGNOSTIC VALUE OF NECT

Effect of Cisternal and Ventricular Blood on Risk of Delayed Cerebral Ischemia After Subarachnoid Hemorrhage

The Fisher Scale Revisited

Jan Claassen, MD; Gary L. Bernardini, MD, PhD; Kurt Kreiter, MA; Joseph Bates, BS; Yunling E. Du, PhD; Daphne Copeland, MPH; E. Sander Connolly, MD; Stephan A. Mayer, MD

Stroke 2001; 32: 2012-2020

Quantitative Analysis of Hemorrhage Volume for Predicting Delayed Cerebral Ischemia After Subarachnoid Hemorrhage

Sang-Bae Ko, MD, PhD; H. Alex Choi, MD; Amanda Mary Carpenter, BA; Raimund Helbok, MD; J. Michael Schmidt, PhD; Neeraj Badjatia, MD, MS; Jan Claassen, MD, PhD; E. Sander Connolly, MD; Stephan A. Mayer, MD; Kiwon Lee, MD

Stroke 2011; 42: 669-674

The volume of blood contained within the basal cisterns and ventricles

↓

Specific predictor of vasospasm and prognosis

PROGNOSTIC VALUE OF NECT

Subarachnoid Hemorrhage Grading Scales

A Systematic Review

*David S. Rosen and R. Loch Macdonald**

Neurocrit Care 2005; 2: 110-118

The amount of blood visible on the intracranial level in SAH (subarachnoid, intraventricular and intraparenchymal)

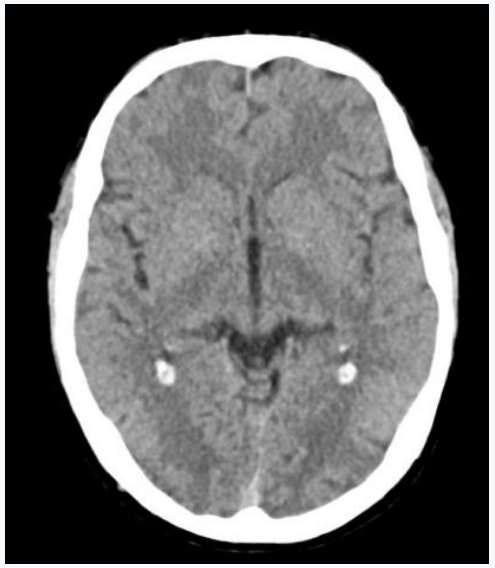
↓

High predictive power for the development of hydrocephalus and vasospasm

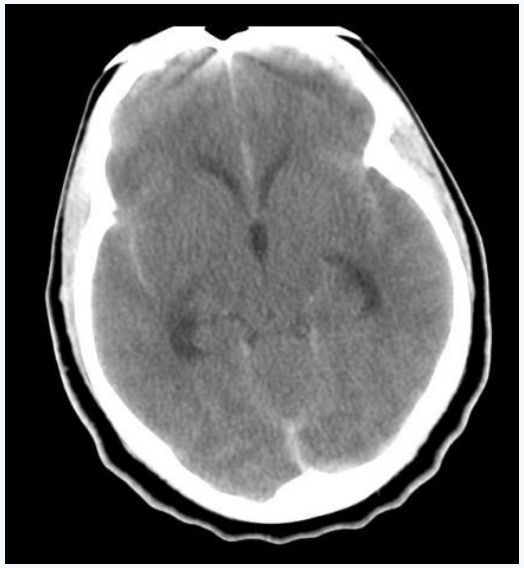
↓

Classifications to stratify this risk into categories of increasing prognostic severity

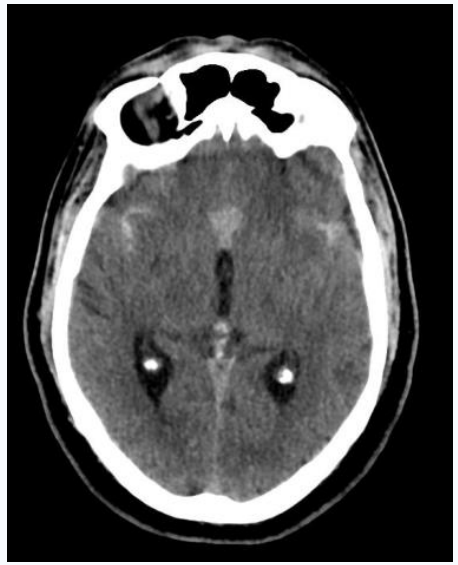
THE FISHER GRADING SCALE



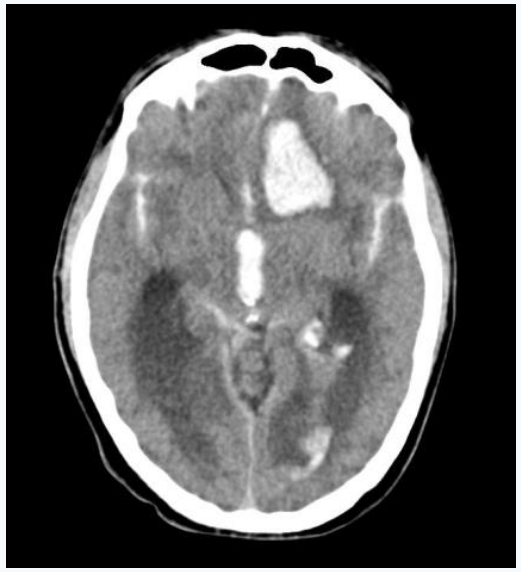
Grade 1



Grade 2



Grade 3

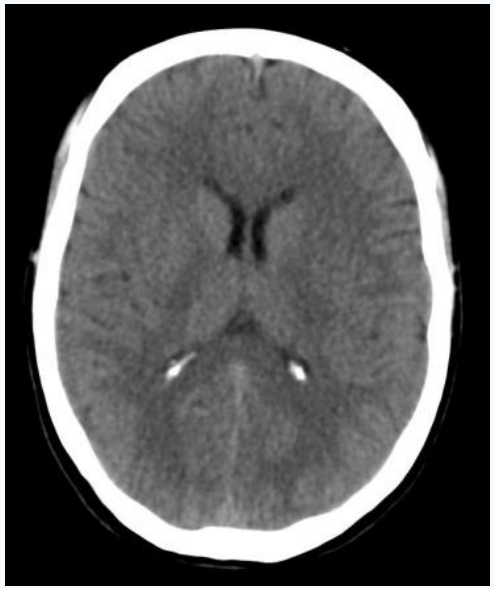


Grade 4

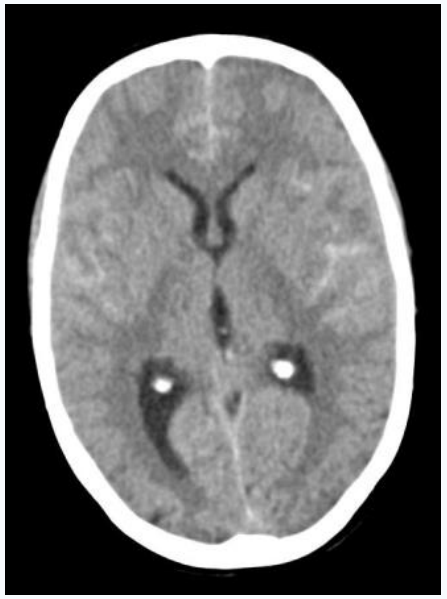
- ***Grade 1***= no bleeding
- ***Grade 2*** = diffuse presence of blood in the subarachnoid space, in the absence of vertical layers of blood deposition ≥ 1 mm of thickness
- ***Grade 3*** = diffuse presence of blood in the subarachnoid space, in presence of vertical layers of blood deposition ≥ 1 mm of thickness
- ***Grade 4*** = diffuse presence of blood in the subarachnoid space of any thickness, in the presence of intraparenchymal or intraventricular blood effusion

Fisher CM et al. Neurosurgery 1980; 6: 1-9

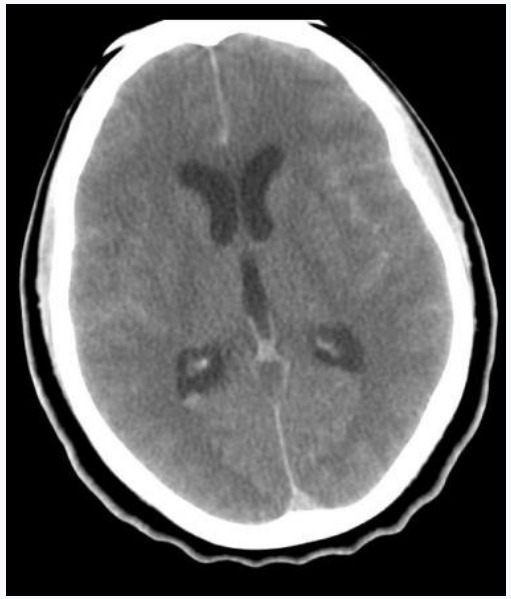
MODIFIED FISHER GRADING SCALE



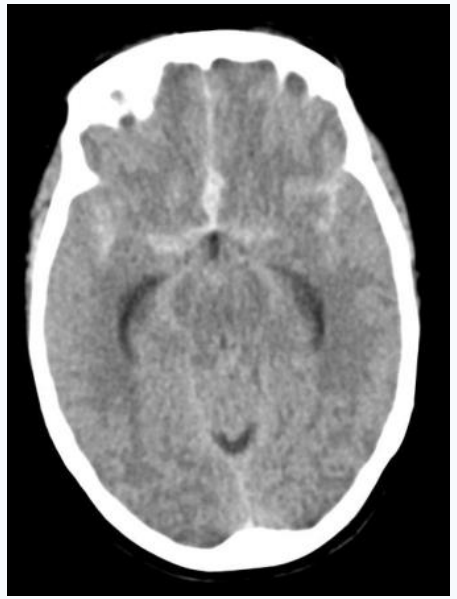
Grade 0



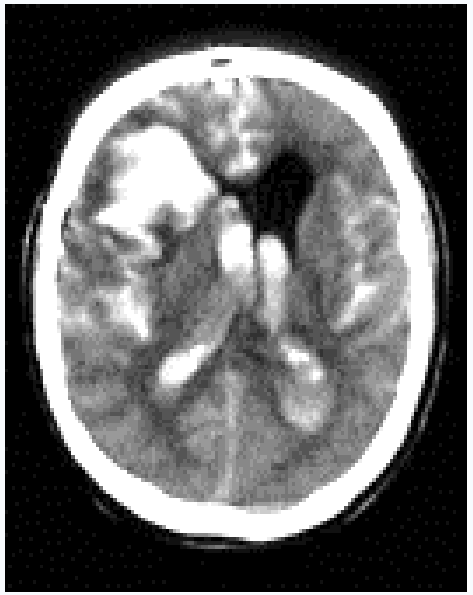
Grade 1



Grade 2



Grade 3

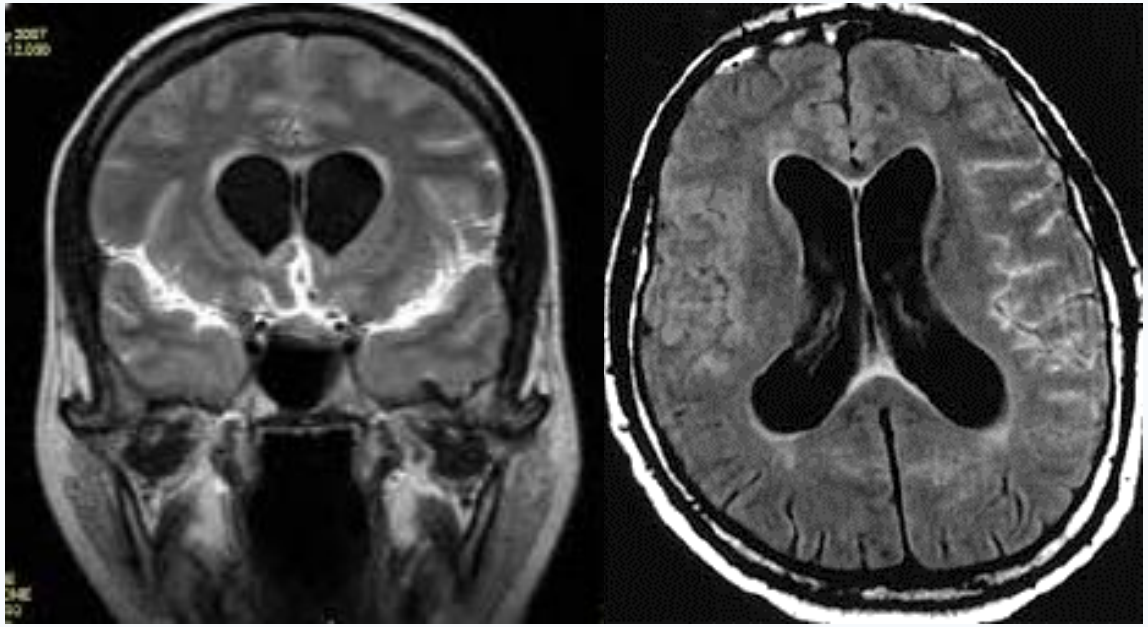


Grade 4

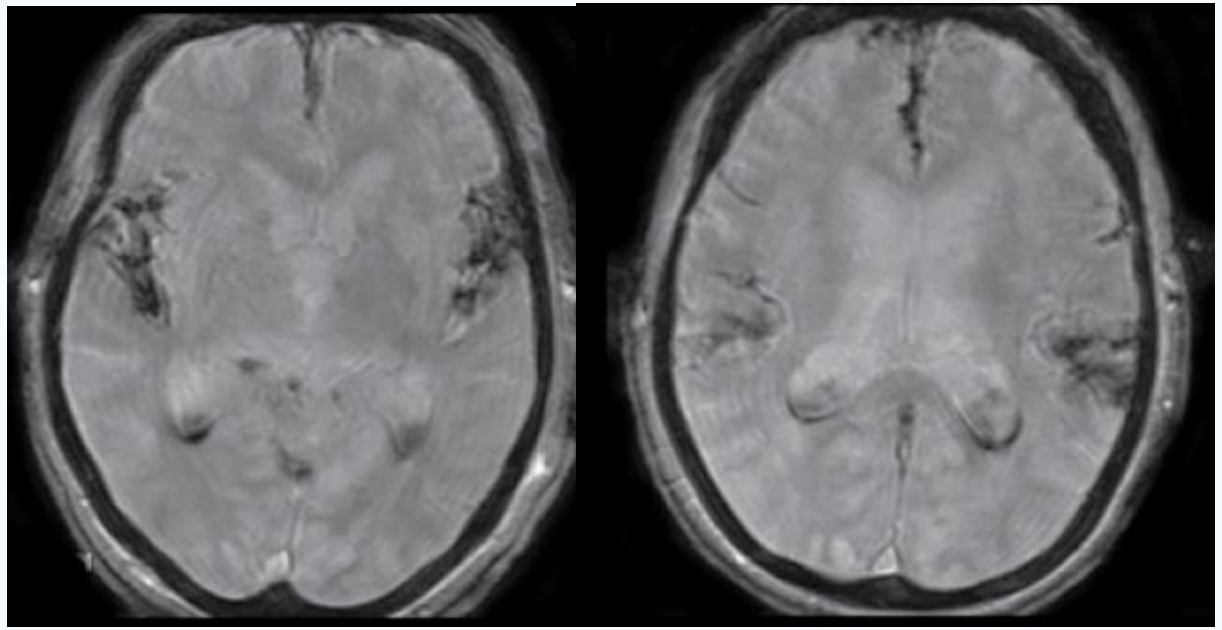
- ***Grade 0*** = no bleeding
- ***Grade 1*** = minimal subarachnoid bleeding, no intraventricular blood effusion
- ***Grade 2*** = minimal subarachnoid bleeding, with intraventricular blood effusion
- ***Grade 3*** = large subarachnoid bleeding, no intraventricular blood effusion
- ***Grade 4*** = large subarachnoid bleeding, with intraventricular effusion

Claassen J et al. Stroke 2001; 32: 2012-2020

MRI



FLAIR



GRE

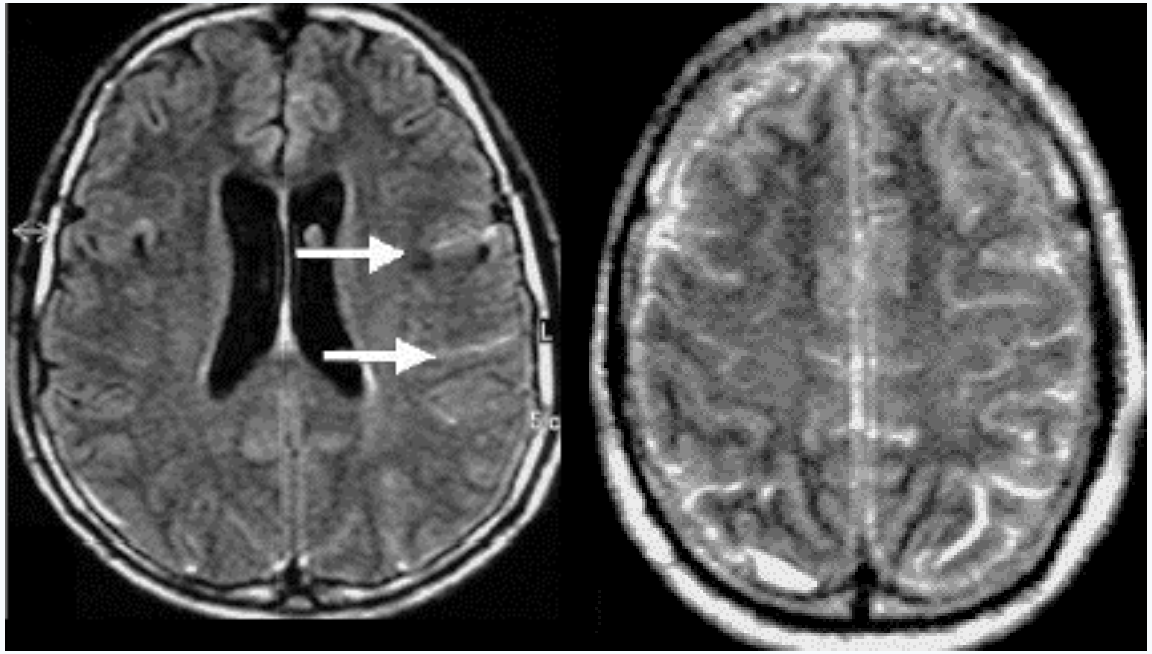
Extreme reliability in the diagnosis of SAH:

• FLAIR (hyperintense material in the subarachnoid space) = 80% sensitivity in the acute phase, 90% in the subacute phase

