# Acute Stroke Imaging

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**ACR Education Center 2025**

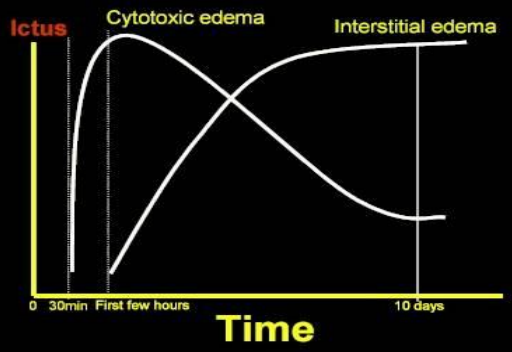
# Learning Objectives

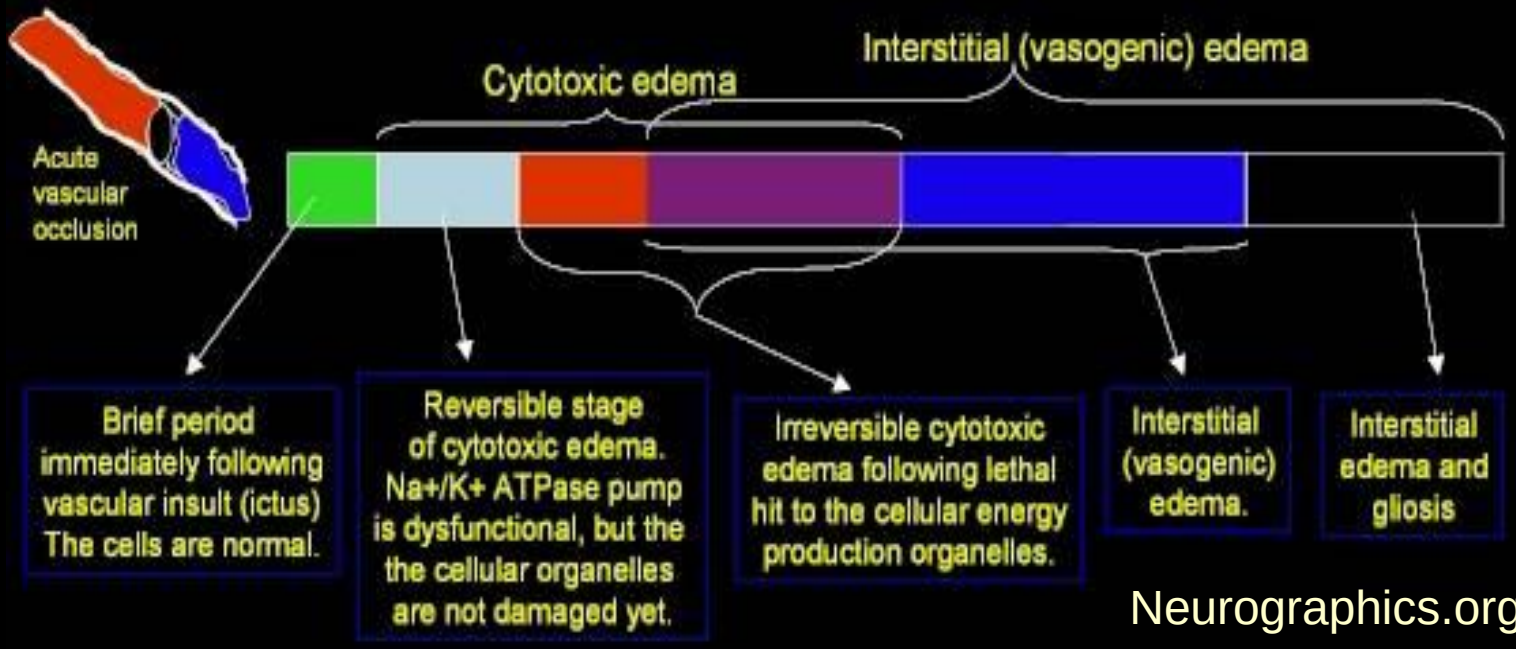
- Review the CT and MR appearance of acute ischemic brain injuries.
- Discuss treatment options for acute ischemic brain injuries.
- Appreciate the impact of some of the newer imaging techniques.
- Case based approach.

# Epidemiology of Stroke

- Ischemic stroke is the third leading cause of death in the USA
- Thrombolytic therapy is beneficial in select patients with acute ischemia
- Unfortunately, only a small minority of patients receive thrombolytic therapy
- Goal of imaging is to improve outcome
- The challenge is to select the patients who may benefit

# Stroke: Pathophysiology




Neurographics.org

# Brain Attack

- Acute CNS injury with abrupt onset
- First imaging NCCT
  - Hemorrhage?
  - Ischemic stroke mimic?
  - Treatable (less than 1/3 of MCA distribution) ischemic stroke?
- Need for additional imaging
  - Rapid imaging and interpretation are essential
  - Time is brain!
  - Depends upon the imaging and therapeutic options

# Time is Brain!

- In a typical large vessel ischemic stroke, the patient loses:
  - 1,900,000 neurons per minute
  - 14,000,000,000 synapses per minute
  - 7.5 miles of myelinated fibers per minute

Saver JL et al. Stroke 37:263-266 (2006)

# Imaging for Stroke Therapy

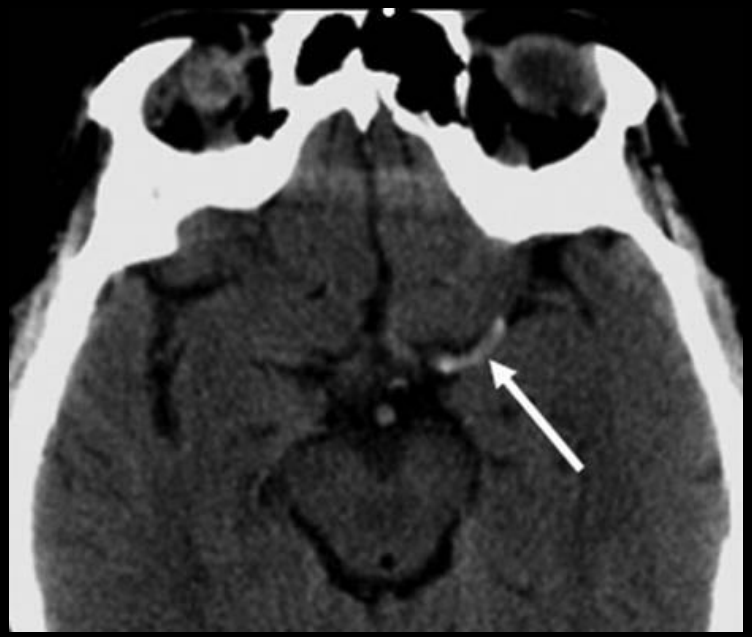
- NCCT
- NCCT + CTA
- NCCT + CTA + CTP
- NCCT + CTA + DWI
- NCCT + DWI + MRA + MRP

# Imaging: NCCT

- Is there an infarct?
  - Direct signs
  - Indirect signs
- Infarct size
  - ASPECTS score
- Is there an alternative diagnosis?
  - Neoplasm?
- Is there hemorrhage?
  - If there is hemorrhage; no therapy

# Imaging: NCCT

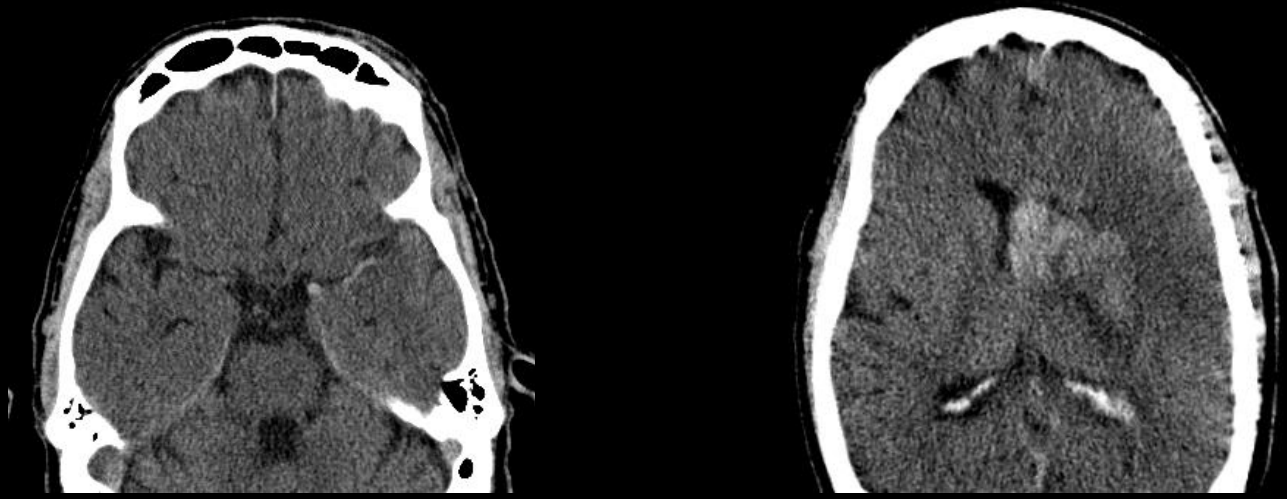
- Dense MCA sign
  - Thrombus in MCA
  - Longer thrombus implies poorer outcome
  - Describe the clot length in your report
  - Therapy is usually clot retrieval for clot > 8mm.



Srinivasan, Ashok, et.al.
RadioGraphics 26:S75-95 (2006)

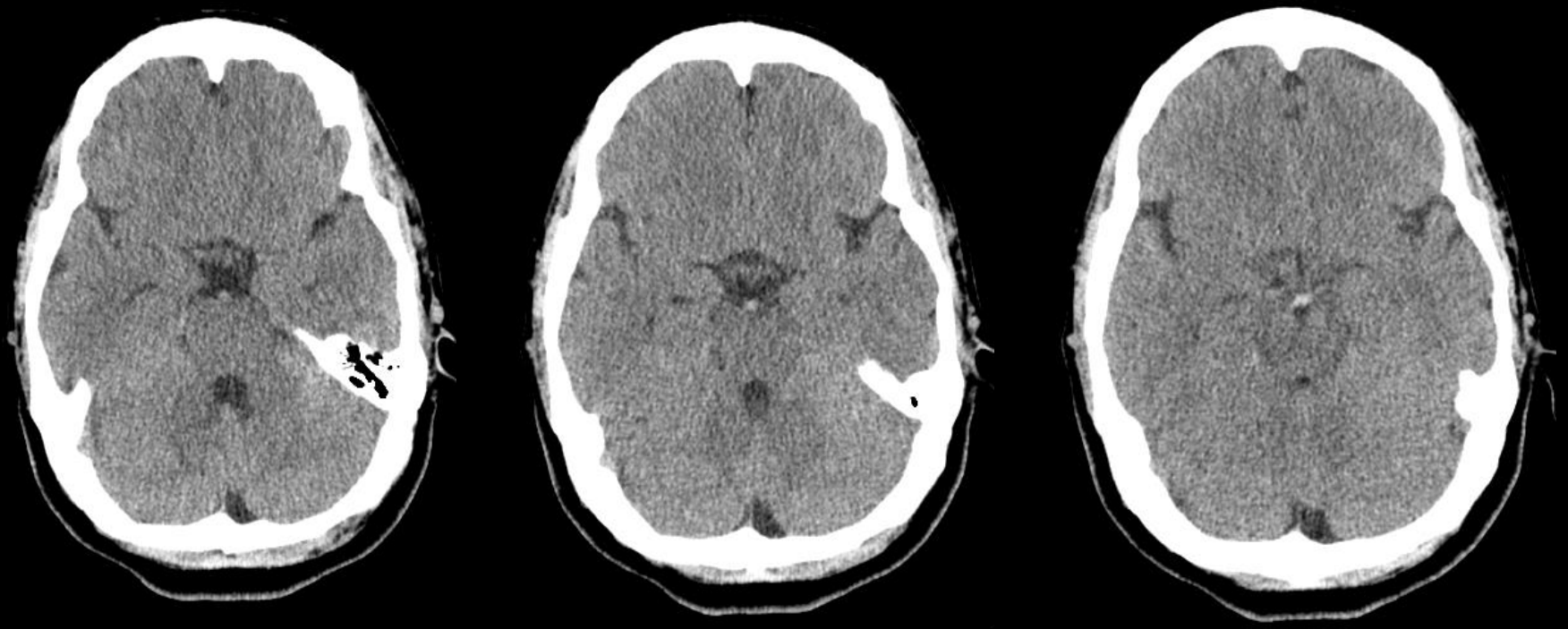
# Right Sided Weakness: CT

- Initial CT shows dense MCA
- IV thrombolysis results in hemorrhage
- Proximal, long clots do poorly with IV



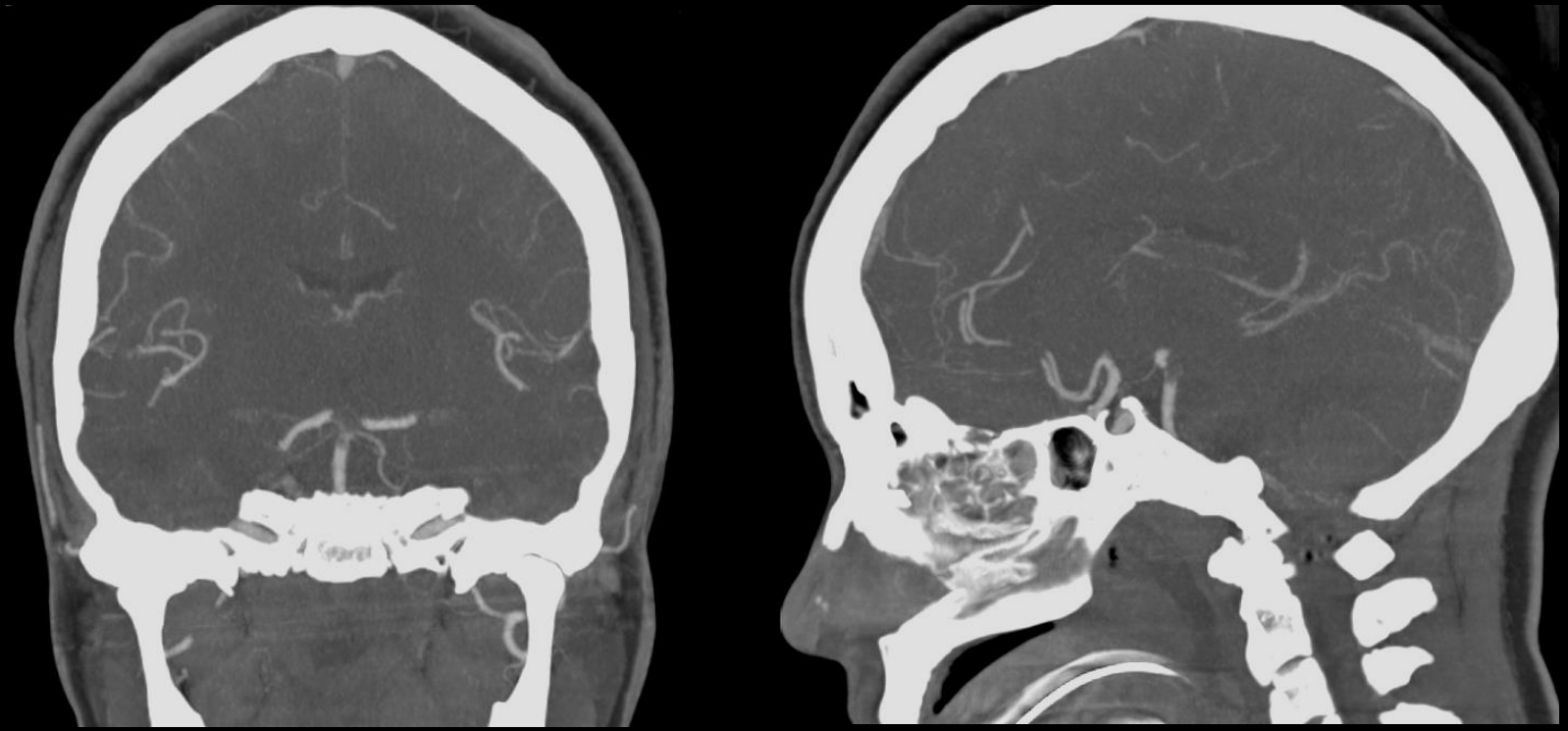
# Case: Unresponsive Pt: CT

- What is the abnormality?



# Case: Unresponsive Pt: CTA

- Thrombus at the basilar tip

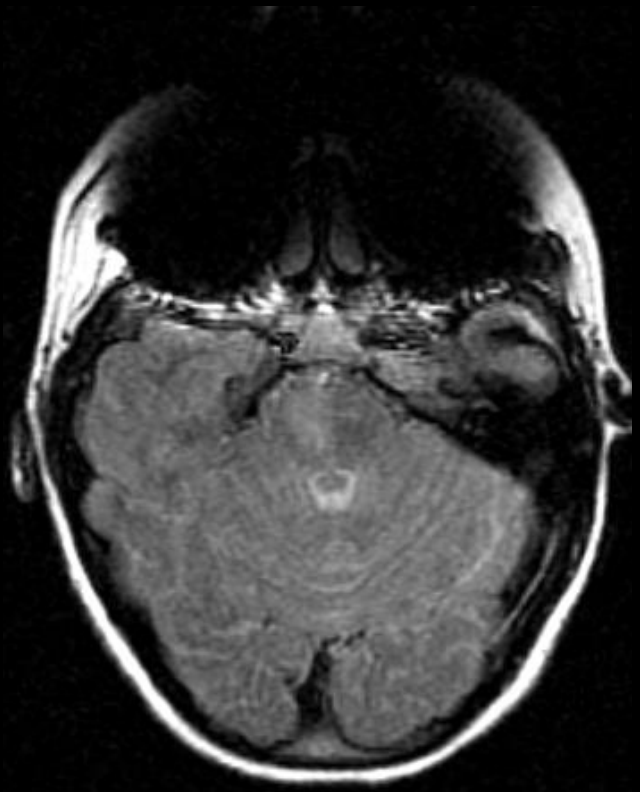


# Case: Ataxia, R/O Stroke: CT

- Ataxia in a teenager

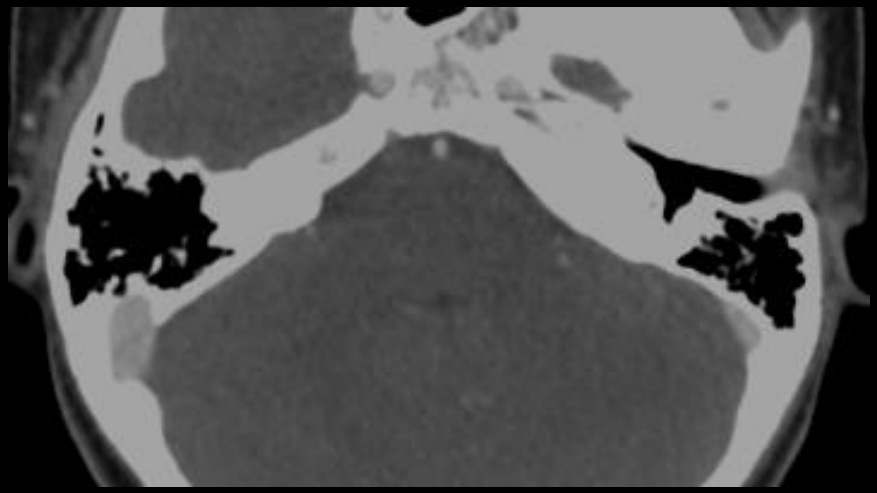
# Case: Ataxia: FLAIR

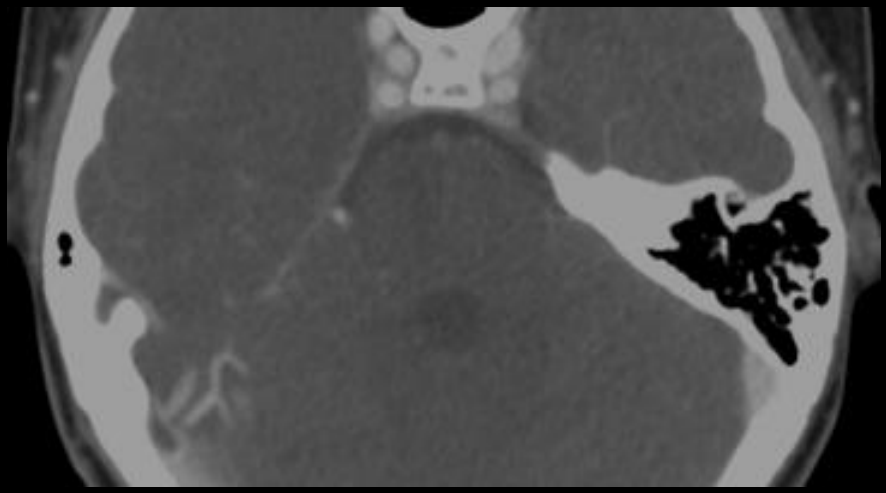
- Ataxia in a teenager
- MR limited by dental artifact
- Increased signal in pons
- Pons obscured on DWI