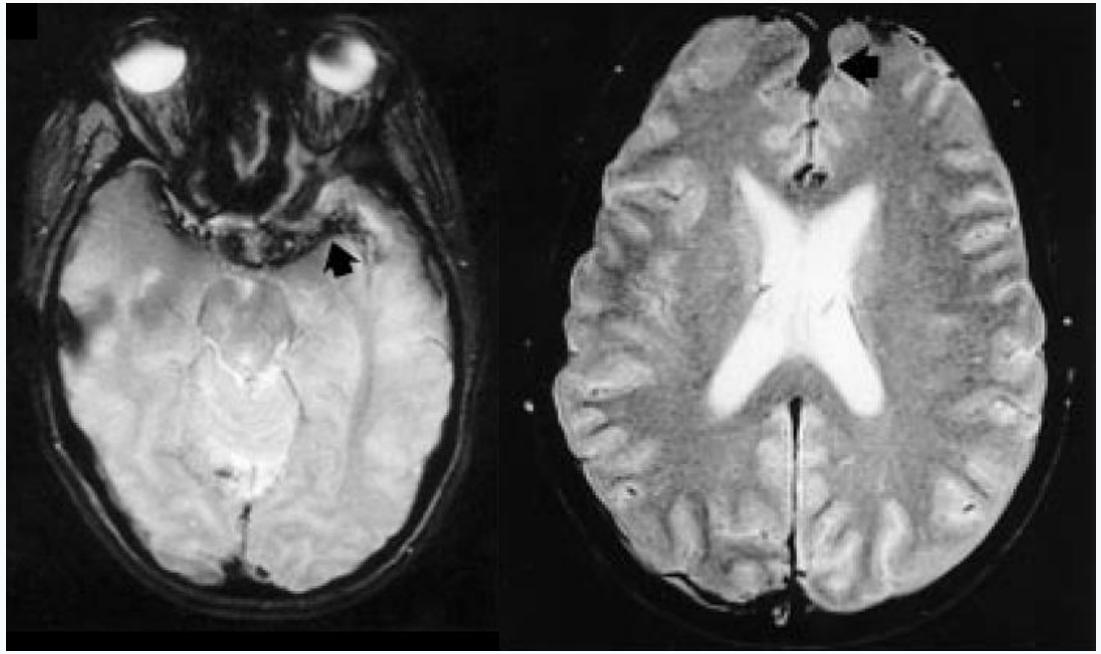
• GRE (hypointense material in the subarachnoid space) = 95% sensitivity in the acute phase, 100% in the subacute phase

Mitchell P et al. J Neurol Neurosurg Psychiatry 2001; 70: 205-211; Fiebach JB et al. Neuroradiology 2004; 46:44-48;
Wiesmann M et al. J Neurosurg 2002; 96: 684-689; Imaizumi T et al. Stroke 2003; 34: 1693-1698;
da Rocha AJ et al. J Comput Assist Tomogr 2006; 30: 295-303

LIMITATIONS OF MRI



FLAIR

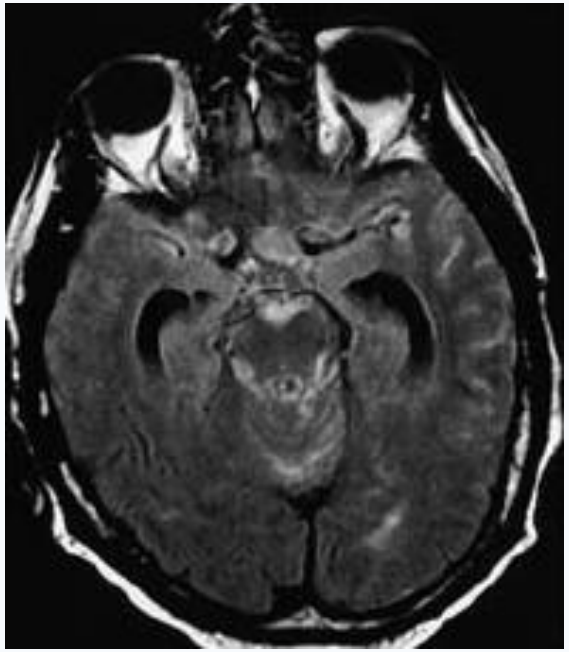


GRE

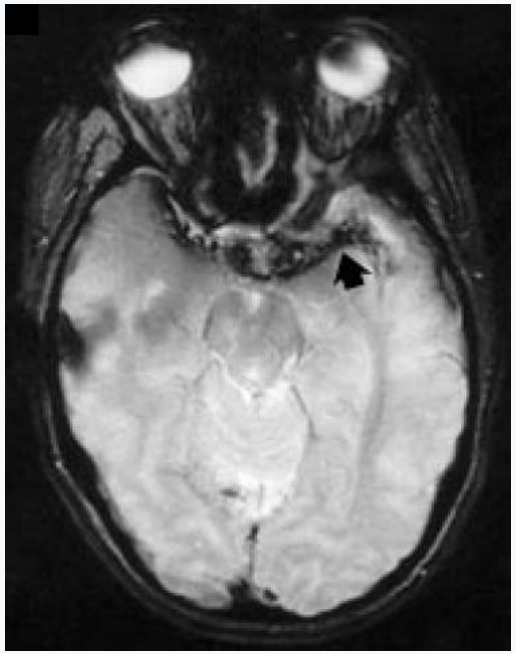
- "Consumes time“: the acquisition takes about 10’
- More contraindications than CT (pace-maker, metal implants, claustrophobia, patient collaboration)
- Not all centers have adequate MR technology

Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323
Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666

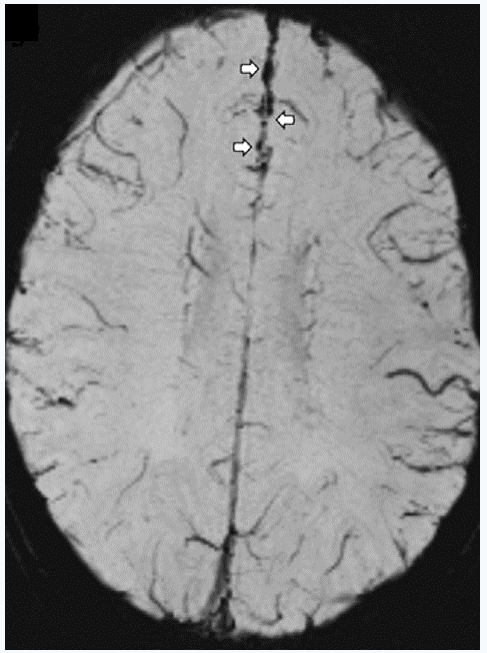
MRI



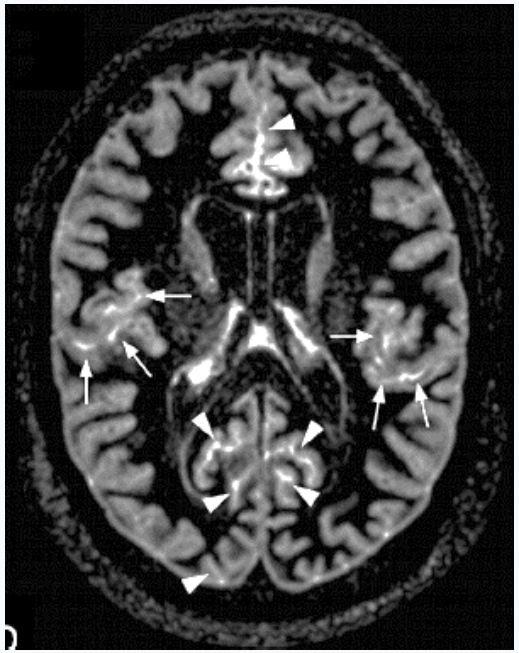
FLAIR



GRE



SWI



DIR

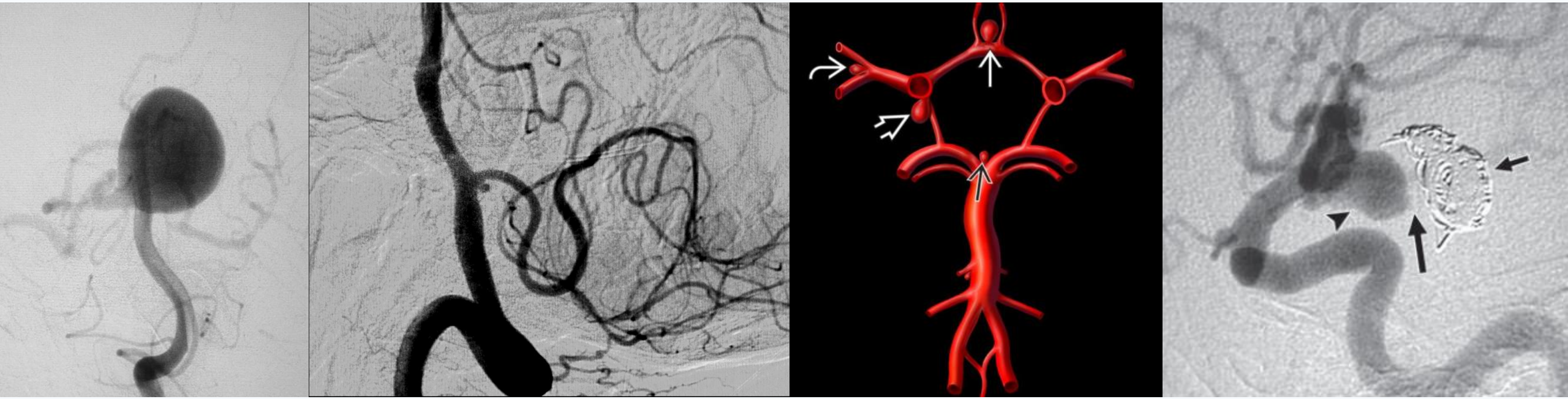
MRI is recommended:

• In the acute phase when the CT is negative and the SAH clinical suspicion is very strong (although it can not replace the lumbar puncture in terms of accuracy)

• In the subacute phase because it has a higher sensitivity to CT identifying the SAH (in this stage may been useful SWI and DIR sequences)

van Gijn J et al. Lancet 2007; 369: 306-318; Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323
de Oliveira Manoel AL et al. Crit Care 2014; 18: 557; Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666;
Verma RK et al. Eur J Radiol 2013; 82: 1539-1545; Hodel J et al. AJNR Am J Neuroradiol 2015; 36: 251-258

DSA

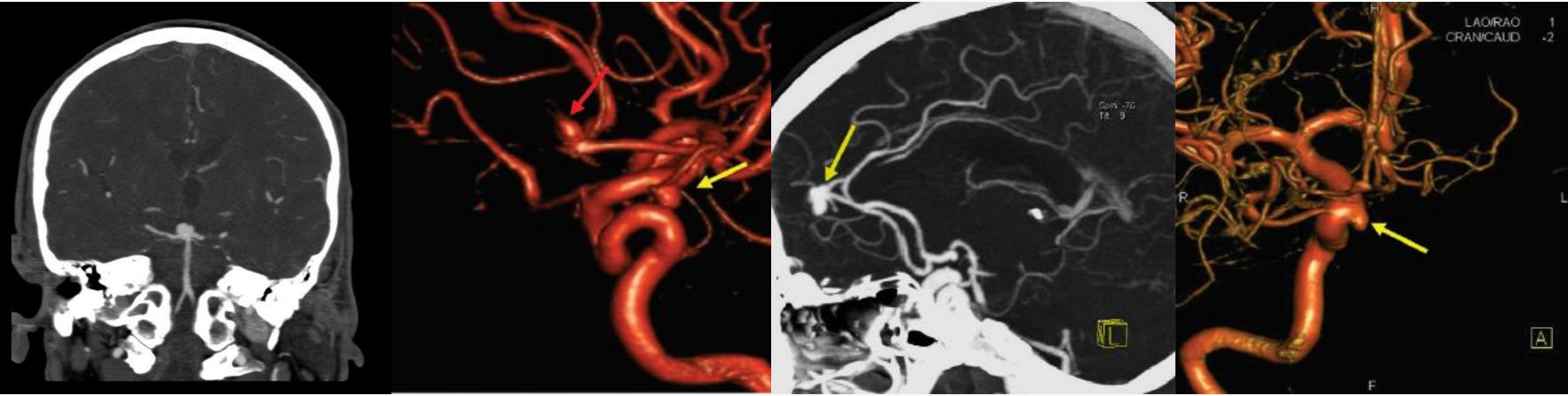


Gold standard:

- Recognition of the position, size and shape of the aneurysm responsible for bleeding
- Essential in treatment planning
- Follow up of aneurysms treated surgically or endovascularly

van Gijn J et al. Lancet 2007; 369: 306-318; Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323
Hacein-Bey L, Provenzale JM. AJR Am J Roentgenol 2011; 196: 32-44; de Oliveira Manoel AL et al. Crit Care 2014; 18: 557

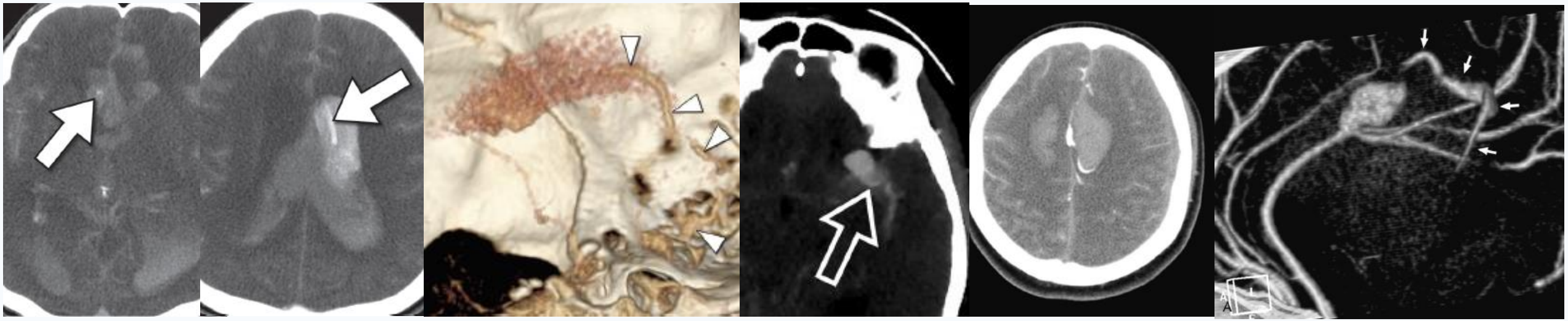
CTA



- 98% sensitivity in the detection of aneurysms > 3 mm, 60% if ≤3 mm
- First-line survey for the diagnosis of aneurysms
- Useful for planning surgery and endovascular procedures
- Can not replace the DSA that should always be performed especially if the CTA is negative

Menke J et al. Ann Neurol 2011; 69: 646-654; Westerlaan HE et al. Radiology 2011; 258: 134-145;
Lu L et al. Radiology 2012; 262: 605-612;; Bechan RS et al. Neuroradiology 2015; 57: 1239-1246;
Heit JJ et al. AJNR Am J Neuroradiol 2016; 37: 297-304; Aulbach P et al. AJNR Am J Neuroradiol 2016; 37: 236-243

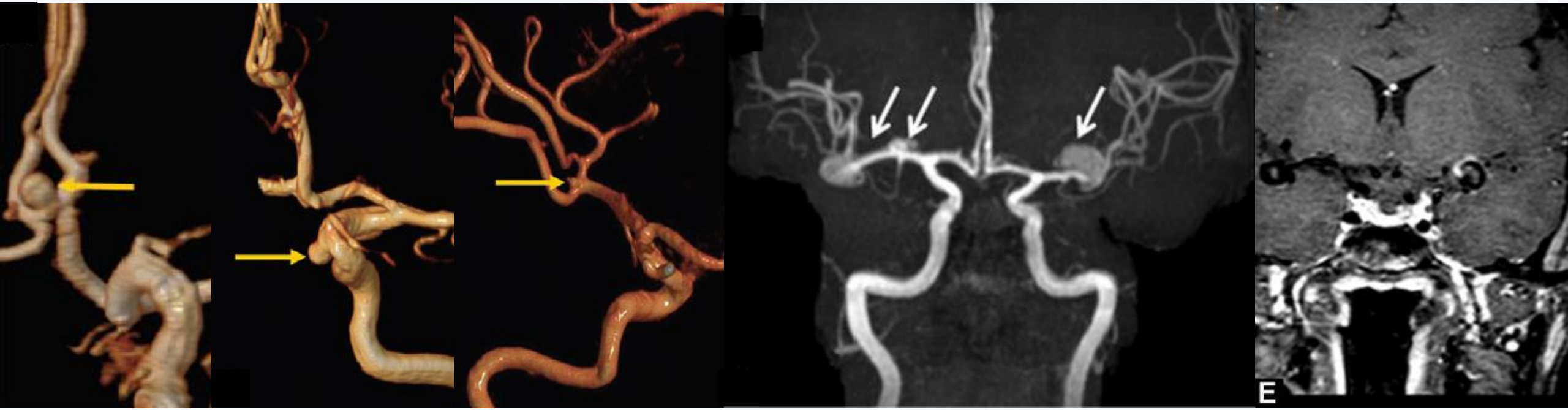
ACTIVE BLEEDING



- Focal areas of extravasation of contrast medium in the native images of the CTA
- “Nebulous" or "bubble" aspect of the aneurysm in the site of the bleeding in progress
- Appearance of vascular-like structures around the bleeding aneurysm

Nakatsuka M et al. Neuroradiology 2002; 44: 25-30
Ryu CW, et al. J Comput Assist Tomogr 2005; 29: 677-679
Suzuki K et al. AJNR Am J Neuroradiol 2012; 33: 1374-1379

MRA



- 95% sensitivity for aneurysms with dimensions> 3 mm (3T)
- Identifies bleeding ("bubble" appearance in angiographic reconstructions and circumferential parietal enhancement in post-contrastographic T1 images)
- Affected by the limitations of MR techniques (time, contraindications, lack of availability)

Li MH et al. Stroke 2009; 40: 3127-3129; Li MH et al. Neurology 2011; 77: 667-676;
Li MH et al. Radiology 2014; 271: 553-560; Sailer AMH et al. Stroke 2014; 45:119-126
Edjlali M et al. Diagn Interv Imaging 2015; 96: 657-666

HYSTORY OF RUPTURED ANEURYSMS

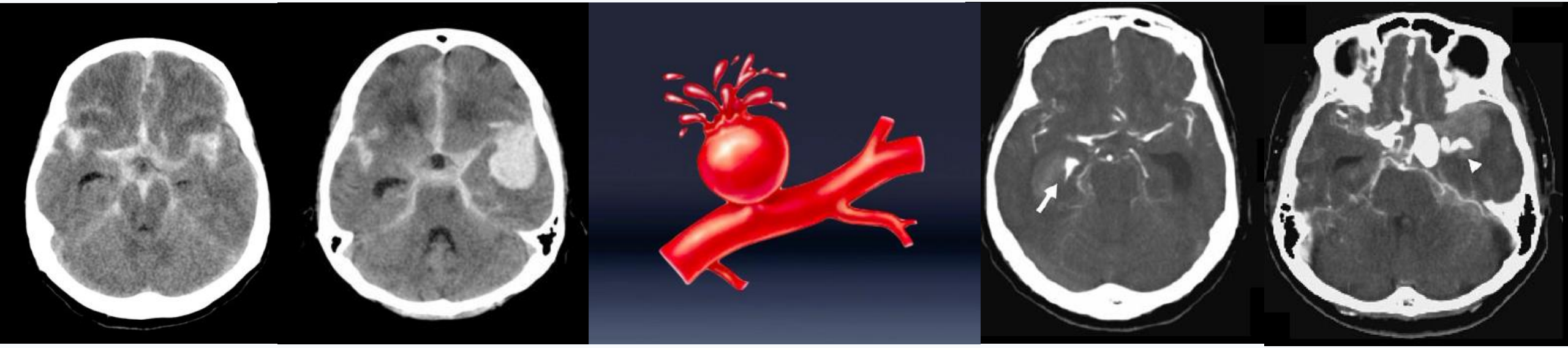
- Mortality without hospitalization: 56-86%
- In-hospital mortality: 26%
- Mortality at 30 days 38%

- Most deaths within 2 weeks (61% within 48h)
- 20% of survivors are dependent on neurological deficits

- Peak of rebleeding in the first 24h (in 8-23% within a few hours)
- Without treatment: 20% rebleeding in the first 2 weeks, 50% within 6 months, then risk stabilizes on 3% per year
- Second SAH mortality> 50%

Surgical or endovascular treatment of an aneurysm hemorrhagic should NOT be delayed

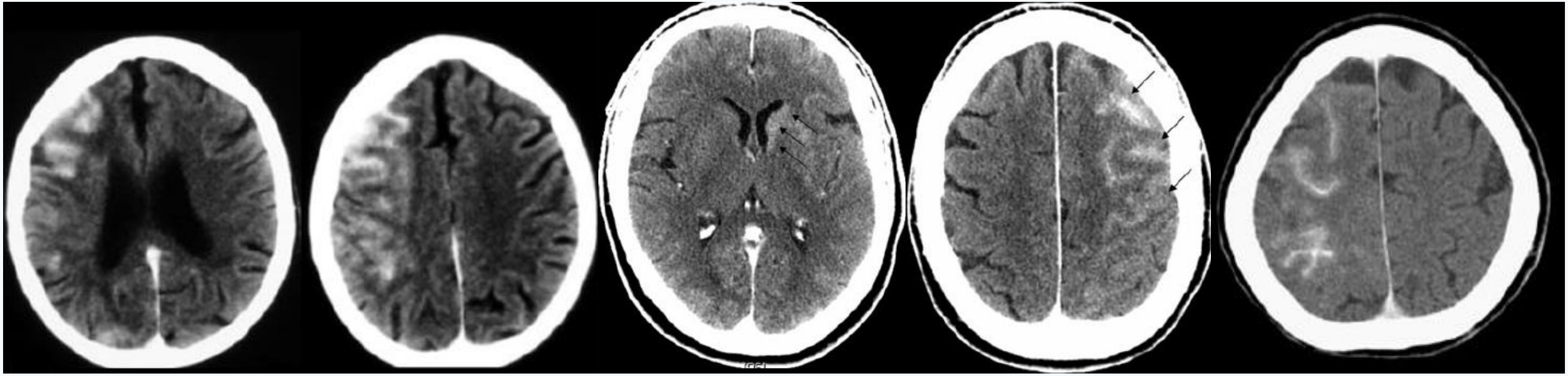
POST-SAH COMPLICATIONS: RE-BLEEDING



- 8-23% of cases in the first 24 hours from the onset
- Particularly common in the first 6 hours after the first bleeding
- Bad outcome

Hashiguchi A et al. Neurosurg Rev 2007; 30: 151-154
Starke RM et al. Neurocrit Care 2011; 15: 241-246.
Larsen CC, Astrup J. World Neurosurg 2013; 79: 307-312
Tang C et al. PLoS ONE 9: e99536.