# Case: Ataxia: CTA

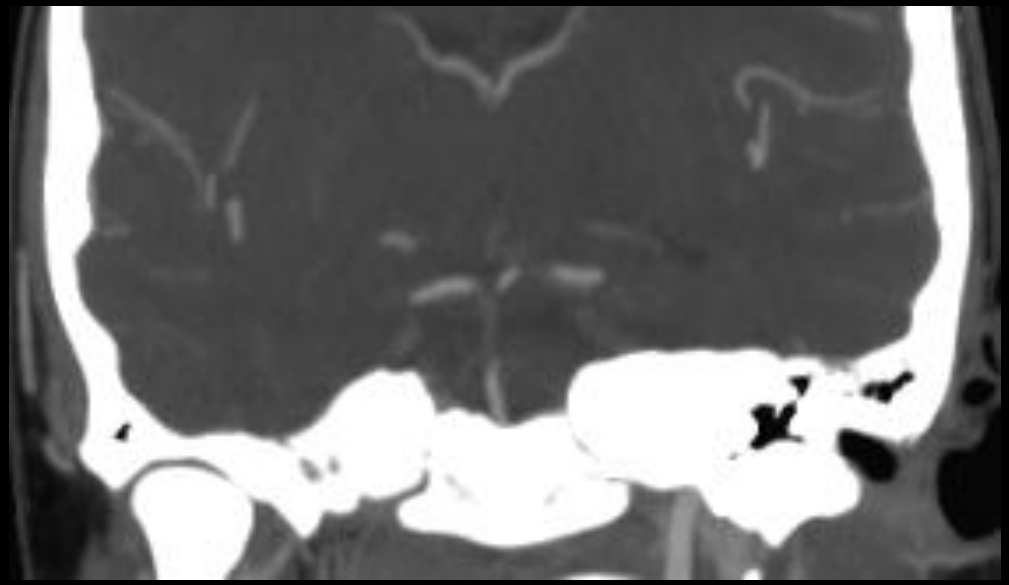
- Ataxia in a teenager
- Absent filling of mid basilar artery





# Case: Ataxia: CTA

- Clot within the basilar artery



# Case: Ataxia: Angiography

- Ataxia in a teenager
- Clot was retrieved, patient recovered

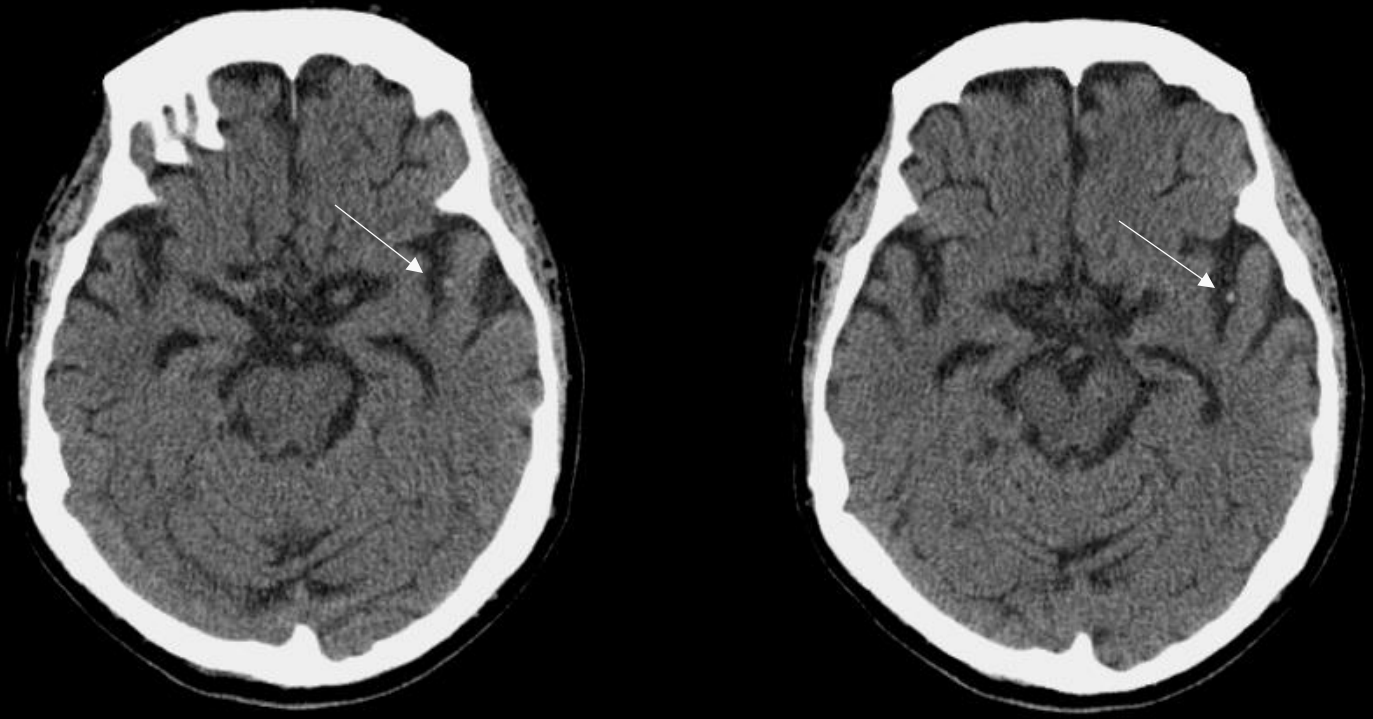
# Imaging: NCCT

- Dot sign
  - Thrombus in dstal (M2) MCA branch

Srinivasan, Ashok, et.al.
Radiographics 26:Sup 1 (2006)

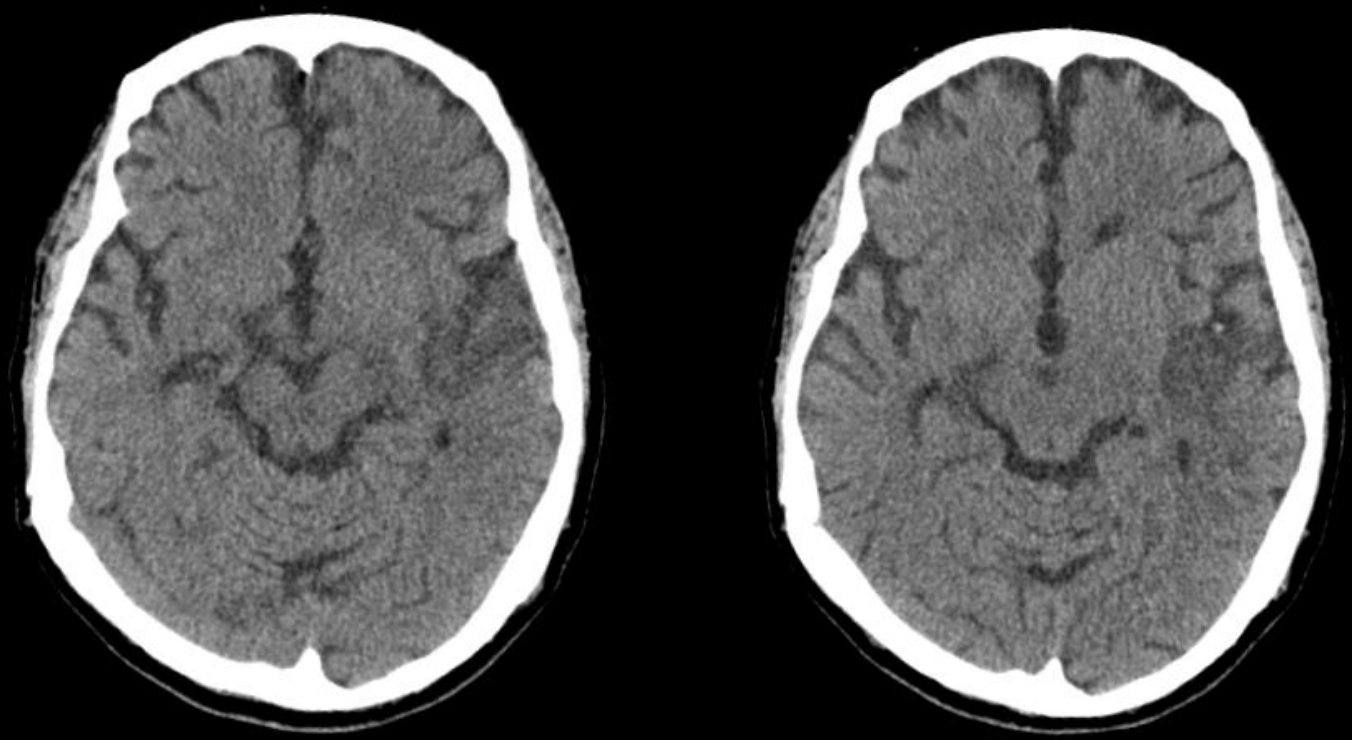
# Right Sided Weakness: CT

- Dense left MCA branch (dot sign)



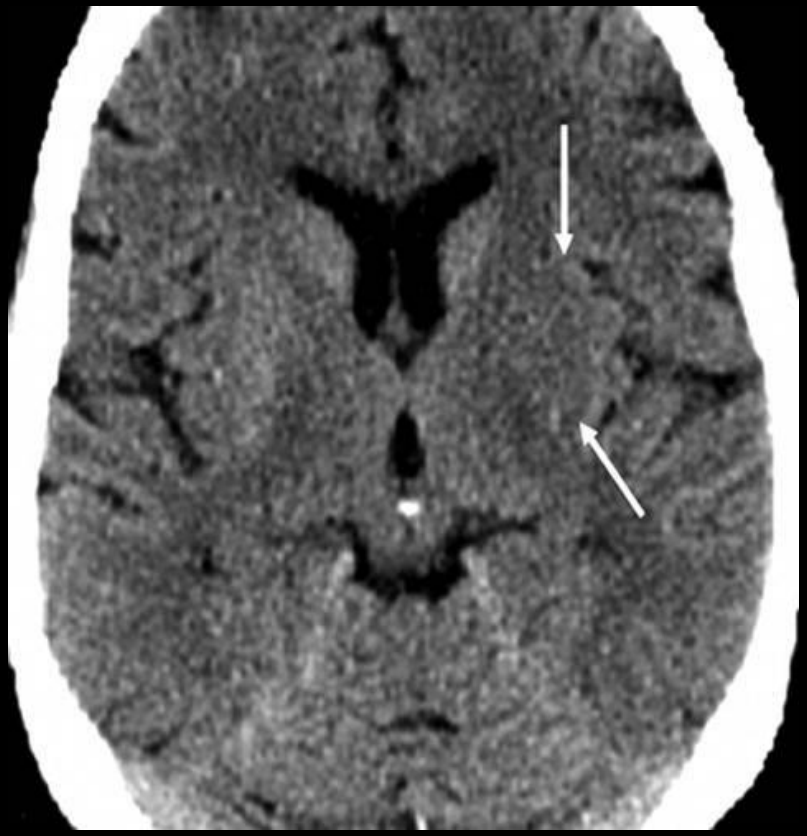
# Right Sided Weakness: CT

- A few days later L MCA stroke is apparent



# Imaging: NCCT

- Obscuration of lentiform sign
  - Implies ischemia or infarct in the territory of lenticulostriate arteries arising from M1



Srinivasan, Ashok, et.al.
RadioGraphics 26:75-95 (2006)

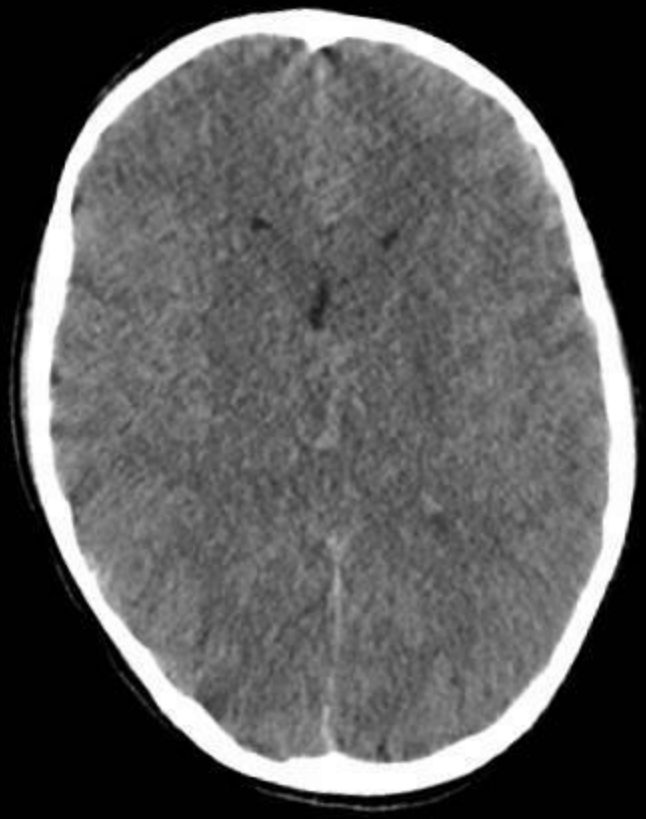
# Imaging: NCCT

- Insular ribbon sign
  - Decreased density in insular cortex
  - Implies MCA ischemia or infarct
- Partial obscuration of lentiform

Srinivasan, Ashok, et.al.
RadioGraphics 26:75-95 (2006)

# Case Global Anoxia: CT

- Patient S/P arrest
- R/O anoxia
- Loss of grey-white differentiation in basal ganlia



# Case Global Anoxia: CT

- Patient S/P arrest
- R/O anoxia
- Pseudo-subaracnoid hemorrhage
  - Engorged venous structures appear in comparison to the hypodense brain

# Imaging: NCCT

- Patient presents with left hemiparesis
- Is there ischemia or infarct?

Srinivasan, Ashok, et.al.
RadioGraphics 26:S75-95 (2006)

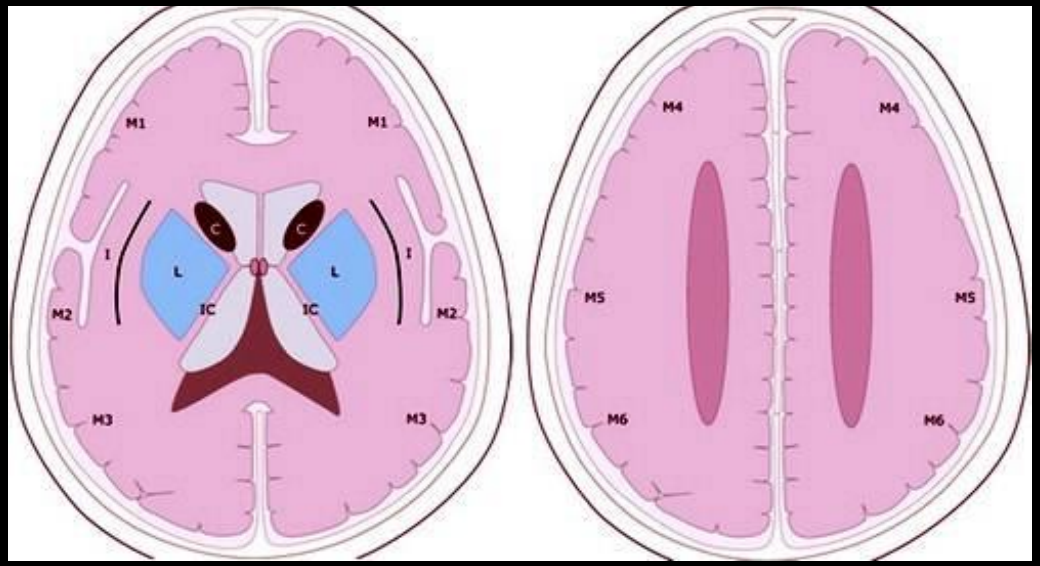
# Imaging: NCCT

- Right hemiparesis
- Ischemia or infarct?
  - Narrowed WW from 80 HU to 10 HU
  - Partial obscuration of lentiform and likely involvement of posterior limb of IC

Srinivasan, Ashok, et.al.
RadioGraphics 26:S75-95 (2006)

# Imaging: NCCT ASPECTS

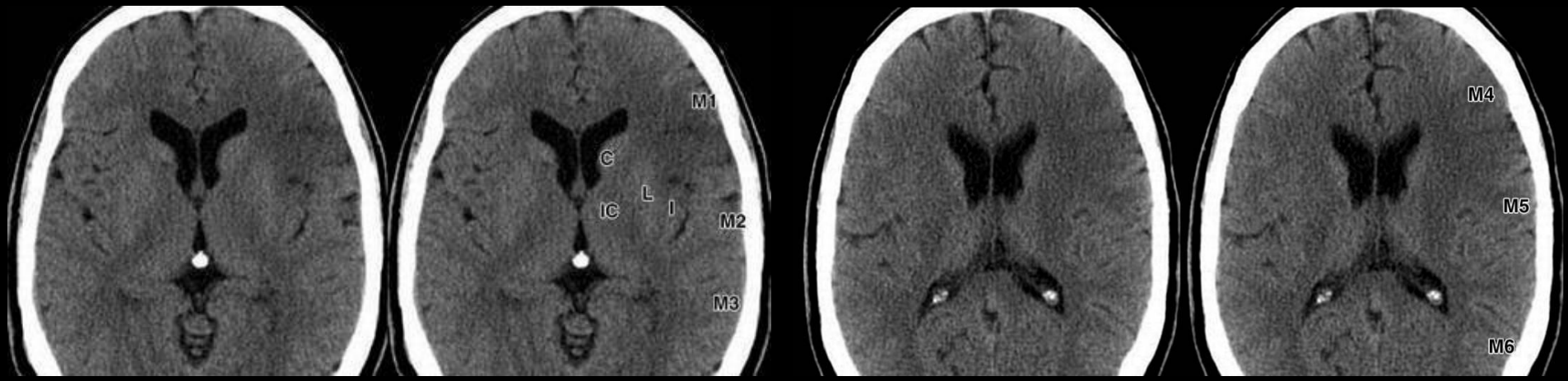
- ASPECTS 10-point scale
  - 6 cortical areas, insula, lentiform, caudate, IC
  - Low ASPECTS score portends poor outcome




Kunst MM, Schaefer PL. Radiol Clin NA 49:1-26 (2011)

# Imaging: NCCT ASPECTS

- ASPECTS 10-point scale
  - 6 cortical areas, insula, lentiform, caudate, IC
  - M1, insula, lentiform are abnormal
  - ASPECTS score: 10 – 3 = 7