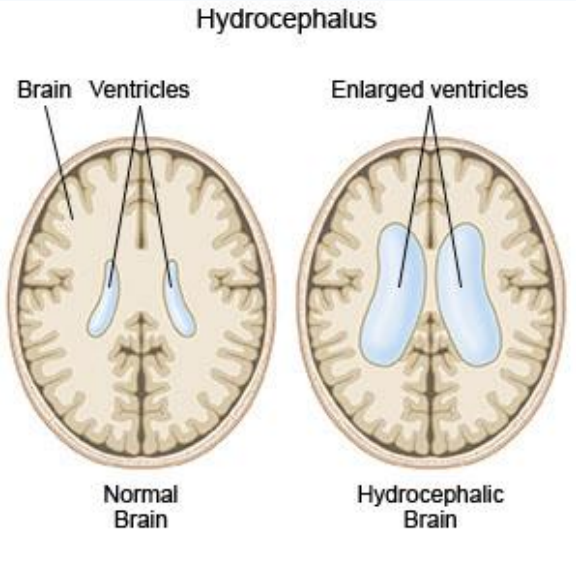
POST-PROCEDURAL CM EXTRAVASATION

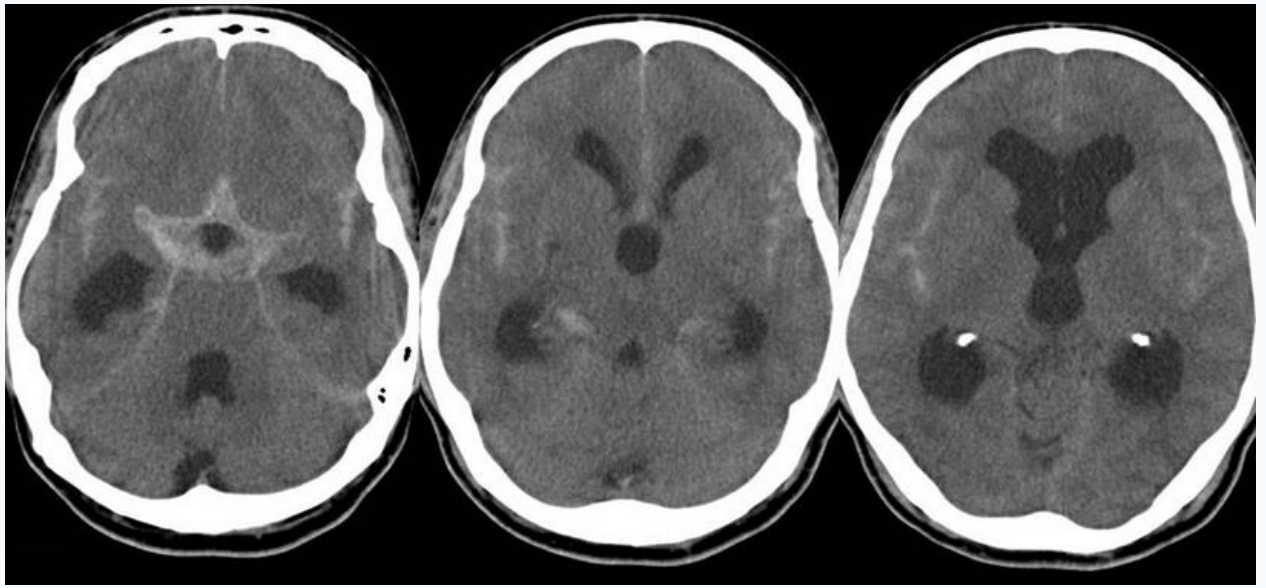


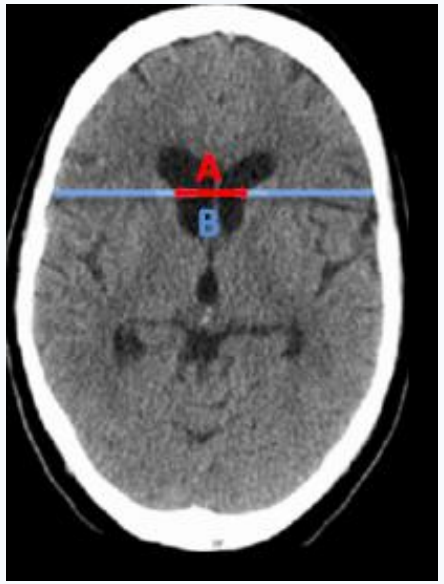
- Visible in NECT performed immediately after the embolization procedure in 20-50% of cases
- Can be confused with subarachnoid re-bleeding
- Disappears spontaneously after approximately 24 hours and is asymptomatic
- Determined by an increase in the permeability of the blood-brain barrier (BEE) induced by an excessive dose of iodinated contrast medium (hyperosmolarity, viscosity)

Ozturk A et al. AJNR Am J Neuroradiol 2006; 27: 1866-1875
Brisman JL et al. AJNR Am J Neuroradiol 2008; 29: 588-593
Baik SK et al. Neuroradiology 2008; 50: 259-266

POST-SAH COMPLICATIONS: HYDROCEPHALUS



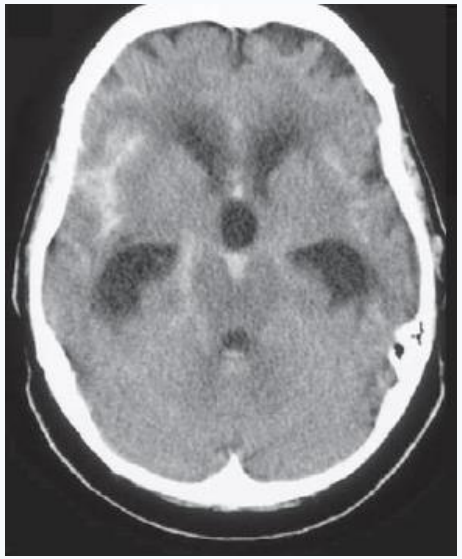


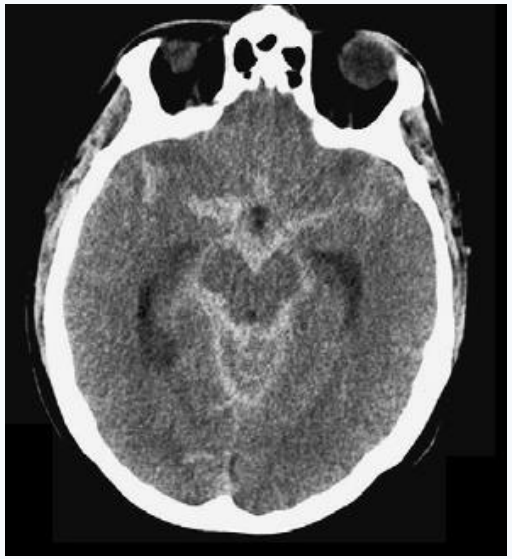


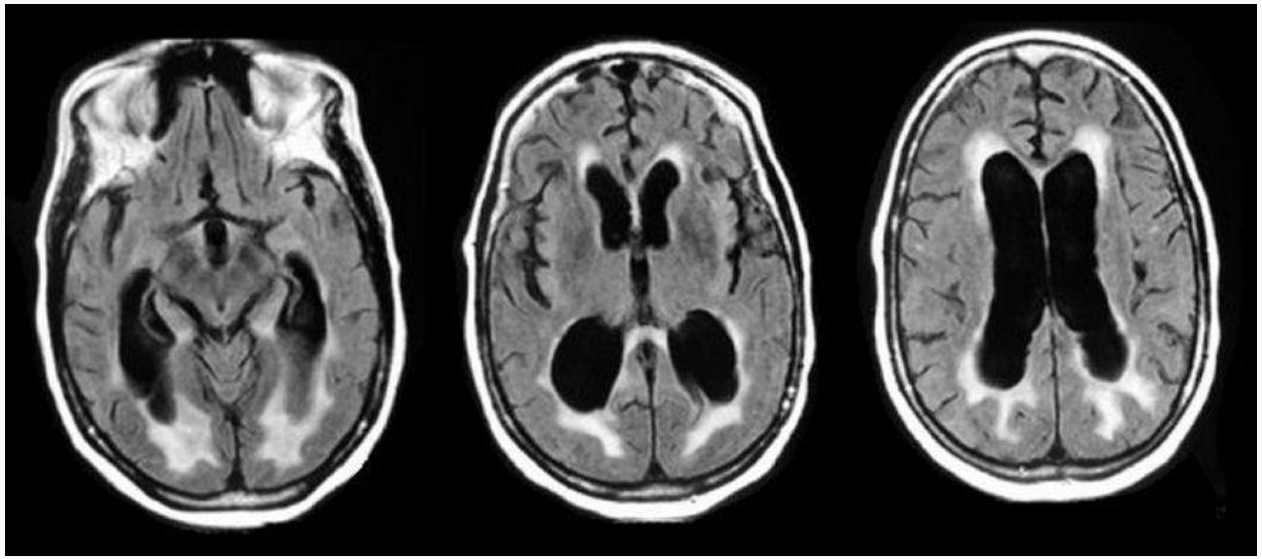
- Occurs at the NECT in 20-40% of patients:
- 20% within the first 48 hours of onset (acute hydrocephalus)
- 2-3% within 3-7 days from ESA (subacute hydrocephalus)
- 10-20% after 7 days from the event (chronic hydrocephalus)
- Can be measured with the Bicaudate Index

Van Gijn J et al. J Neurosurg 1985; 63: 355-362
Germanwala AV et al. Neurosurg Clin N Am 2010; 21: 263-270

POST-SAH COMPLICATIONS: HYDROCEPHALUS



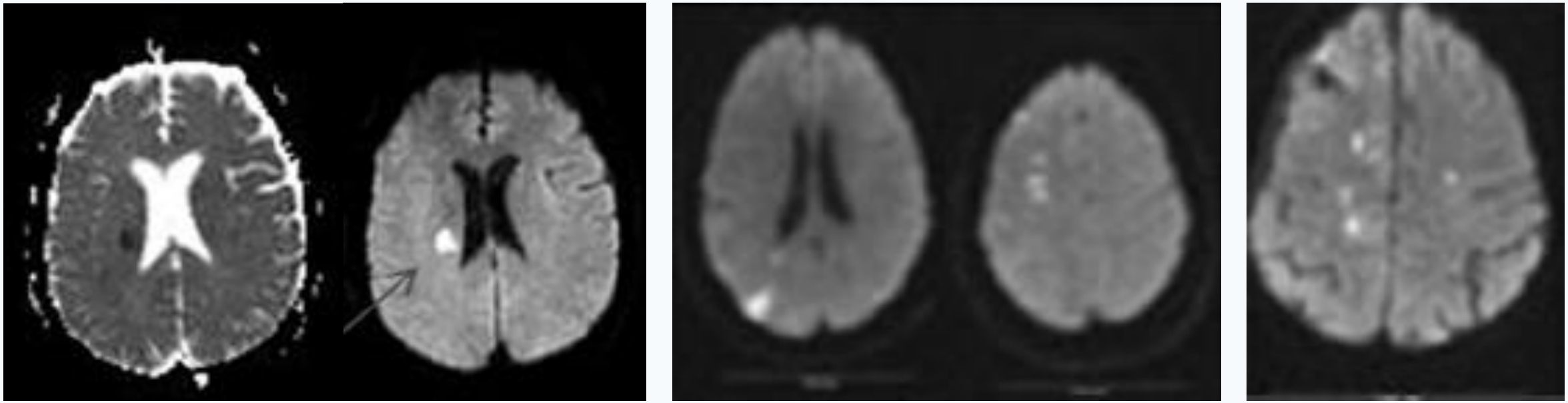




- Communicating (deposit of blood degradation products at the level of arachnoid granulations with consequent obstacle to the flow of liquor and reduced reabsorption)
- Obstructive (fibrosis with obstruction of Luschka and Magendie forams)
- MRI can be useful to better define the radiological picture (ventricular dilatation, trans-ependymal resorption)

Germanwala AV et al. Neurosurg Clin N Am 2010; 21: 263-270

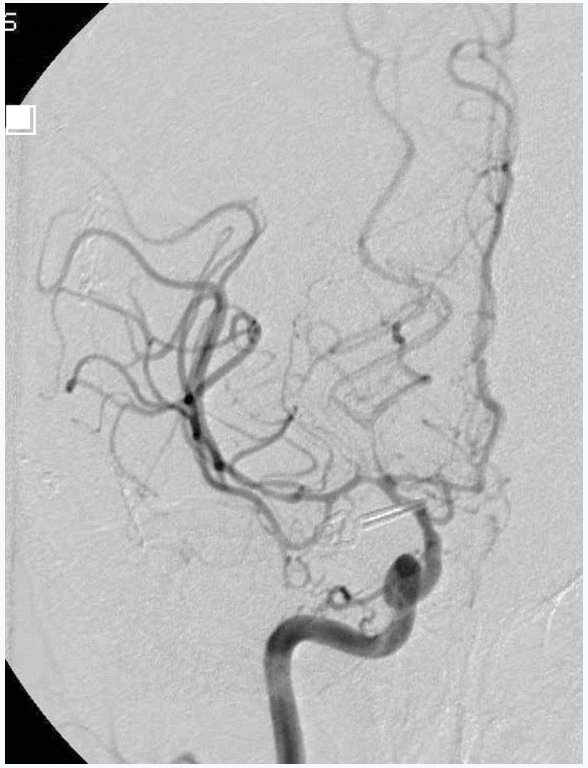
SILENT EMBOLIC CEREBRAL INFARCTION

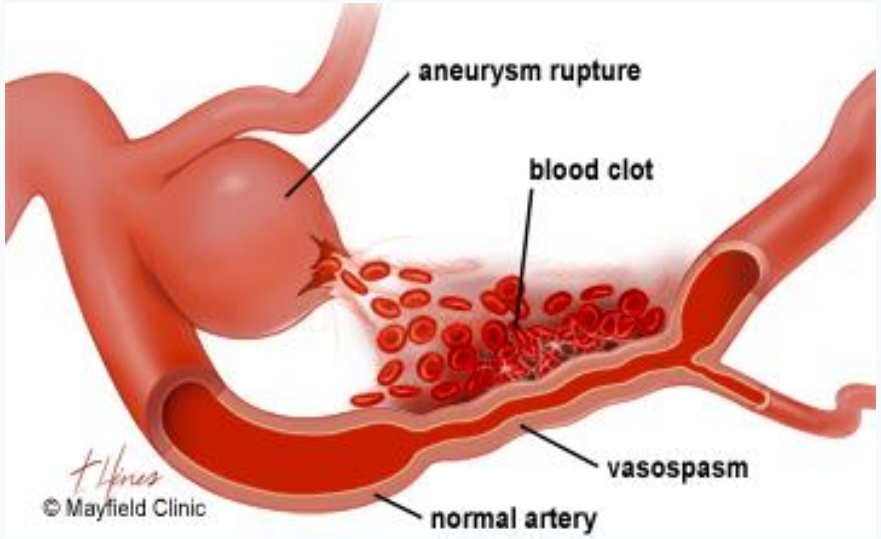


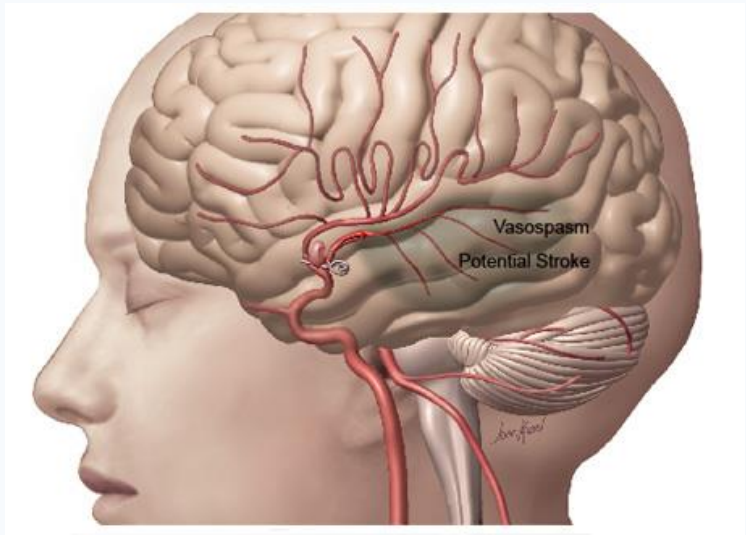
- Focal lesions highlighted by DWI after clipping or coiling / flow diverting stents
- 10-70% of cases
- Mostly asymptomatic
- Territory of the treated artery (micro-embolism) or in distant territories (hemodynamic disorders)
- Correlation with development of neuropsychological deficits