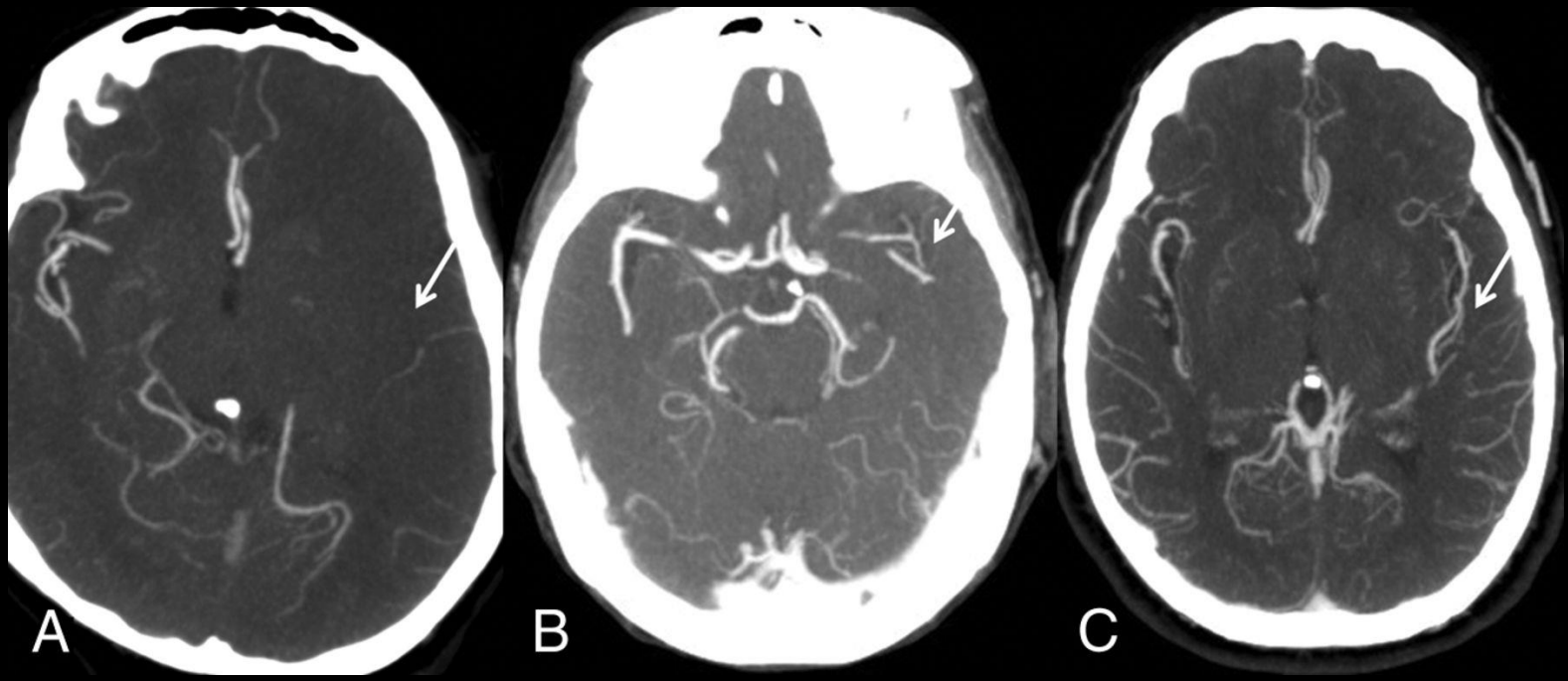

Srinivasan, Ashok, et.al. RadioGraphics 26:S75-95 (2006)

# Imaging: Arteries

- Are the vessels patent?
  - –CTA, MRA
  - –Patients with large vessel arterial occlusions do better with clot retrieval
  - –Patients with good arterial collaterals have more salvageable brain and do better
  - –“Malignant pattern” of poor arterial collaterals is associated with larger infarcts and poorer functional outcomes

# Grading: Arterial Collaterals

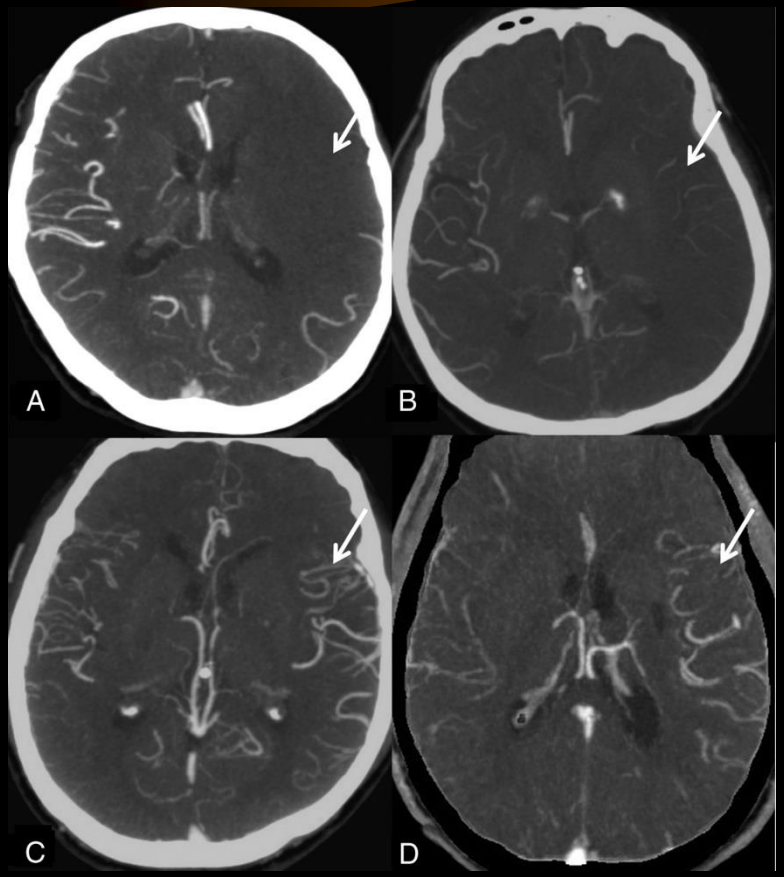
- Grade 1 fig A, Grade2 fig B, Grade 3 fig C




Yeo et al. AJNR 36:289-94 (2015)

# Grading: Arterial Collaterals

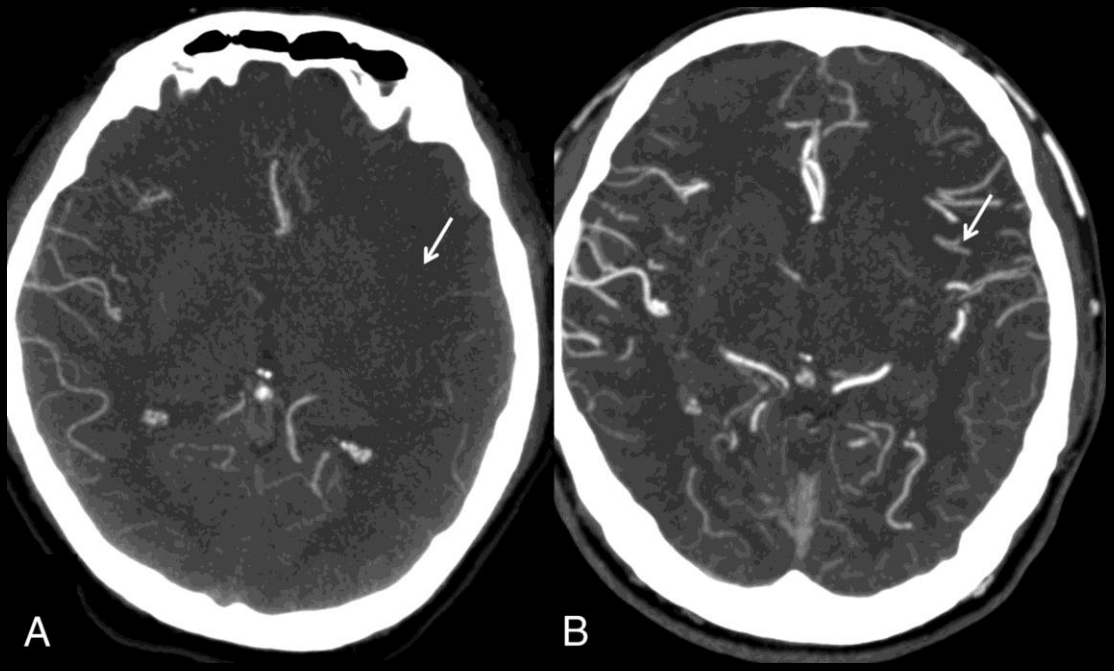
- No opacifiction fig A
- Decreased opac. fig B
- Equal opacification
- Increased opac. fig C
- Exuberant opac. Fig D




Yeo et al. AJNR 36:289-94 (2015)

# Grading: Arterial Collaterals

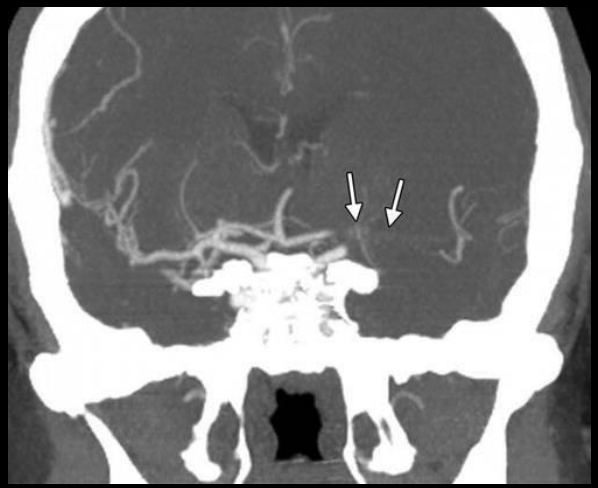
- Less than 50% of MCA fig A
- More than 50% of MCA fig B




Yeo et al. AJNR 36:289-94 (2015)

# Imaging: NCCT & CTA

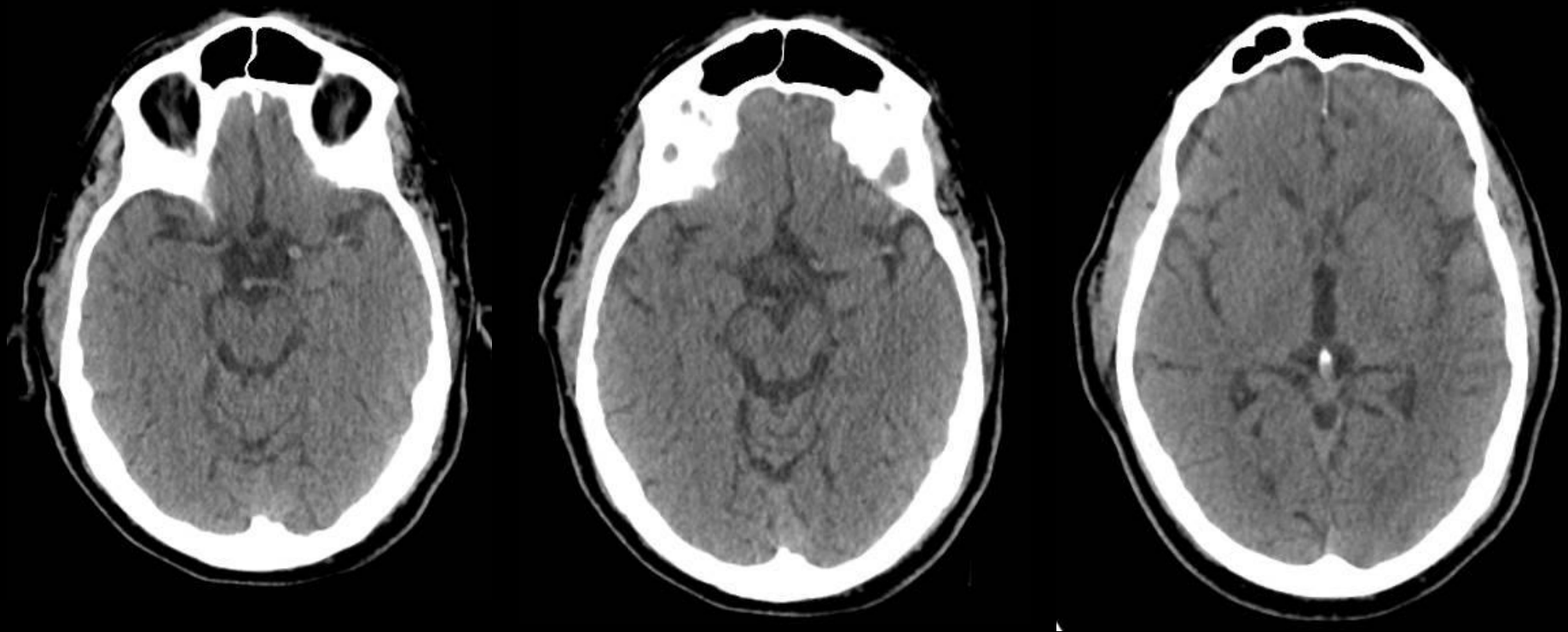
- Dense MCA sign, long clot
- CTA shows carotid summit & M1 occlusion
  - Poor collaterals, “malignant pattern”
  - Note the thick MIPs and coronal reformats



Srinivasan, Ashok, et.al. RadioGraphics 26:S75-95 (2006)

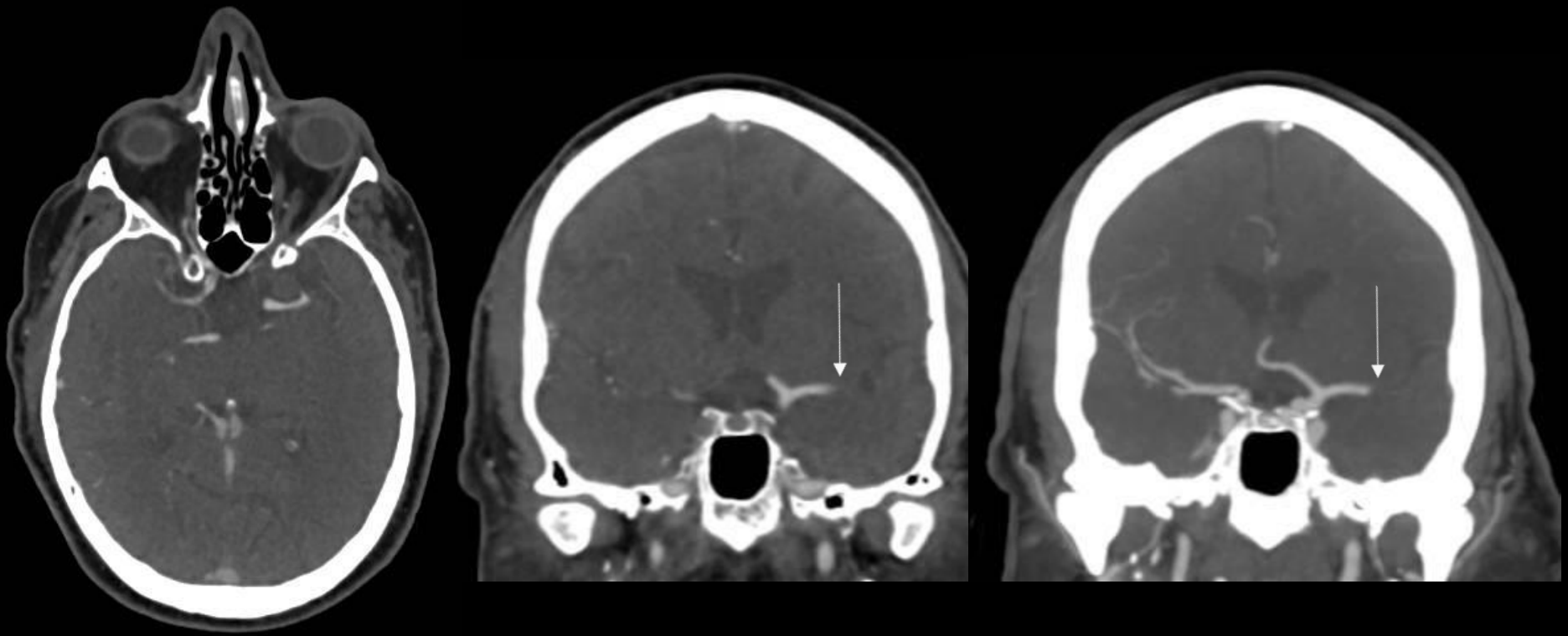
# Case: Poor Arterial Collaterals

- Loss of L insular ribbon



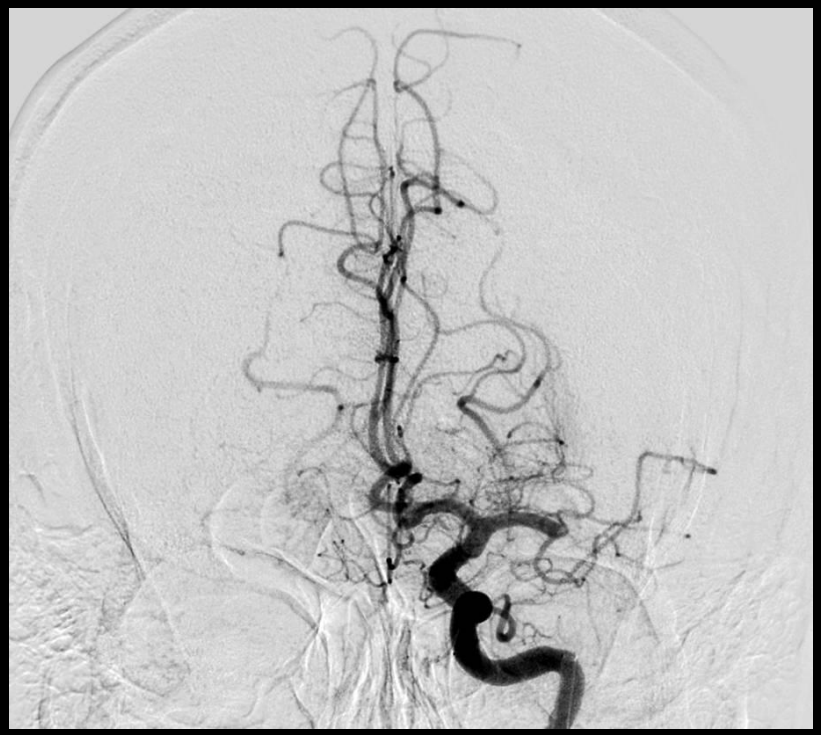
# Case: Poor Arterial Collaterals

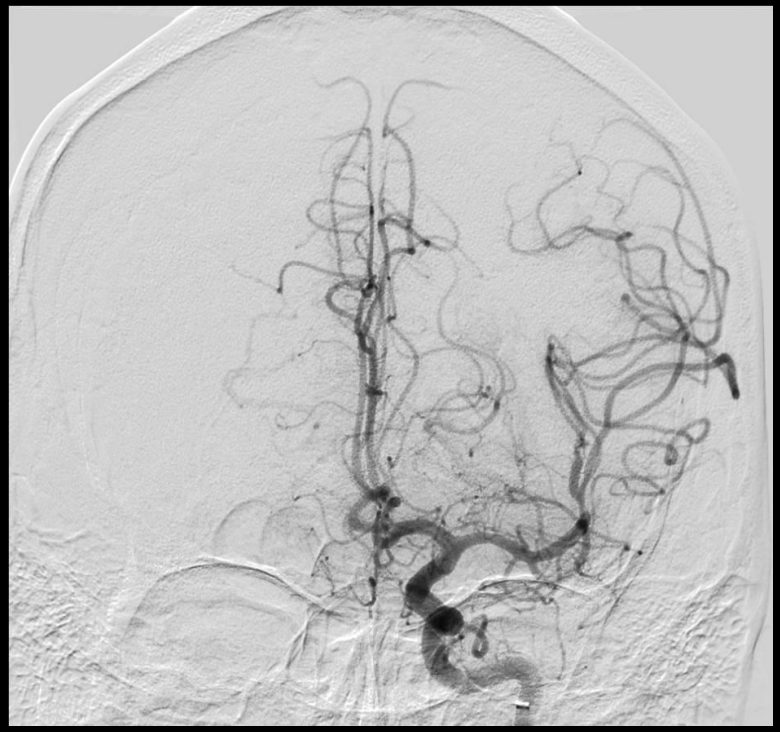
- CTA shows cutoff of L M1 & poor collaterals
  - "Malignant pattern" c/w poor outcome