Bendel P et al. Radiology 2008; 246: 543-552; Weidauer S et al. Neuroradiology 2008; 50: 1-8; Krayenbühl N et al. Stroke 2009; 40:129-133; Kang DH et al. Stroke 2013; 44: 789-791; Iosif C et al. J Neurosurg 2015; 122: 627-636; Korbakis G et al. Neurocrit Care 2016; 24: 428-435

POST-SAH COMPLICATIONS: VASOSPASM



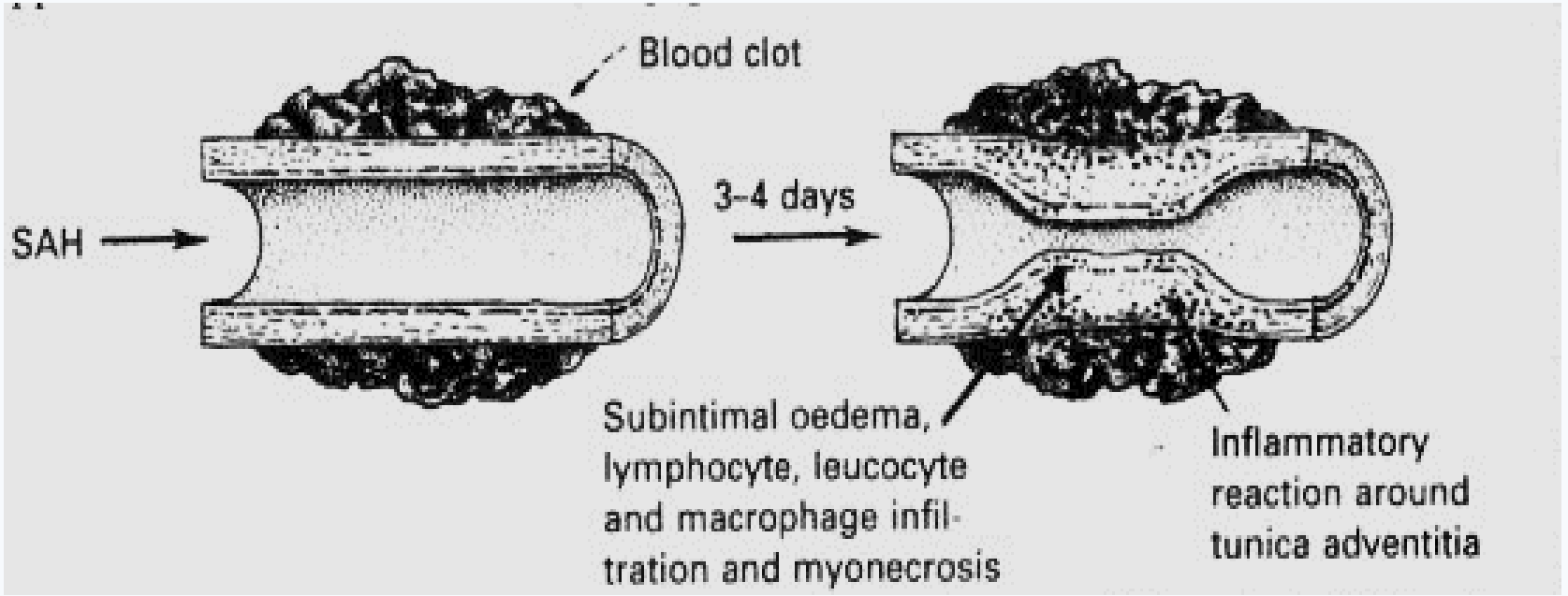




- Narrowing of the vessel caliber resulting from the contraction of the smooth muscle of the arterial wall (vasoconstriction)
- 3 -14 days after bleeding in about 60-70% of patients with ESA
- Associated with an unfavorable prognosis

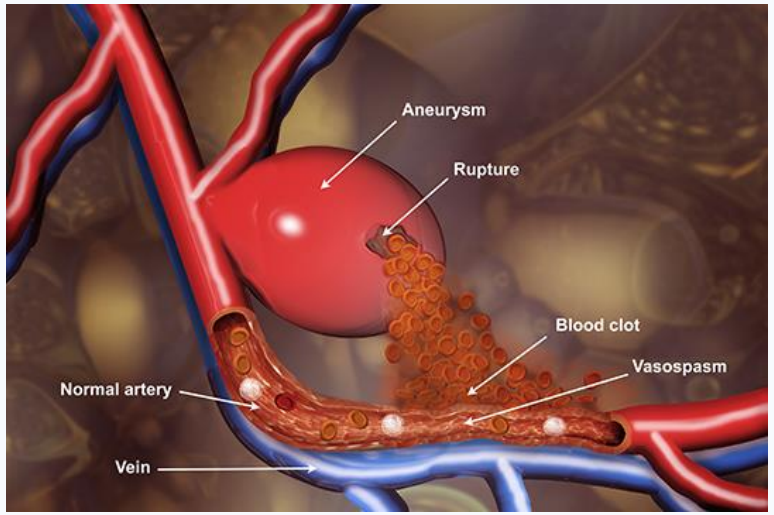
Baggott CD, Aagaard-Kienitz B. Neurosurg Clin N Am 2014; 25: 497-528
Penn DL et al. J Clin Neurosci 2015; 22: 1-5

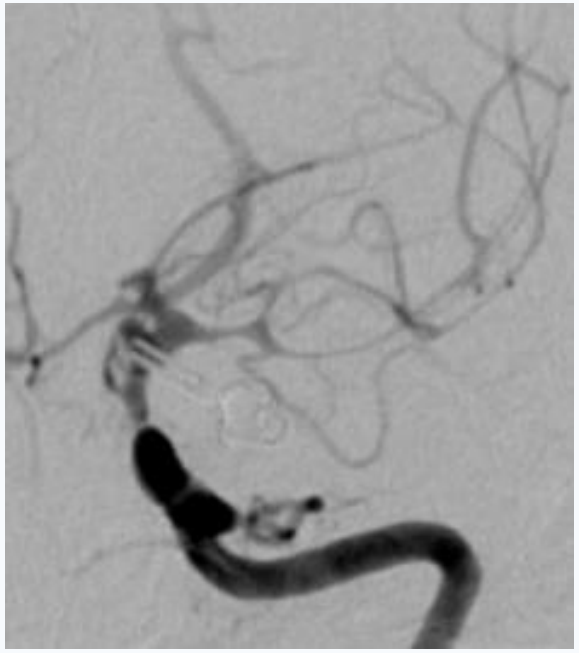
VASOSPASM

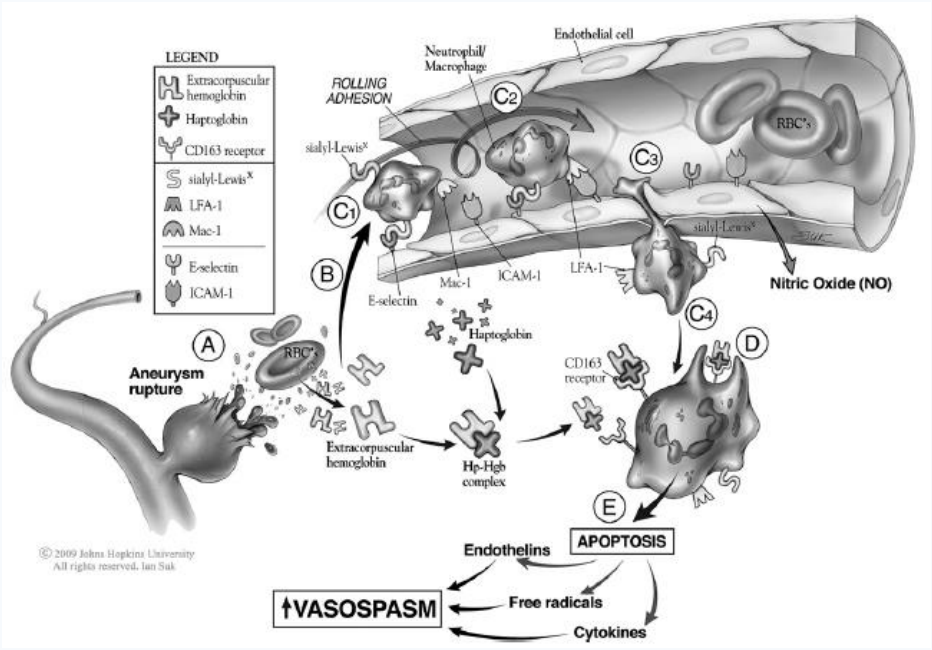


- Inflammatory reaction of the vessels in the presence of subarachnoid blood, resulting in a narrowing of the lumen
- Persistent contraction of the intracranial arteries
- Subsequent structural modification of the vascular walls

PHYSIOPATHOLOGICAL MECHANISMS





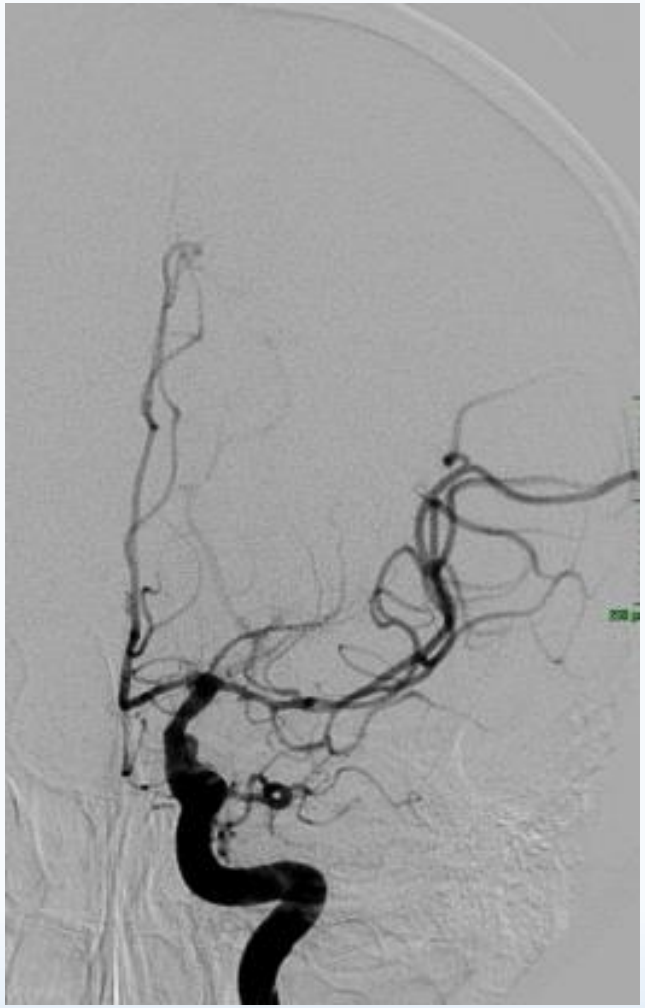


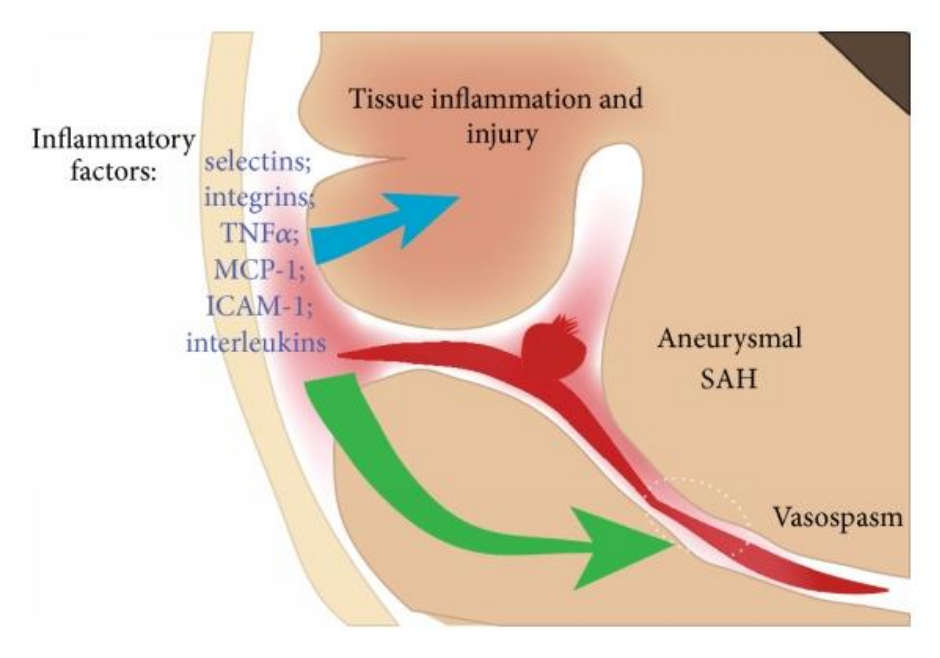
- Hemoglobin degradation products (desoxyHb and oxyHb) that are deposited on the arterial wall = vasoconstriction
- Damage of the BBB by rupture of the aneurysmal wall = input and trapping of neutrophils and macrophages within the subarachnoid space with phagocytosis of Hb

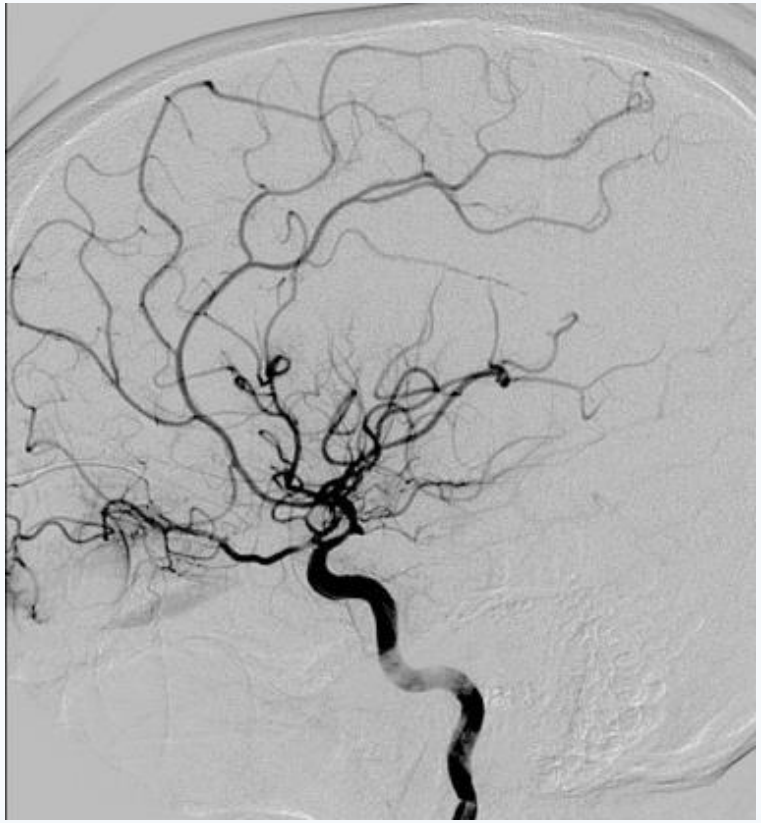
Inflammatory reaction (MMPs + pro-inflammatory cytokines + free radicals) = reduction of NO + release of Endothelin-1 = vasoconstriction

Macdonald RL et al. Nat Clin Pract Neurol 2007; 3: 256-263; Pradilla G et al. Neurosurg Clin N Am. 2010; 21: 365-379; Marshall SA et al. Neurosurg Clin N Am 2010; 21: 305-323 ; Baggott CD, Aagaard-Kienitz B. Neurosurg Clin N Am 2014; 25: 497-528; Macdonald RL. Nat Rev Neurol 2014; 10: 44-58; Budohoski KP et al. J Neurol Neurosurg Psychiatry 2014; 85 :1343-1353

PHYSIOPATHOLOGICAL MECHANISMS







inflammatory response

↓

amplification of vasospasm

↓

- Treatment resistance + tendency to relapse

- Nimodipine reduces the percentage of unfavorable outcome by 40%, without decreasing the frequency of vasospasm

CEREBRAL AUTOREGULATION

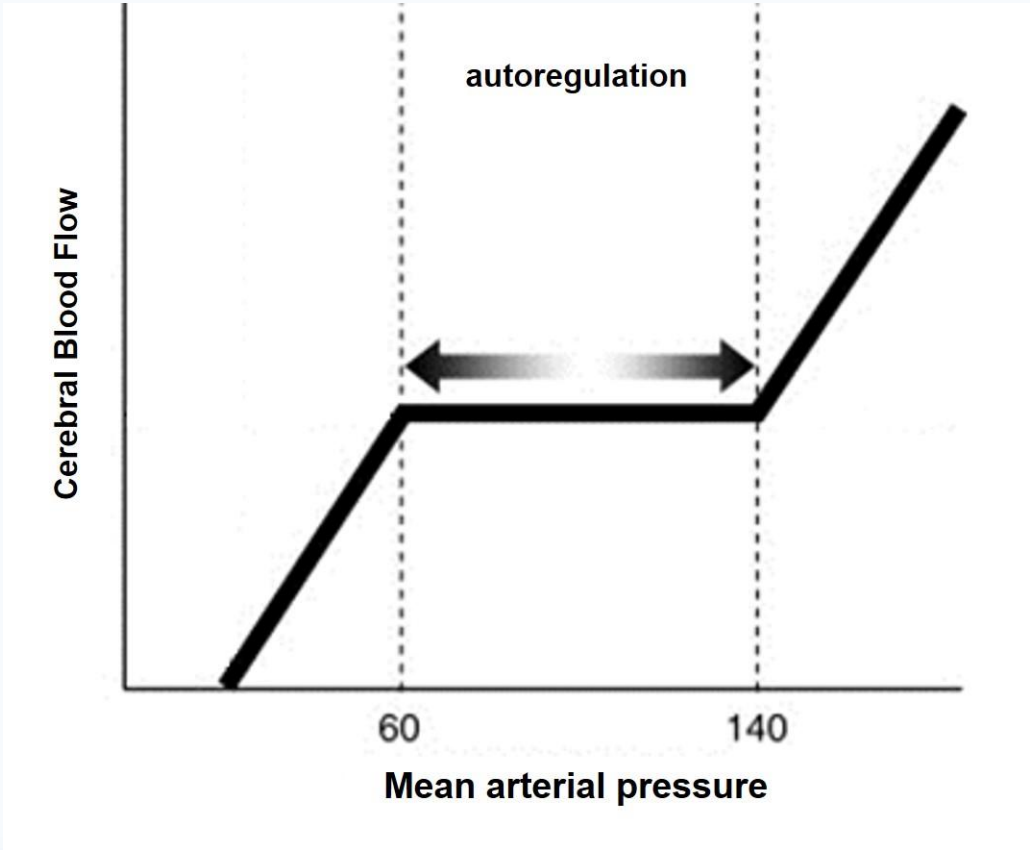
- Maintains cerebral blood flow (CBF) = cerebral perfusion pressure (CPP) constant