# Case: Poor Arterial Collaterals

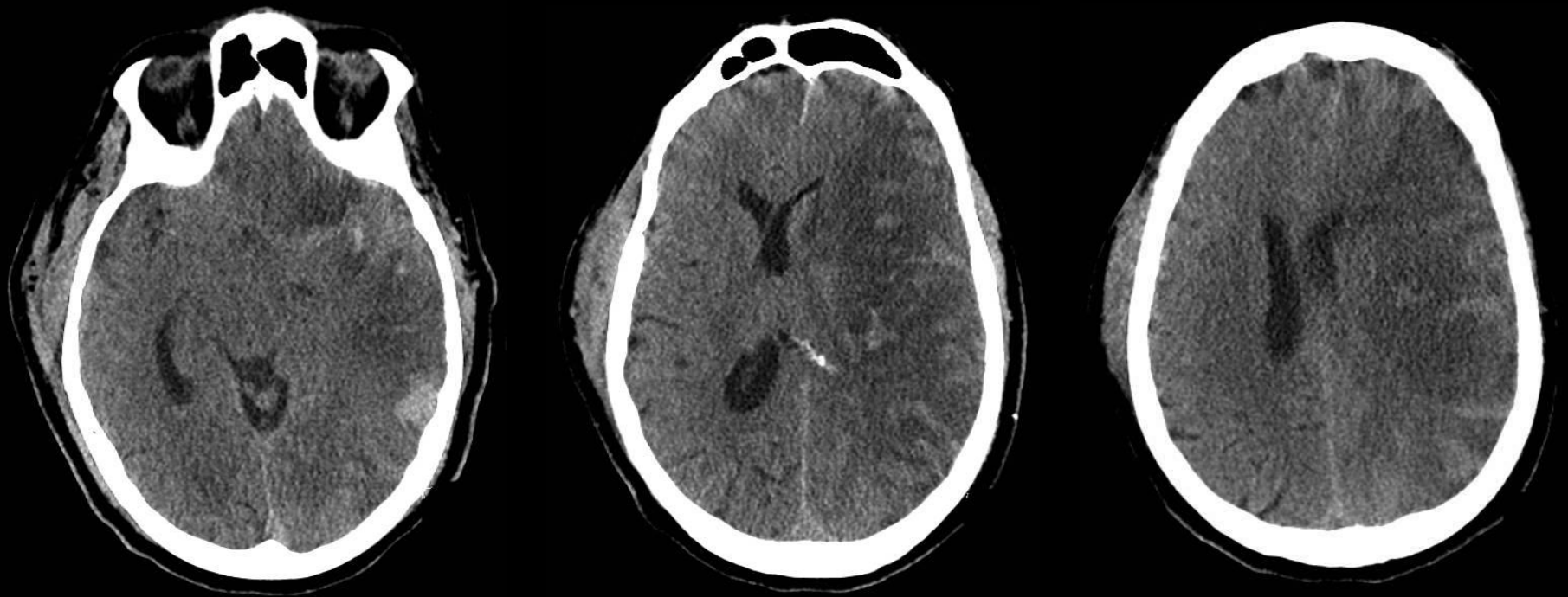
- LICA angiogram confirms LMCA occlusion
- Angiographically successful clot retrieval





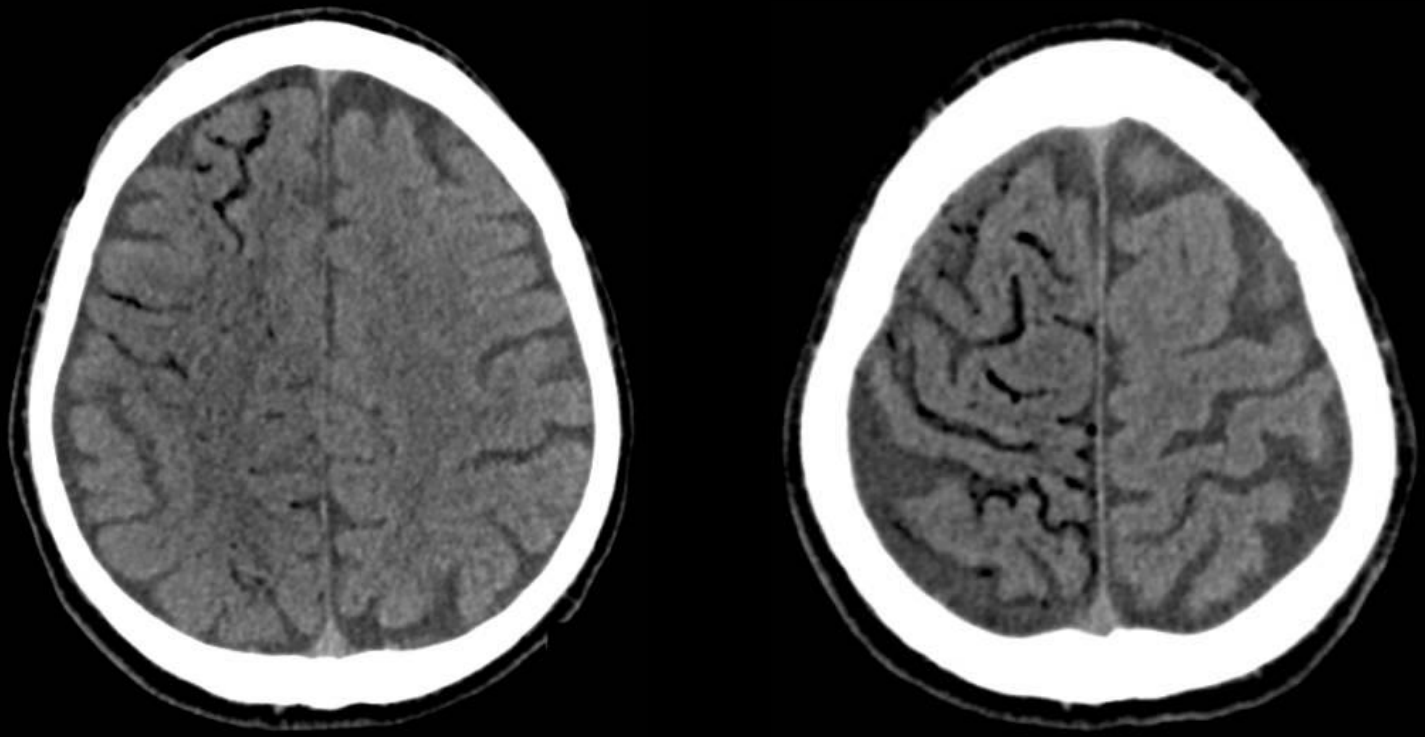
# Case: Poor Arterial Collaterals

- Post treatment CT shows:
  - Large L MCA infarct
  - Mass effect with subfalcine herniation