↓

- Independently of changes in systemic blood pressure

↓

Adjusting the cerebrovascular resistance (CVR)
CBF = CPP / CVR

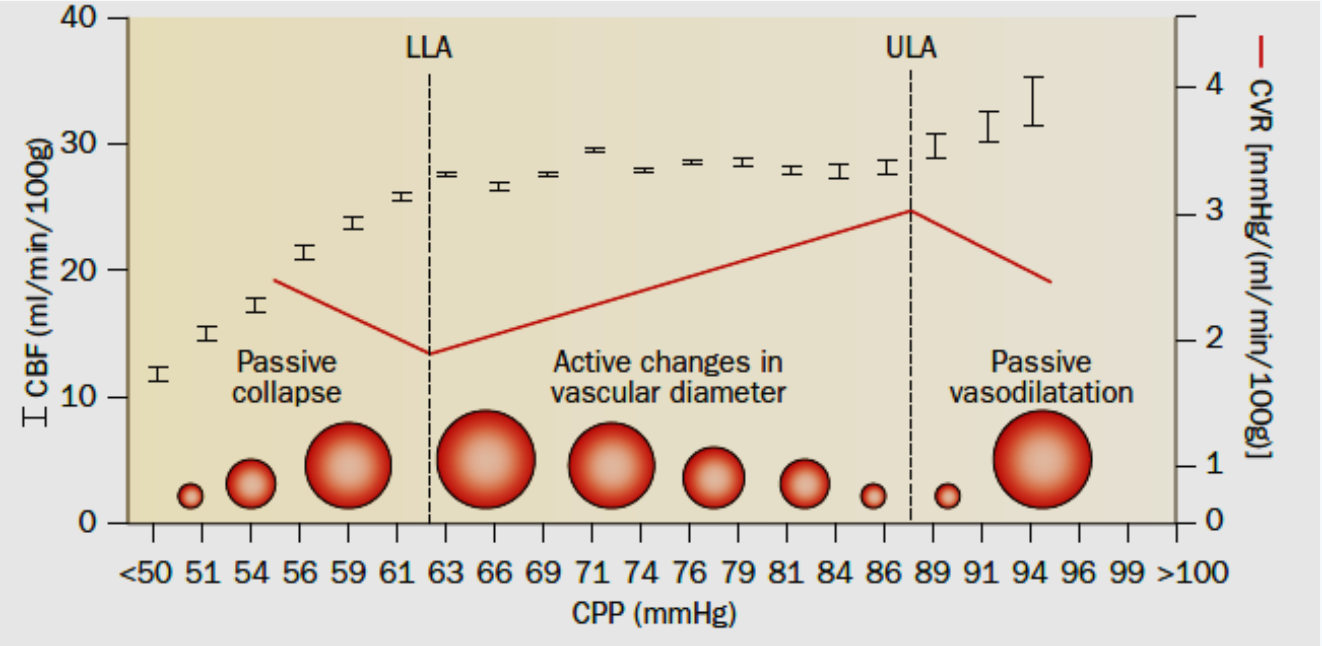


Hypertension = Hyperperfusion = Increase in CPP → Vasoconstriction = Increase in CVR = CBF reduction

Hypotension = Hypoperfusion = Reduction of CPP → Vasodilatation = Reduction of CVR = increase in CBF

Budohoski KP et al. Nat Rev Neurol 2013; 9: 152-163

IMPAIRMENT OF CEREBRAL AUTOREGULATION



Hypoperfusione = CPP reduction

↓

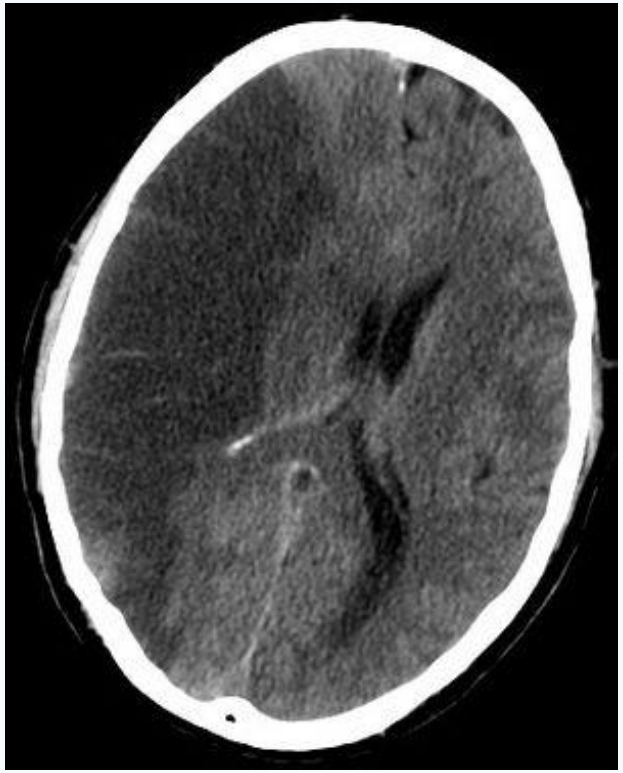
Maximal vasodilatation (vasoparalysis) = CVR minimal reduction

↓

CBF reduction = risk of ischemia

Budohoski KP et al. Nat Rev Neurol 2013; 9: 152-163

DELAYED CEREBRAL ISCHEMIA



Stroke 2009; 40: 1963-1968

Defining Vasospasm After Subarachnoid Hemorrhage

What Is the Most Clinically Relevant Definition?

Jennifer A. Frontera, MD; Andres Fernandez, MD; J. Michael Schmidt, PhD; Jan Claassen, MD; Katja E. Wartenberg, MD; Neeraj Badjatia, MD; E. Sander Connolly, MD; Stephan A. Mayer, MD

Stroke 2010; 41: 2391-2395

Definition of Delayed Cerebral Ischemia After Aneurysmal Subarachnoid Hemorrhage as an Outcome Event in Clinical Trials and Observational Studies

Proposal of a Multidisciplinary Research Group

Mervyn D.I. Vergouwen, MD, PhD; Marinus Vermeulen, MD, PhD; Jan van Gijn, MD, FRCP, FRCP(Edin); Gabriel J.E. Rinkel, MD; Eelco F. Wijdicks, MD, PhD; J. Paul Muizelaar, MD, PhD; A. David Mendelow, MD, PhD; Seppo Juvela, MD, PhD; Howard Yonas, MD; Karel G. Terbrugge, MD, FRCPC; R. Loch Macdonald, MD, PhD; Michael N. Diringer, MD; Joseph P. Broderick, MD; Jens P. Dreier, MD, PhD; Yvo B.W.E.M. Roos, MD, PhD

Vasopasm can cause Delayed Cerebral Ischemia (DCI):

- Clinical deterioration = new focal and / or diffused neurological deficit
- Areas of infarction = new ischemic lesions to CT or MRI

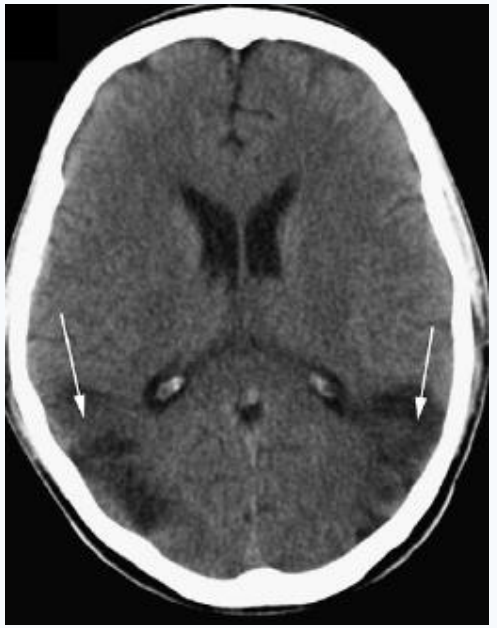
Sanelli PC et al. AJNR Am J Neuroradiol 2014; 35: 2209-2214
Baggott CD, Aagaard-Kienitz B. Neurosurg Clin N Am 2014; 25: 497-528
Budohoski KP et al. J Neurol Neurosurg Psychiatry 2014; 85 :1343-1353

DIAGNOSIS OF VASOSPASM: NECT

Attributing Hypodensities on CT to Angiographic Vasospasm Is Not Sensitive and Unreliable

George M. Ibrahim, MD; Stephan Weidauer, MD; Hartmut Vatter, MD, PhD; Andreas Raabe, MD, PhD; R. Loch Macdonald, MD, PhD

Stroke 2012; 43: 109-112



41% sensitivity in identifying severe angiographic vasospasm

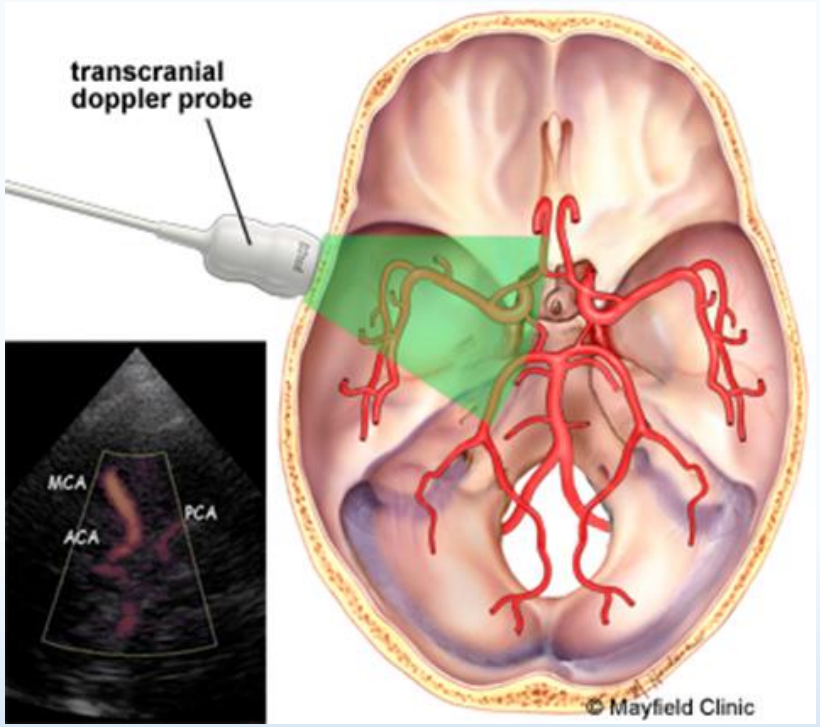
↓

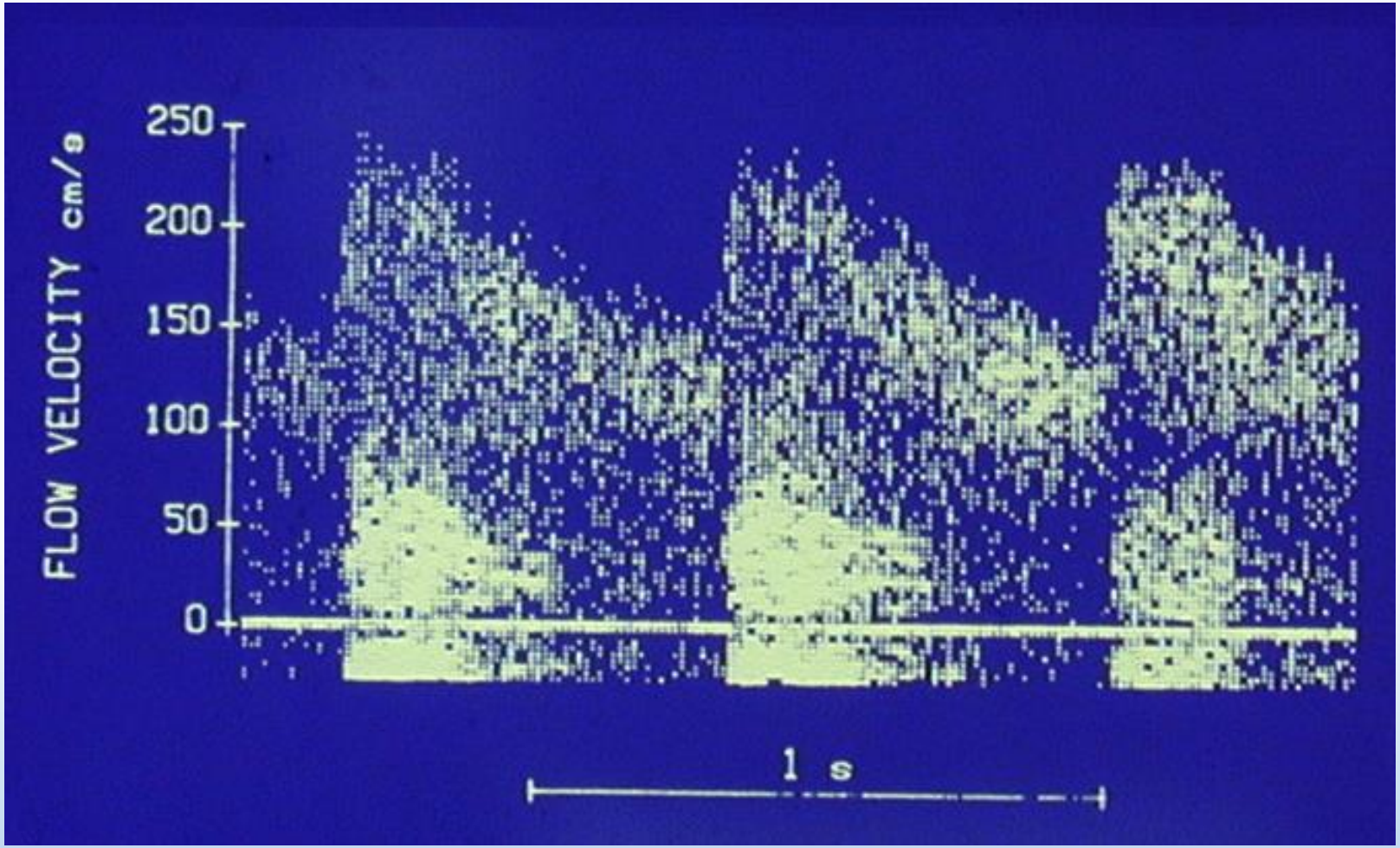
Not a reliable indicator of vasospasm

DIAGNOSIS OF VASOSPASM: TCD

TCD Vasospasm – Velocity Increase, Lindegaard ratio elevated, Turbulence, Bruits, Musical Murmurs

J. Neurosurg.60:37-41,1984





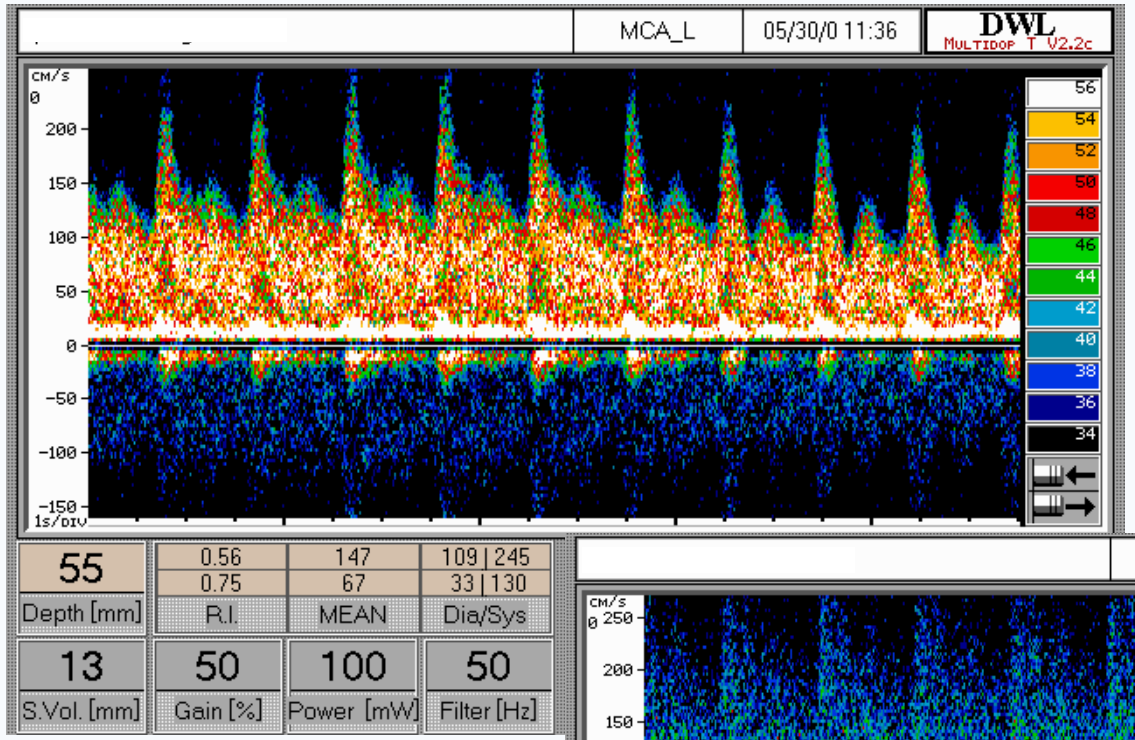
DIAGNOSIS OF VASOSPASM: TCD

Lindegaard Index

$$L.I. = \frac{FVm_{MCA}}{FVm_{ICAe}}$$

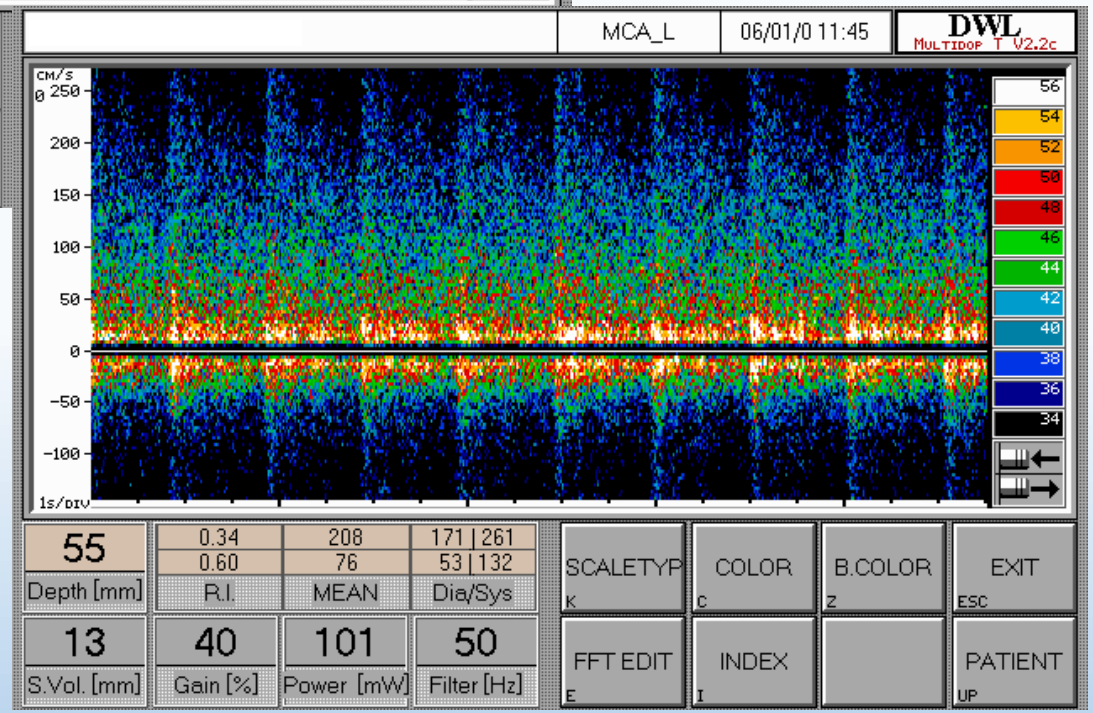
MFV cm/s	Lindegaard index		lumen narrowing DSA
>120	<3	Hyperemia	absent
>120	3-6	Moderate VS	25-50%
>200	>6	Severe VS	>50%

TCD MONITORING OF VASOSPASM

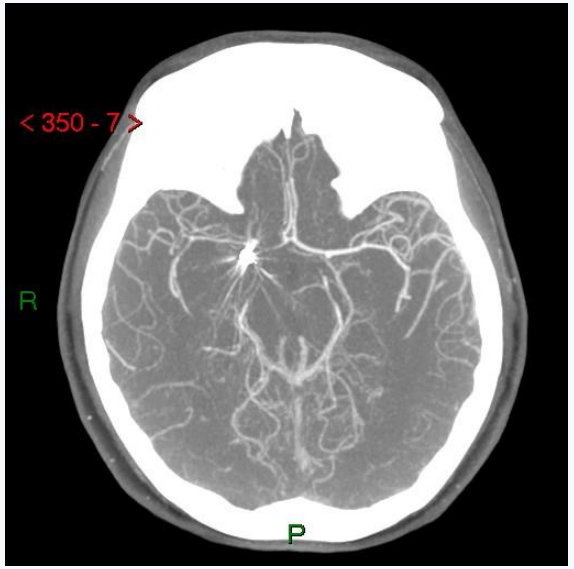


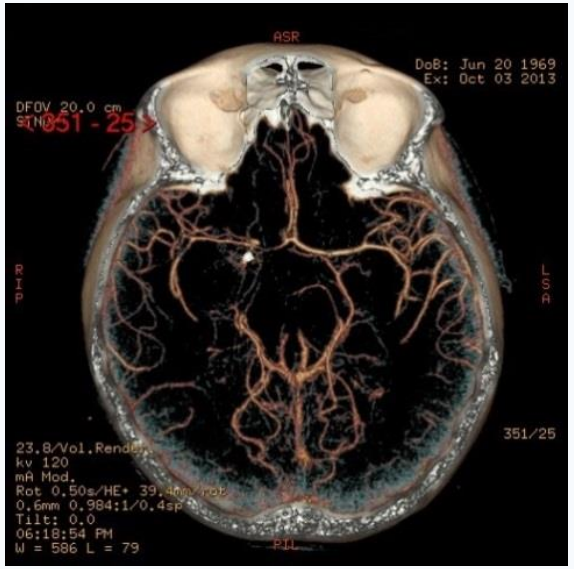
Vasospasm

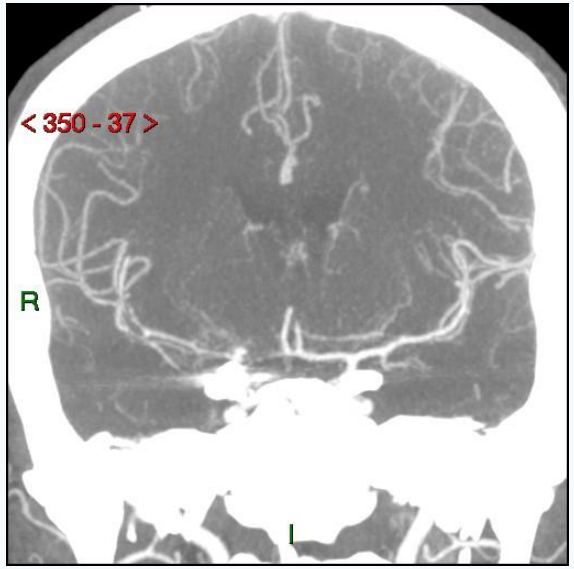
Severe Vasospasm

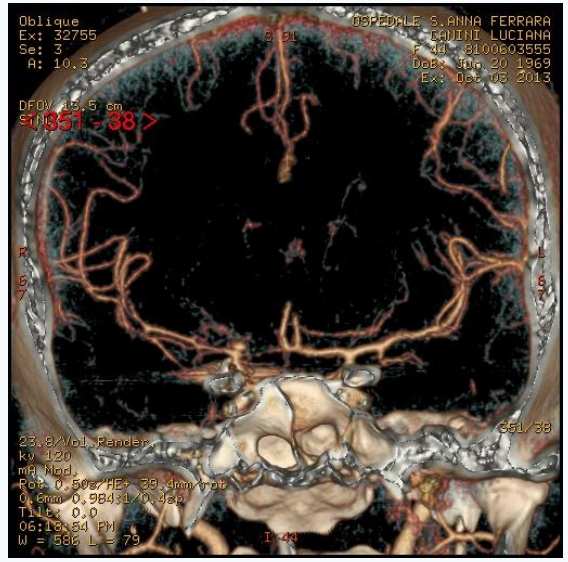


DIAGNOSIS OF VASOSPASM: CTA









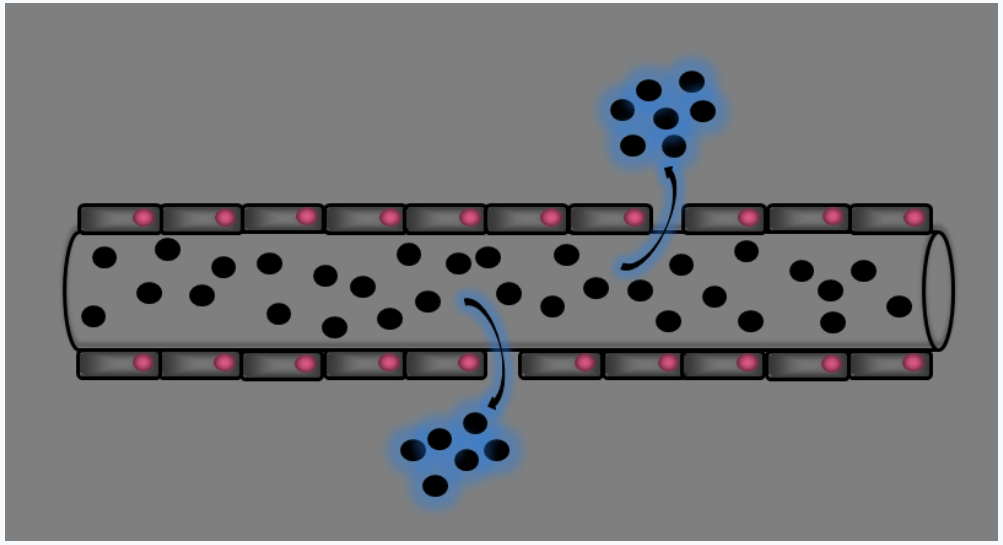
- 80% sensitivity

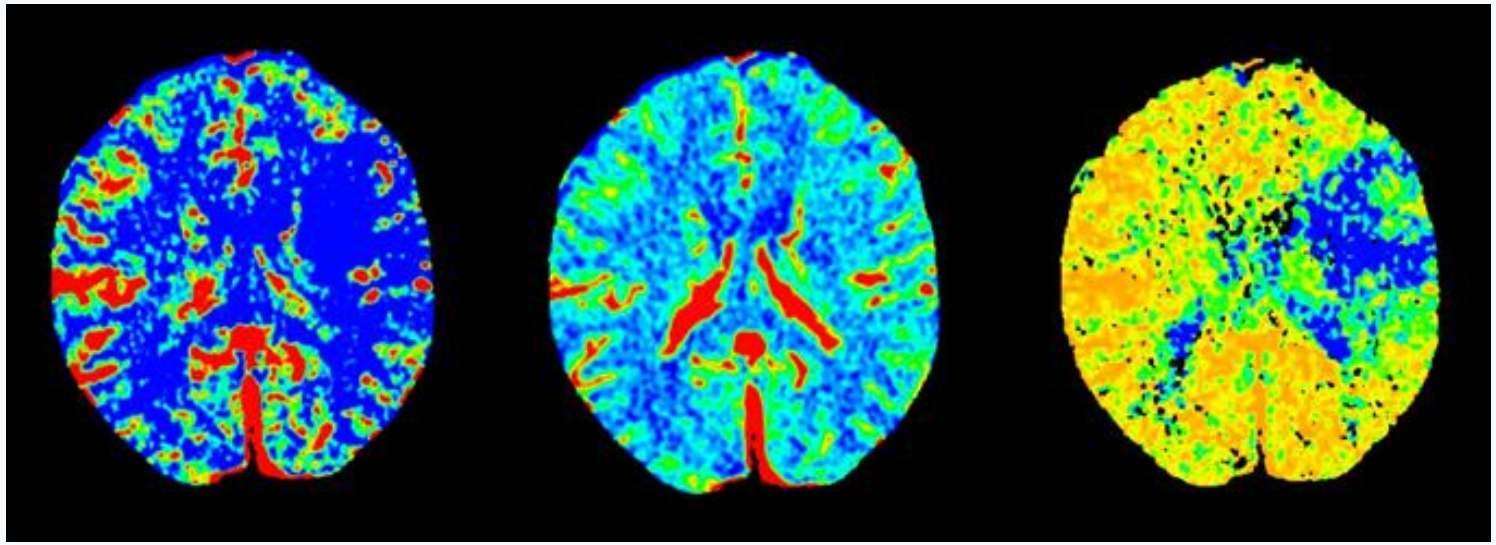
- Reduced sensitivity in highlighting the vasospasm of:
  - arterial branches distal to the proximal ones
  - segments adjacent to surgical or endovascular devices (clips and coils) for the appearance of metallic artifacts

- Useful for the diagnosis of vasospasm but can not replace DSA

Yoon DY et al. AJNR Am J Neuroradiol 2006; 27: 370-377; Binaghi S et al. AJNR Am J Neuroradiol 2007; 28: 750-758; Chaudhary SR et al. Cerebrovasc Dis 2008; 25: 144-150; Greenberg ED et al. Am J Neuroradiol 2010; 31: 1853-18 60; Wilson CD, Shankar JJ. Can J Neurol Sci 2014; 41: 314-319

CTP: CEREBRAL HEMODYNAMICS





CBF
(ml/100gr/min)

CBV
(ml/100gr)

MTT
(sec)

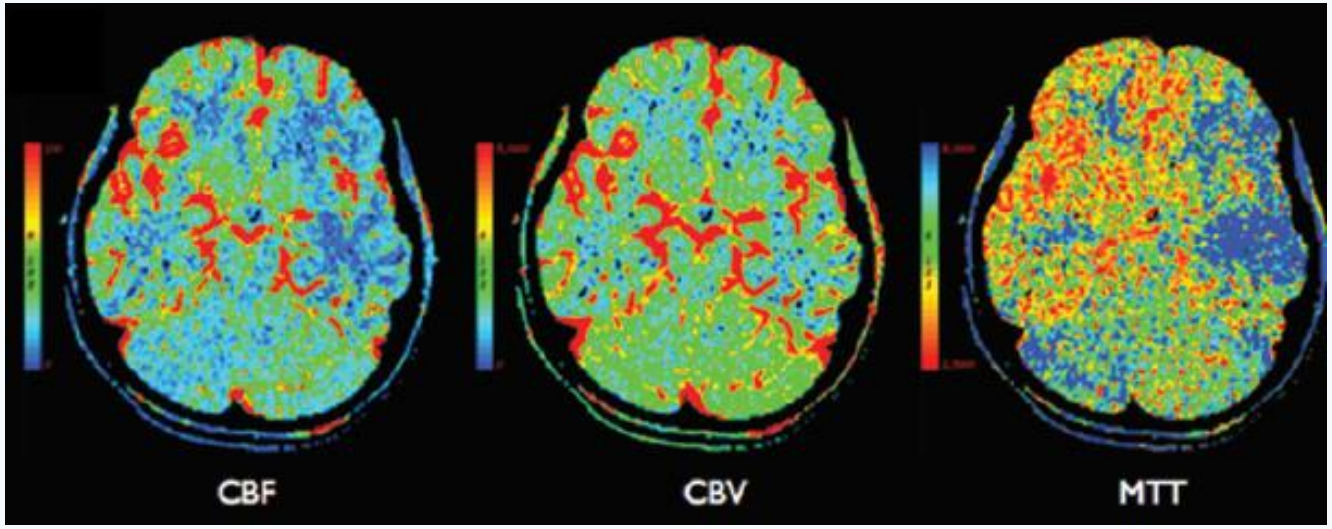
- Measures *the blood flow along the cerebral capillaries (microcirculation)*

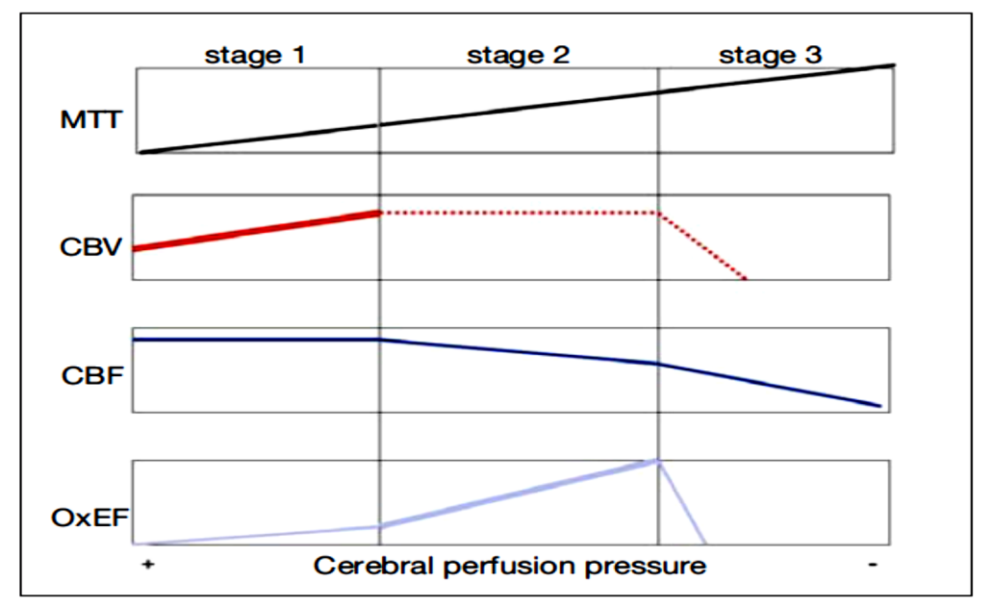
- Studies the main perfusion parameters:

  - **CBF** = the amount of blood that passes through a certain volume of tissue in a given time
  - **CBV** = the amount of blood that passes through a certain volume of tissue
  - **MTT** = the circulation time

in relation to each other by the central volume principle CBF = CBV / MTT

PERFUSIONAL PROFILES IN VASOSPASM



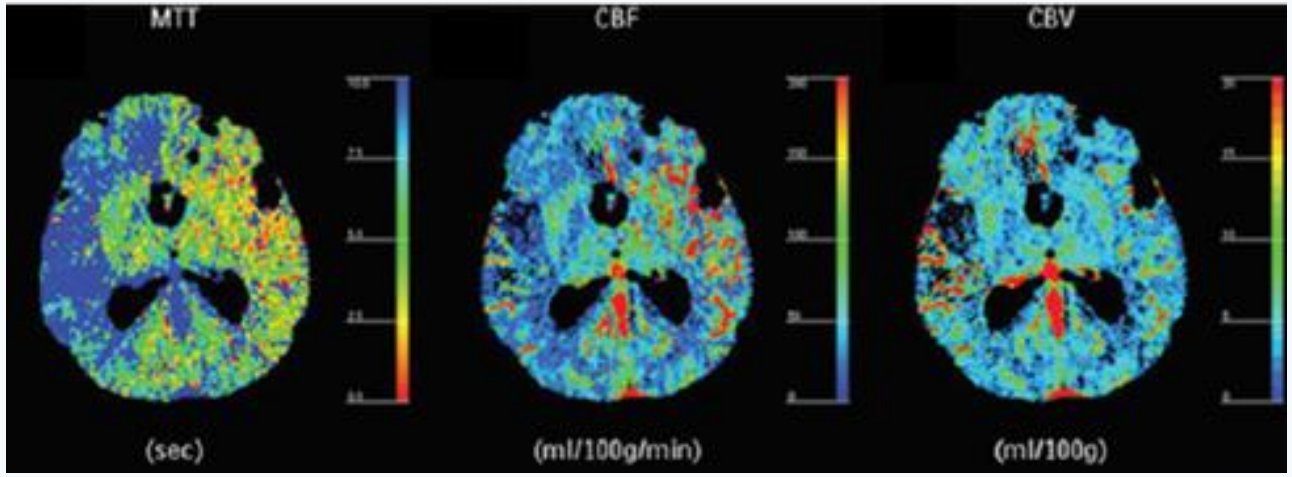


- **Reduced CBF + normal CBV + prolonged MTT** (self-regulation **disorder**) = impairment of cerebral self-regulation which does not sufficiently compensate vasoconstriction with adequate vasodilation due to the absence of collateral circulation = tissue at risk of reversibly damaged infarction = a condition similar to that of **ischemic penumbra**

- **Reduced CBF + reduced CBV + prolonged MTT** (self-regulation **failure**) = irreversibly damaged tissue = **infarct**

van der Schaaf I et al. Neurology 2006; 66: 1533-1538; Binaghi S et al. AJNR Am J Neuroradiol 2007; 28: 750-758; Dankbaar JW et al. Neuroradiology 2009; 51: 813-819; Dankbaar JW et al. Stroke 2010; 41: 1927-1932; Dankbaar JW et al. Cerebrovasc Dis 2011; 32:133-140; Sanelli PC et al. Neuroradiology 2011; 53: 425-434; Dolatowski K et al. Eur J Radiol 2014; 83: 1881-1889

ACCURACY OF CTP



- A reduction of CBF and / or an extension of MTT have a 75-90% sensitivity in identifying ischemic lesions in case of clinical suspicion or vasospasm doppler
- Excellent reliability in establishing the location and severity of ischemia
- High predictive power for the development of ischemic lesions in the classical period of onset of vasospasm (3-14 days post-SAH) in the absence of clinical suspicion or doppler

Binaghi S et al. AJNR Am J Neuroradiol 2007; 28: 750-758; Pham M et al. Neurology 2007; 69: 762-765;
Dankbaar JW et al. Stroke 2009; 40: 3493-3498; Huang AP et al. Neurosurgery 2010; 67: 964-974;
Greenberg ED et al. Am J Neuroradiol 2010; 31: 1853-18 60; Sanelli PC et al. AJNR Am J Neuroradiol 2011; 32: 2047-2053;
Dankbaar JW et al. Cerebrovasc Dis 2011; 32:133-140; Sanelli PC et al. Am J Neuroradiol 2013; 34: 292-298;
Killeen RP et al. AJNR Am J Neuroradiol 2014; 35: 459-465; Cremers CH et al. J Cereb Blood Flow Metab 2014; 34: 200-207;
Mir DI et al. AJNR Am J Neuroradiol 2014; 35: 866-871; Malinova V et al. J Neurosurg 2016; 125: 128-136

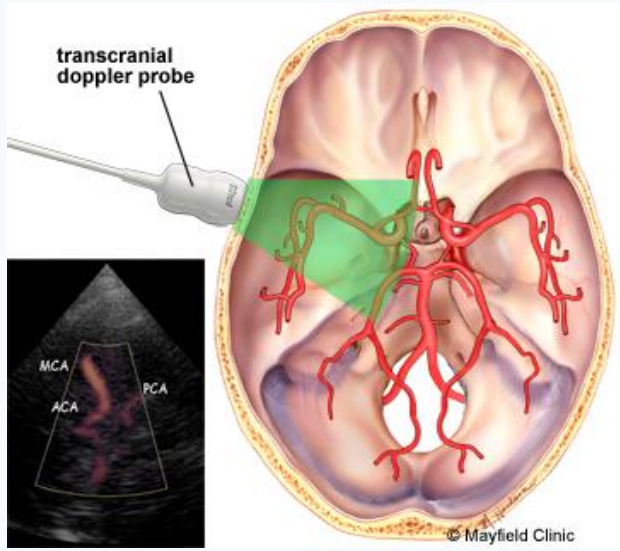
ACCURACY OF CTP

Transcranial Doppler Versus Angiography in Patients With Vasospasm due to a Ruptured Cerebral Aneurysm

A Systematic Review

Christopher Lysakowski, MD; Bernhard Walder, MD;
Michael C. Costanza, PhD; Martin R. Tramèr, MD, DPhil

Stroke 2001; 32: 2292-2298

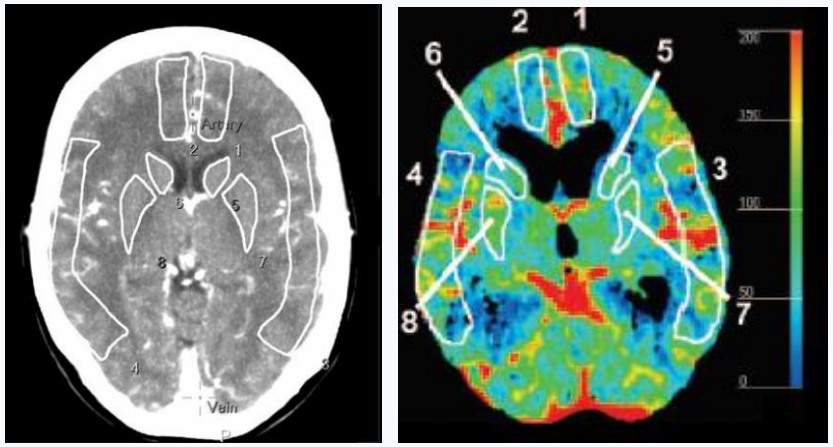


- Superior sensitivity to transcranial doppler (TCD) in recognizing signs of cerebral ischemia

- TCD remains the screening test for suspected cerebral ischemia in patients with ESA, especially in those who are sedated

Marshall SA et al. Neurosurg Clin N Am 2010; 21: 291-303
McGuinness B, Gandhi D.Neurosurg Clin N Am 2010; 21: 281-290
Sanelli PC et al. AJNR Am J Neuroradiol 2014; 35: 2209-2214
Westermaier T et al. Neurocrit Care 2014; 20: 406-512
Sanelli PC et al. Am J Neuroradiol. 2014; 35: 1714-1720

PERFUSIONAL THRESHOLD VALUES



Differences in CT Perfusion Maps Generated by Different Commercial Software: Quantitative Analysis by Using Identical Source Data of Acute Stroke Patients[1]

Radiology

Kudo K et al. Radiology 2010; 254: 200-209

- Variability in the optimal threshold values for the diagnosis of ischemia because different commercial software provide different absolute values:

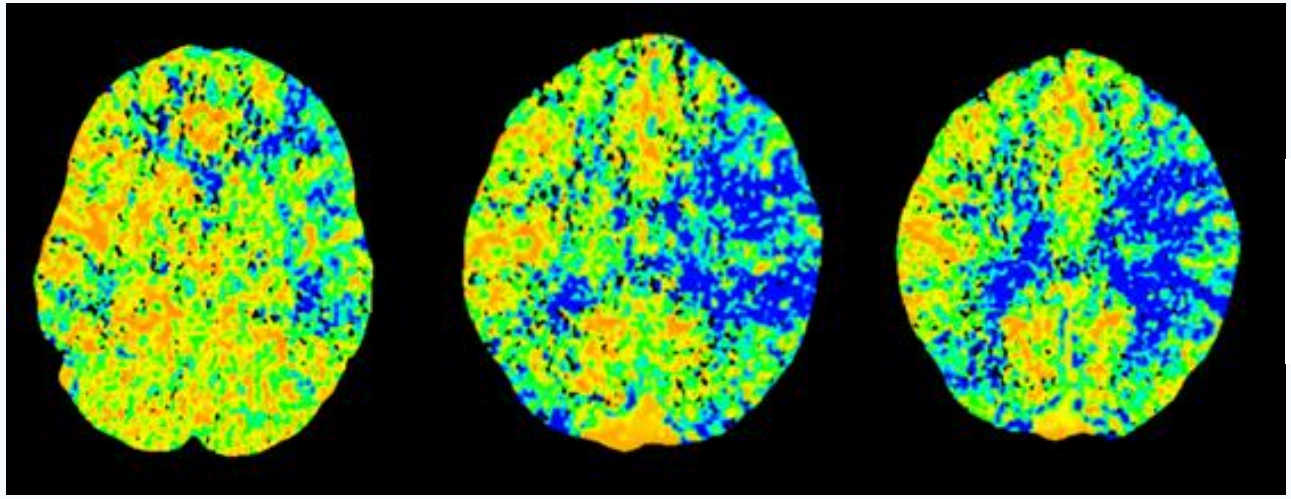
- CBF = 17.7 / 25.0-30.5 ml / 100gr / min

- MTT = 5.0 / 5.9-6.4 sec

- Visual analysis based on the qualitative demonstration of CBF and MTT disorders remains the recommended approach

Wintermark M et al. AJNR Am J Neuroradiol 2006; 27: 26-34; Wintermark M et al. Cerebrovasc Dis 2008; 26: 163-170
Dankbaar JW et al. Stroke 2010; 41: 1927-1932; Huang AP et al. Neurosurgery 2010; 67: 964-974;
Dankbaar JW et al. Cerebrovasc Dis 2011; 32: 133-140; Sanelli PC et al. Neuroradiology 2011; 53: 425-434;
Sanelli PC et al. Am J Neuroradiol 2013; 34: 292-298; Cremers CH et al. Neuroradiology. 2015; 57: 897-902

MTT MAPS AND LESION PATTERNS



Patterns of Cerebral Infarction in Aneurysmal Subarachnoid Hemorrhage

Alejandro A. Rabinstein, MD; Stephen Weigand, MS; John L.D. Atkinson, MD; Eelco F.M. Wijdicks, MD

Stroke 2005; 36: 992-997

MTT maps are the most sensitive to understand the appearance of focal ischemic accidents that can be:

- a territorial distribution = areas of spraying of the main cerebral arteries
- a non-territorial distribution = junctional zone of border between the main cerebral arteries
- cortical and / or subcortical (deep)
- single or multiple

Dankbaar JW et al. Stroke 2010; 41: 1927-1932;
Sanelli PC et al. AJNR Am J Neuroradiol 2011; 32: 2047-2053
Etminan N et al. Stroke 2013; 44: 1260-1266
Dolatowski K et al. Eur J Radiol 2014; 83: 1881-1889

Huang AP et al. Neurosurgery 2010; 67: 964-974
Brown RJ et al. Neurosurgery 2013; 72: 702-707
Malinova V et al. J Neurosurg 2016; 125: 128-136

Le linee guida

Guidelines for the Management of Aneurysmal Subarachnoid Hemorrhage

A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association

The American Academy of Neurology affirms the value of this statement as an educational tool for neurologists.

Endorsed by the American Association of Neurological Surgeons and Congress of Neurological Surgeons; and by the Society of NeuroInterventional Surgery

E. Sander Connolly, Jr, MD, FAHA, Chair; Alejandro A. Rabinstein, MD, Vice Chair; J. Ricardo Carhuapoma, MD, FAHA; Colin P. Derdeyn, MD, FAHA; Jacques Dion, MD, FRCPC; Randall T. Higashida, MD, FAHA; Brian L. Hoh, MD, FAHA; Catherine J. Kirkness, PhD, RN; Andrew M. Naidech, MD, MSPH; Christopher S. Ogilvy, MD; Aman B. Patel, MD; B. Gregory Thompson, MD; Paul Vespa, MD, FAAN; on behalf of the American Heart Association Stroke Council, Council on Cardiovascular Radiology and Intervention, Council on Cardiovascular Nursing, Council on Cardiovascular Surgery and Anesthesia, and Council on Clinical Cardiology

Stroke 2012; 43: 1711-1737

Delayed Cerebral Ischemia in Aneurysmal Subarachnoid Hemorrhage: Proposal of an Evidence-Based Combined Clinical and Imaging Reference Standard

P.C. Sanelli, S. Kishore, A. Gupta, H. Mangat, A. Rosengart, H. Kamel, and A. Segal

AJNR Am J Neuroradiol 2014; 35: 2209-2214

In caso di sospetto clinico o doppler di ischemia cerebrale il protocollo TC multimodale (TC/CTA/CTP) e il protocollo RM multimodale (RM/MRA/DWI/PWI) sono equiparati in termini di affidabilità

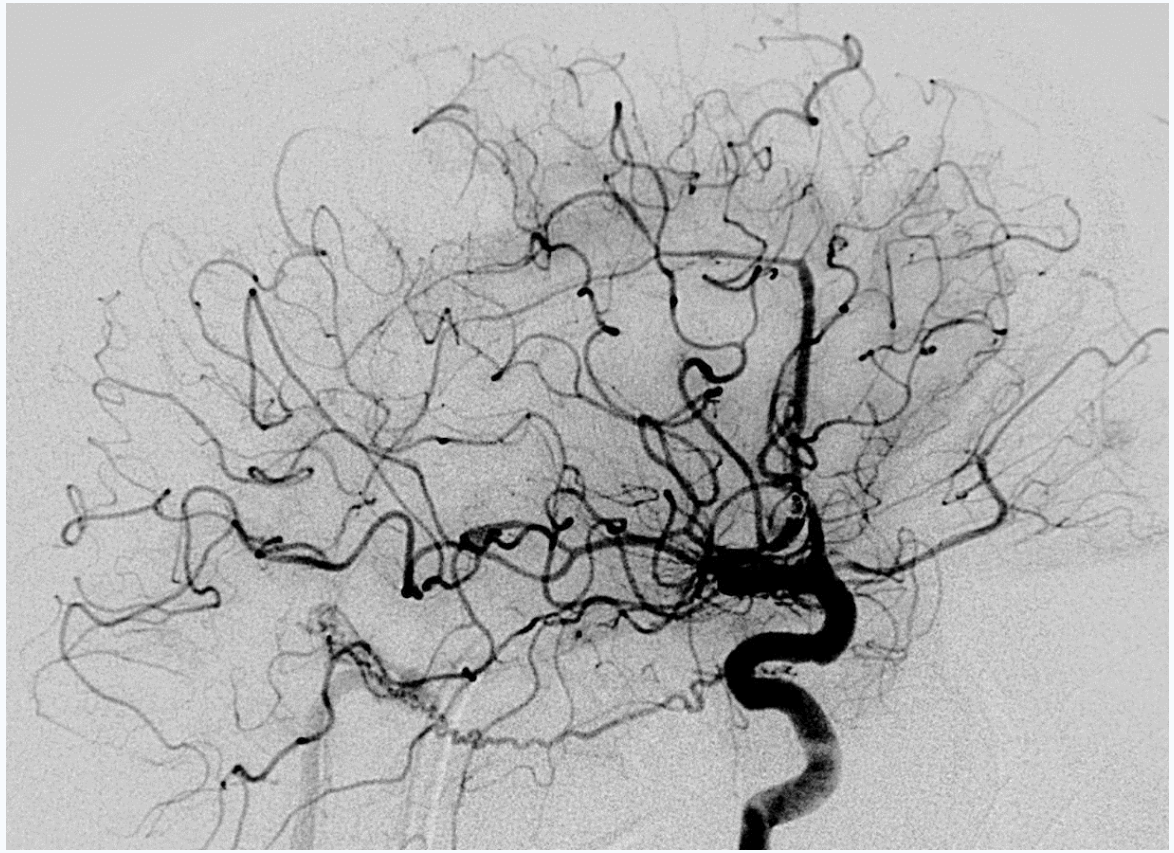
↓

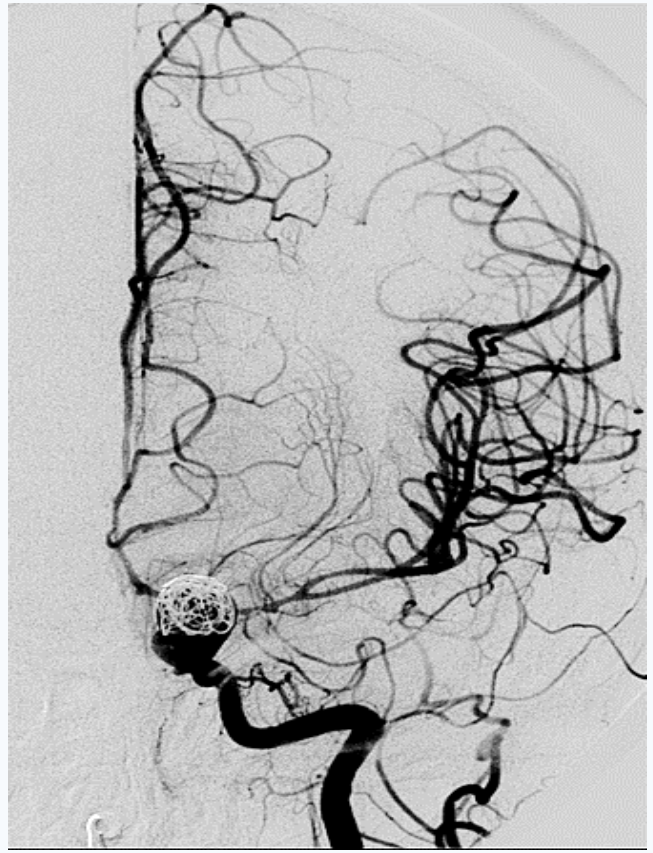
la scelta dipende dal livello di accessibilità delle due metodiche in ogni singolo centro

↓

nella maggior parte dei centri specializzati si usa il protocollo TC

DIAGNOSIS OF VASOSPASM: DSA





Gold standard

- Identification of the site and extension of vasospasm
- Evaluation of hemodynamics and collateral circulation
- Longitudinal evaluation of endovascular treatment efficacy
- Excellent correlation with TCP

Hacein-Bey L, Provenzale JM. AJR Am J Roentgenol 2011; 196: 32-44
Baggott CD, Aagaard-Kienitz B. Neurosurg Clin N Am 2014; 25: 497-528

DIAGNOSIS OF VASOSPASM: DSA

- Mild VS
  narrowing of caliber <25%
  (10-33%)

- Moderate VS:
  25%> caliber narrowing <50%
  (33% -66%)

- Severe VS:
  caliber narrowing> 50%
  (> 66%)

TREATMENT OF CEREBRAL VASOSPAM

Pharmacological treatment

Intravenous infusion of nimodipine:

- 1 mg / h at the beginning
- 2 mg / h if tolerated

Oral administration of nimodipine (if possible):

- 60 mg every 4 h

Cardinal and preventive therapy, to be initiated at he diagnosis of SAH

TREATMENT OF CEREBRAL VASOSPAM

Pharmacological treatment

- Phosphodiesterase-3 inhibitors (**milrinone**)
- Statins
- Antagonists of ET1
- **Magnesium**
- **Double antiplatelet therapy**

Author, Journal, Year	Type of study	Antiplatelet Therapy	Main Results	Conclusions	Considerations
Mess DMS, Stroke, 2003	Systematic Review (699 pts)	-ASA 100-600mg/day -Dypiridamole -OKY -Cataclot	-RR of DCI 0.65 -RR of haemorrhage 1.19	Reduction of the risk of DCI	Randomized trial is necessary
Van den Bergh WM, Stroke, 2006	Randomized Trial (161 pts)	ASA 100 mg	Inclusion was stopped before the sample size (200 pts)	No significant reduction of DCI	-70% treated surgically -100mg of ASA might be not sufficient
Dorhout MS, Cochrane Collaboration, 2008	Meta-analysis (1385 pts)	ASA 100-600mg/day -Dypiridamole -OKY -Cataclot -Ticlopidine	-RR DCI and poor outcome 0.79 -RR haemorrhage 1.36	Reduction of DCI was not statistically significant	-Ticlopidine was associated with higher reduction of DCI -In Six studies = clipping
Van den Bergh WM, Stroke, 2009	Questionnaire for ISAT centers (19 centers, 1422 pts)	ASA	RR reduction of poor outcome 0.66 after ASA and 0.82 without ASA	No reduction of poor outcome after ASA	No indication that antiplatelets has a negative effect on outcome

Author, Journal, Year	Type of study	Antiplatelet Therapy	Main Results	Conclusions	Considerations
Gross BA, World Neurosurgery, 2014	Retrospective (747 pts) Pts w aneurysms + ASA vs Pts w aneurysms without ASA	ASA	-No significant difference in DCI and vasospasm -Lower rate of SAH in pts tacking ASA 28% vs 40%)	ASA protective against SAH	
Kato Y, Journal of Stroke and cerebrovascular disease, 2015	Multicenter Retrospective (5344 pts with SAH)	ASA	Better outcome after ASA in younger than 60-years-old	ASA suggested in younger patients	
Nagahama Y, Journal of Neurosurgery, 2017	Retrospective (85 pts Clopidogrel + ASA vs 76 pts without)	Clopidogrel 75mg + ASA 325mg/day	Reduction of vasospasm and DCI OR 0.3 and OR 0.084	Double antiplatelet therapy reduce the risk of DCI and vasospasm	-All pts treated with coiling -No Hunt Hess IV and V

TREATMENT OF CEREBRAL VASOSPAM

Pharmacological treatment

Triple H Therapy

Inducing the following in a patient:

- Hypertensive
- (Hypervolemic)
- Hemodilution

TREATMENT OF CEREBRAL VASOSPAM

Endovascular treatment

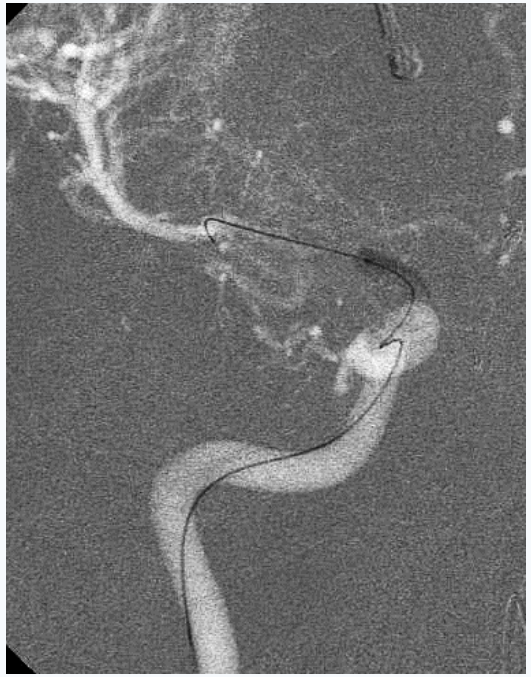
Intra-arterial infusion of nimodipine:

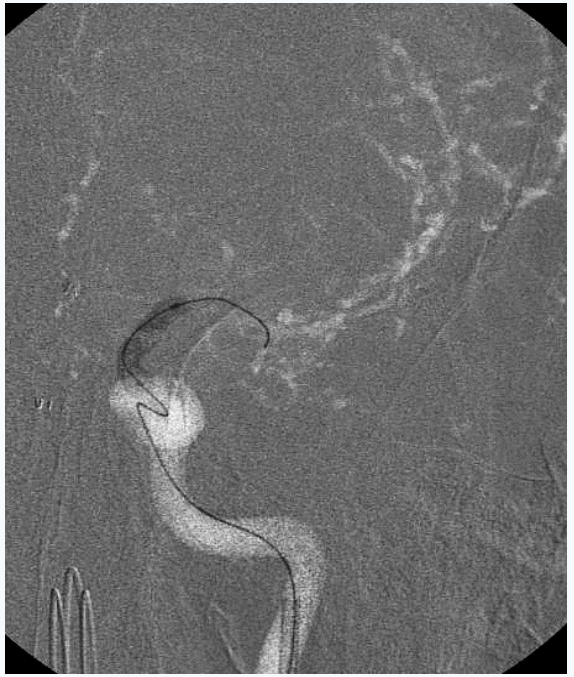
- Local anesthesia under monitoring
- Safe (risk comparable to a diagnostic angiography)
- Infusion by cervical ICA or VA
- 4 or 5 F catheter
- Performed on several vascular axes

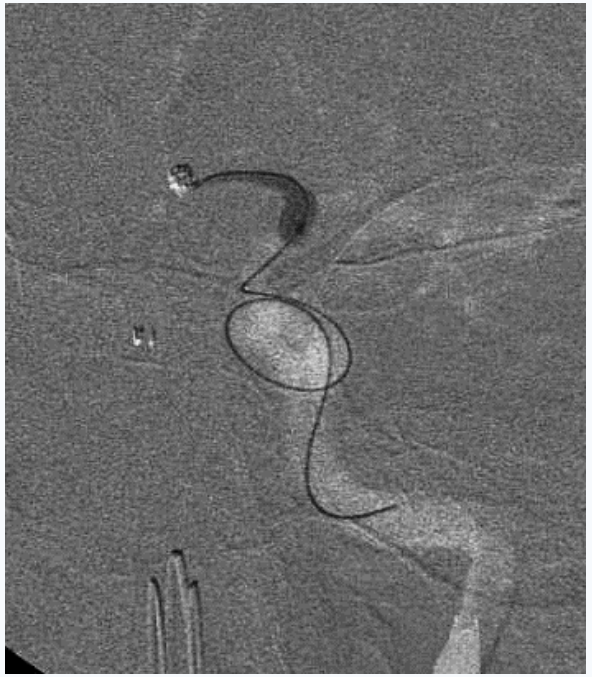
- Performed every ≈ 48 h
- 2-3 mg nimodipine per vascular axis
- 1 mg in 5 minutes

TREATMENT OF CEREBRAL VASOSPAM

Endovascular treatment







Percutaneous transluminal angioplasty

- General anesthesia
- heparinization
- Risk of dissection, rupture, embolism
- ICA, M1, A1, V4, BA, P1

- Semi-compliant remodeling technique balloon
- Durable result
- Balloon inflation 50-90%

TREATMENT OF CEREBRAL VASOSPAM

Endovascular treatment

Continuous Local Intra-arterial Nimodipine Administration in Severe Symptomatic Vasospasm After Subarachnoid Hemorrhage

Christian Musahl, MD*
Hans Henkes, MD‡§
Zsolt Vajda, MD‡
Jan Coburger, MD*
Nikolai Hopf, MD*

Neurosurgery 68:1541–1547, 2011

Continuous intra-arterial nimodipine infusion in patients with severe refractory cerebral vasospasm after aneurysmal subarachnoid hemorrhage: a feasibility study and outcome results

Sylvia Bele[1] · Martin A. Proescholdt[1] · Andreas Hochreiter[1] · Gerhard Schuierer[2] · Judith Scheitzach[1] · Christina Wendl[2] · Martin Kieninger[3] · Andre Schneiker[3] · Elisabeth Bründl[1] · Petra Schödel[1] · Karl-Michael Schebesch[1] · Alexander Brawanski[1]

Acta Neurochir 2015

Local intra-arterial nimodipine infusion

- General anesthesia
- Heparinization →PTT x 2
- Risk of embolism

- Cervical ICA, VA
- 0,4 mg/h
- Challenging management for Neurointensive Care

TREATMENT OF CEREBRAL VASOSPAM

Endovascular treatment

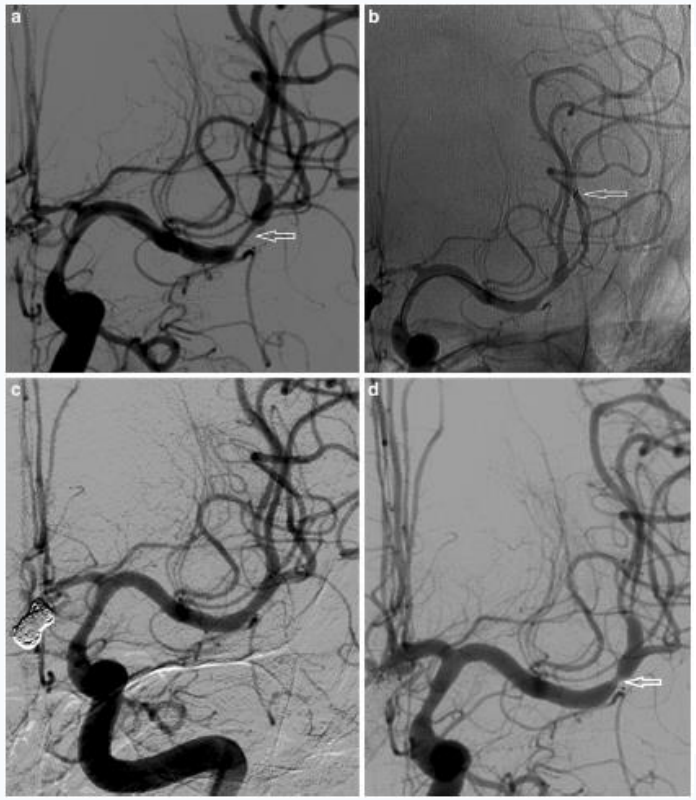
Local intra-arterial nimodipine infusion

- General anesthesia
- Heparinization →PTT x 2
- Risk of embolism

- Cervical ICA, VA
- 0,4 mg/h
- Challenging management for Neurointensive Care

TREATMENT OF CEREBRAL VASOSPAM

Endovascular treatment



Clin Neuroradiol
https://doi.org/10.1007/s00062-018-0711-3

ORIGINAL ARTICLE

CrossMark

Stent-Retriever Angioplasty for Recurrent Post-Subarachnoid Hemorrhagic Vasospasm – A Single Center Experience with Long-Term Follow-Up

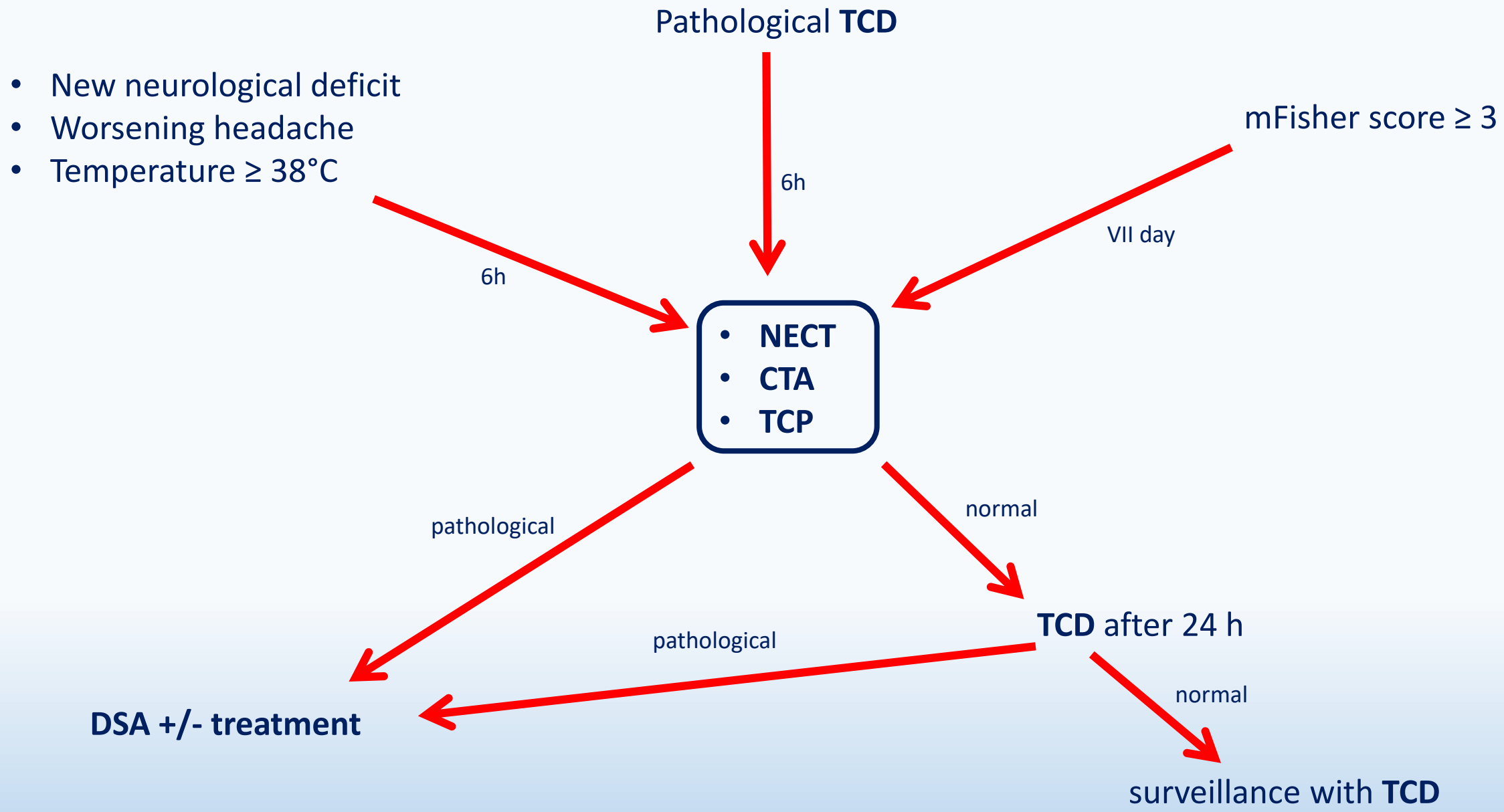
Hyon-Jo Kwon[1] · Jeong-Wook Lim[1] · Hyeon-Song Koh[1] · BumSoo Park[1] · Seung-Won Choi[1] · Seon-Hwan Kim[1] · Jin-Young Youm[1] · Shi-Hun Song[1]

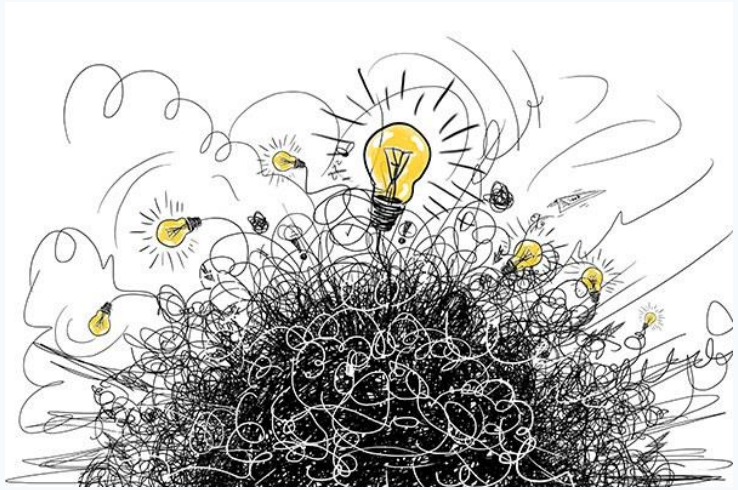
Received: 24 May 2018 / Accepted: 13 July 2018

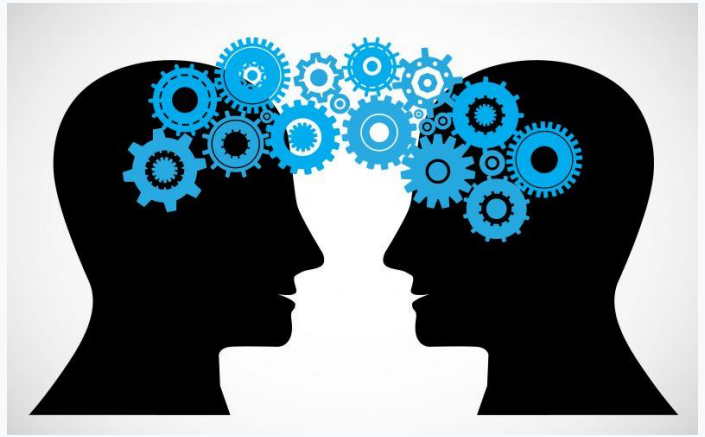
Stent-riever angioplasty

- General anesthesia
- Heparinization →PTT x 2
- Solitaire 4 x 20 + Nicardipine 3 mg in 15 min

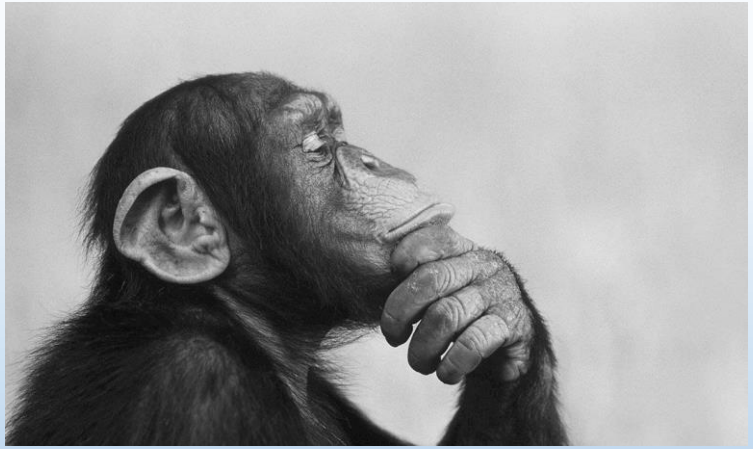
- 12 pts, 2 groups, vd vs sr
- Long term result
- Better vd vs sr


Pathological **TCD**
New neurological deficit
Worsening headache
Temperature ≥ 38°C
6h
6h
mFisher score ≥ 3
VII day
NECT
CTA
TCP
pathological
normal
TCD after 24 h
pathological
normal
DSA +/- treatment
surveillance with **TCD**

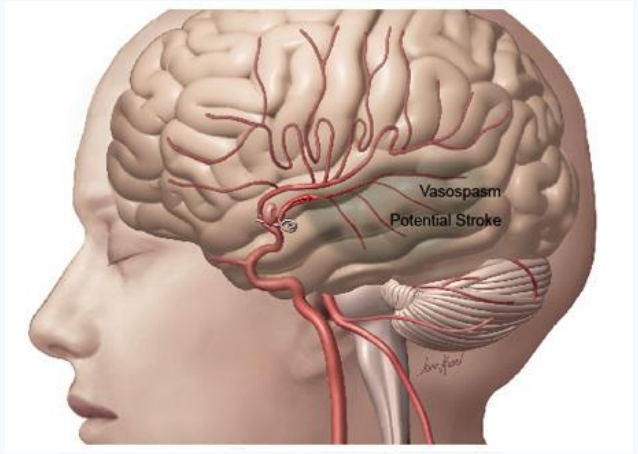




Thank you!



Vasospasmo e DCI



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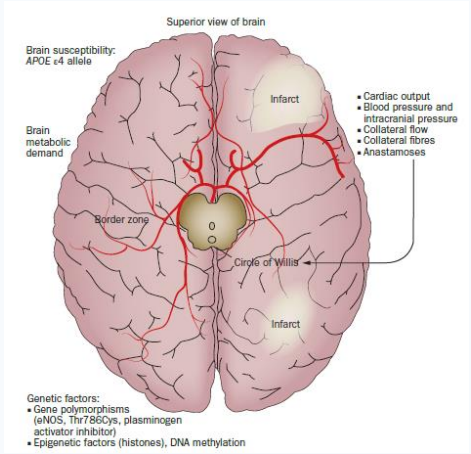

vasospasmo **DCI**

Dankbaar JW et al. Neuroradiology 2009; 51: 813-819; Vergouwen MD et al. Stroke 2010; 41: 2391-2395;
Dhar R et al. Stroke 2012; 43: 1788-1794; Budohoski KP et al. Nat Rev Neurol 2013; 9: 152-163;
Wagner M et al. Clin Neuroradiol 2013; 23: 87-95; Budohoski KP et al. J Neurol Neurosurg Psychiatry 2014; 85 :1343-1353

- **solo il 20-30% dei pazienti con ESA sviluppa DCI (vasospasmo 60-70%)**

- **sino al 30% dei pazienti con DCI presenta un'ischemia focale al di fuori delle aree interessate dal vasospasmo**

- **una discreta quota di pazienti con DCI non è affetta da vasospasmo**

↓

vasospasmo e DCI non sempre coincidono

Vasospasmo precoce

Early Vasospasm on Admission Angiography in Patients with Aneurysmal Subarachnoid Hemorrhage Is a Predictor for In-Hospital Complications and Poor Outcome

Maria E. Baldwin, MD; R. Loch Macdonald, MD, PhD; Dezheng Huo, MD, MS; Roberta L. Novakovia, MD; Fernando D. Goldenberg, MD; Jeffrey I. Frank, MD; Axel J. Rosengart, MD, PhD

Stroke 2004; 35: 2506-2511

Early Vasospasm after Aneurysmal Subarachnoid Hemorrhage Predicts the Occurrence and Severity of Symptomatic Vasospasm and Delayed Cerebral Ischemia

Ramazan Jabbarli[a, b] Matthias Reinhard[c] Mukesch Shah[b] Roland Roelz[b] Wolf-Dirk Niesen[c] Klaus Kaier[d] Christian Taschner[e] Astrid Weyerbrock[b] Vera Van Velthoven[b, f]

Neuroradiology 2014; 56: 817-824

Hyperacute Vasospasm After Aneurysmal Subarachnoid Hemorrhage

B. Bar[1,2] · L. MacKenzie[3] · R. W. Hurst[4] · R. Grant[5] · J. Weigele[4] · P. K. Bhalla[6] · M. A. Kumar[6,7] · M. F. Stiefel[8] · J. M. Levine[6,7,9]

Neurocrit Care 2016; 24: 180-188

Ultra-early angiographic vasospasm associated with delayed cerebral ischemia and infarction following aneurysmal subarachnoid hemorrhage

Fawaz Al-Mufti, MD,[1] David Roh, MD,[1] Shouri Lahiri, MD,[1] Emma Meyers, BA,[1] Jens Witsch, MD,[1] Hans-Peter Frey, PhD,[1] Neha Dangayach, MD,[3] Cristina Falo, PhD,[1] Stephan A. Mayer, MD,[3] Sachin Agarwal, MD,[1,2] Soojin Park, MD,[1,2] Philip M. Meyers, MD,[1,2] E. Sander Connolly, MD,[2] Jan Claassen, MD, PhD,[1,2] and J. Michael Schmidt, PhD, MSc[1]

J Neurosurg 2016 May 27: 1-7. [Epub ahead of print]

- **insorge entro 48 ore dal sanguinamento con una frequenza del 4-10%**

- **si associa a vasospasmo tardivo, DCI e prognosi sfavorevole**