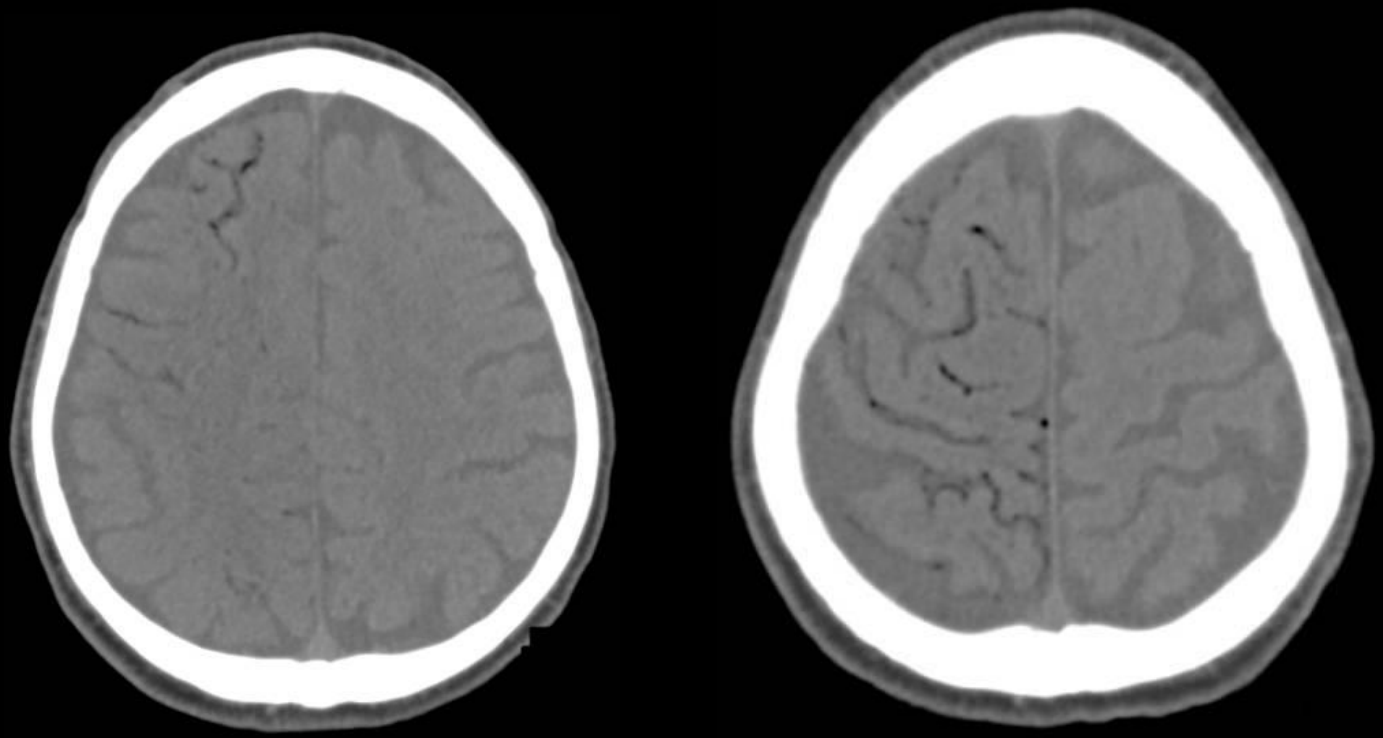
# Case AMS: CT

- Patient “altered” following placement of right central line; R/O infarct



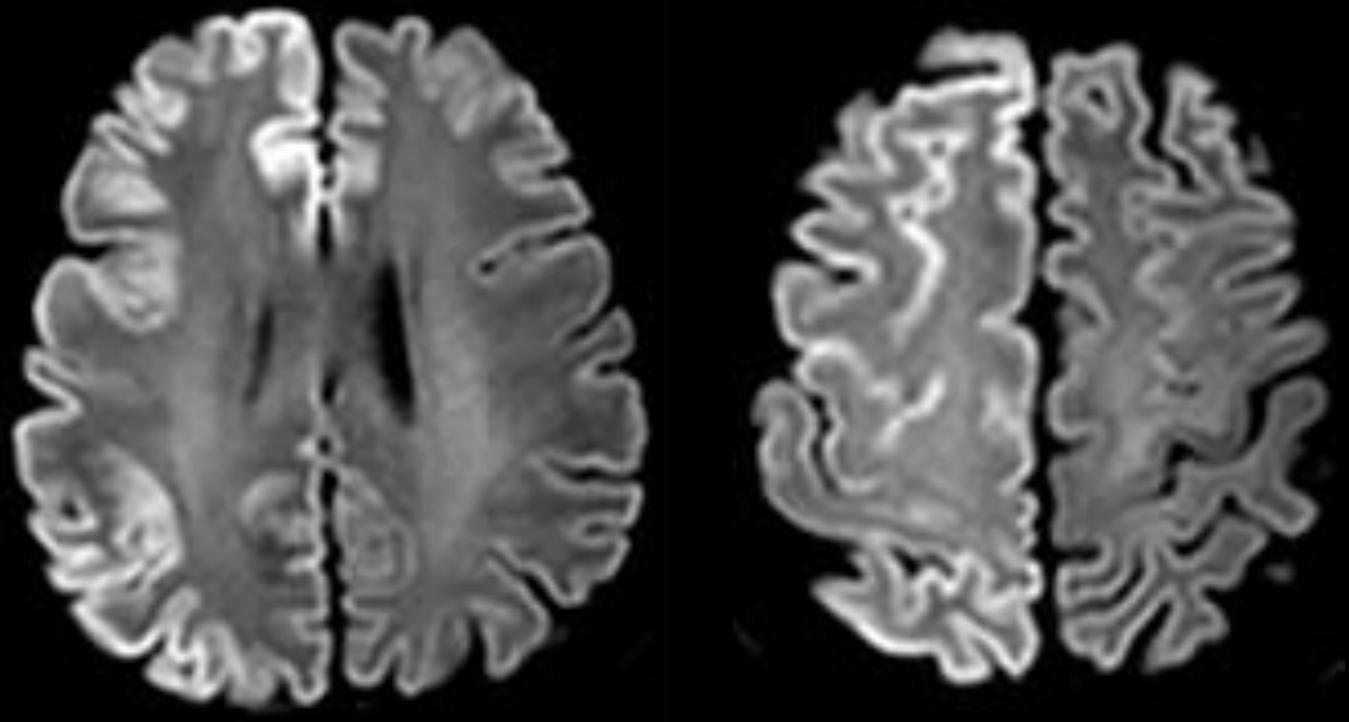
# Case AMS: CT

- Initial CT appeared abnormal; wide windowing confirms intravascular gas



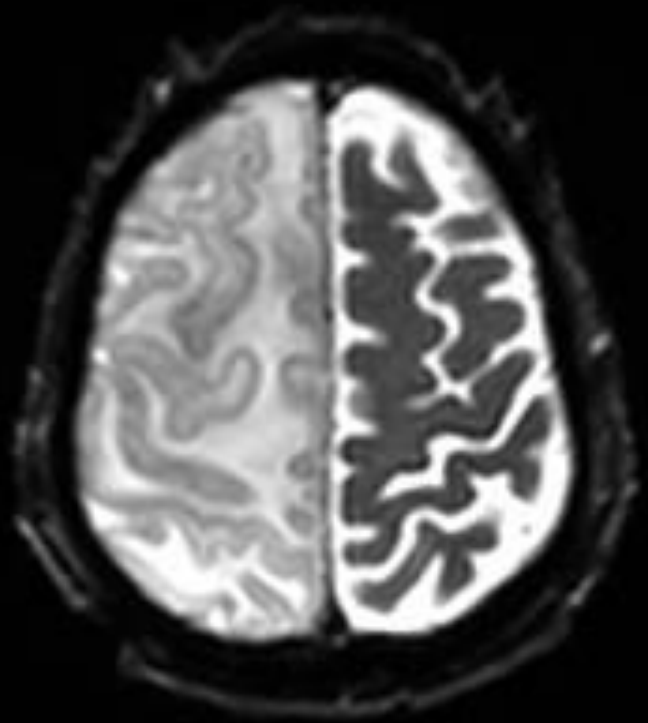
# Case AMS: DWI

- DWI shows extensive right cortical restricted diffusion and brain swelling



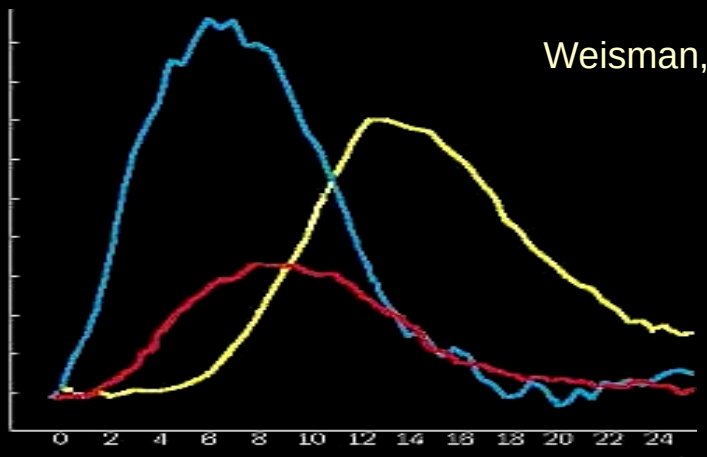
# Case AMS: CT & MR F/U

- Two days later CT and T2 MR show right hemispheric infarct



# Imaging: CT Perfusion

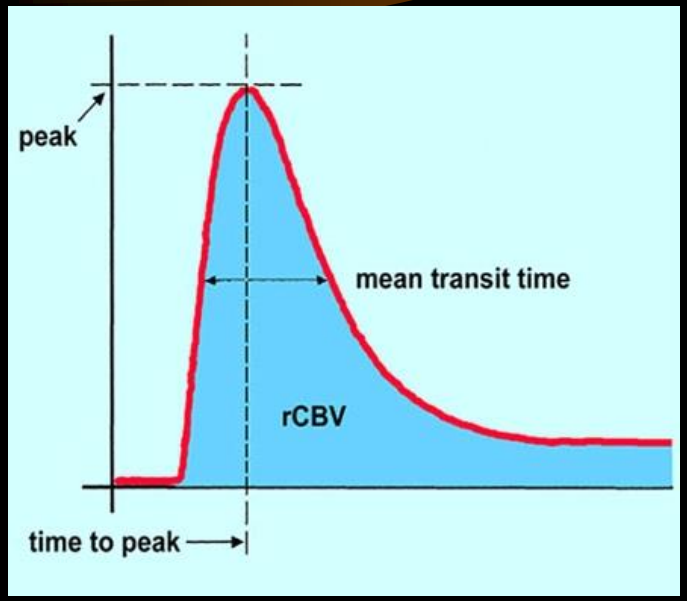
- Infuse 40cc of IV contrast
- Repeatedly scan selected brain regions
- Obtain time – density curves
  - Artery, vein, parenchyma




Weisman, Visions (2006)

# Analysis of time density curves

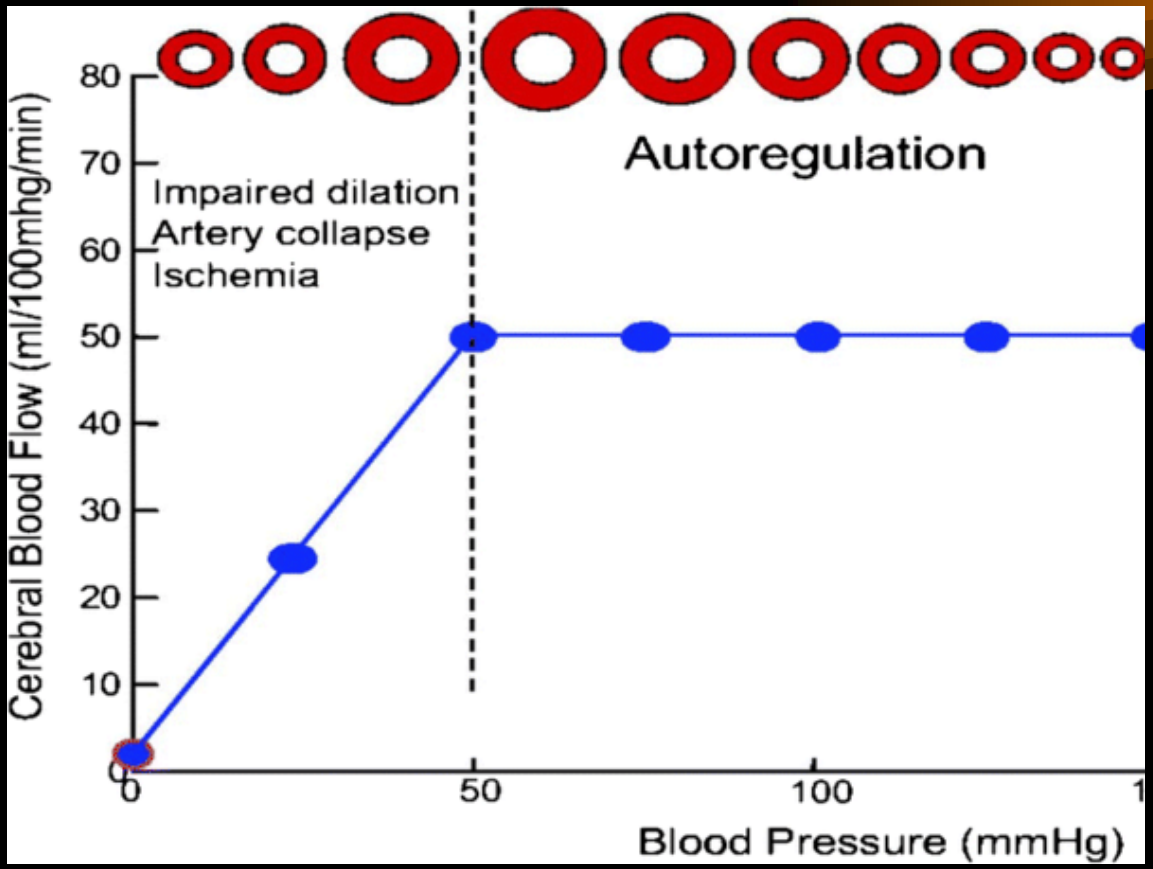
- Deconvolution analysis
  - Time to peak (TTP)
- Width at half max
  - Mean transit time (MTT)
- Area under curve
  - Cerebral blood volume (CBV)
- Cerebral blood flow (CBF) = CBV/MTT



# Autoregulation

- Viable brain shows intracranial vasodilitation in response to decreased perfusion pressure
  - Normal or increased CBV
  - Normal to decreased CBF
- Infarcted brain cannot autoregulate
  - Decreased CBV
  - Decreased CBF

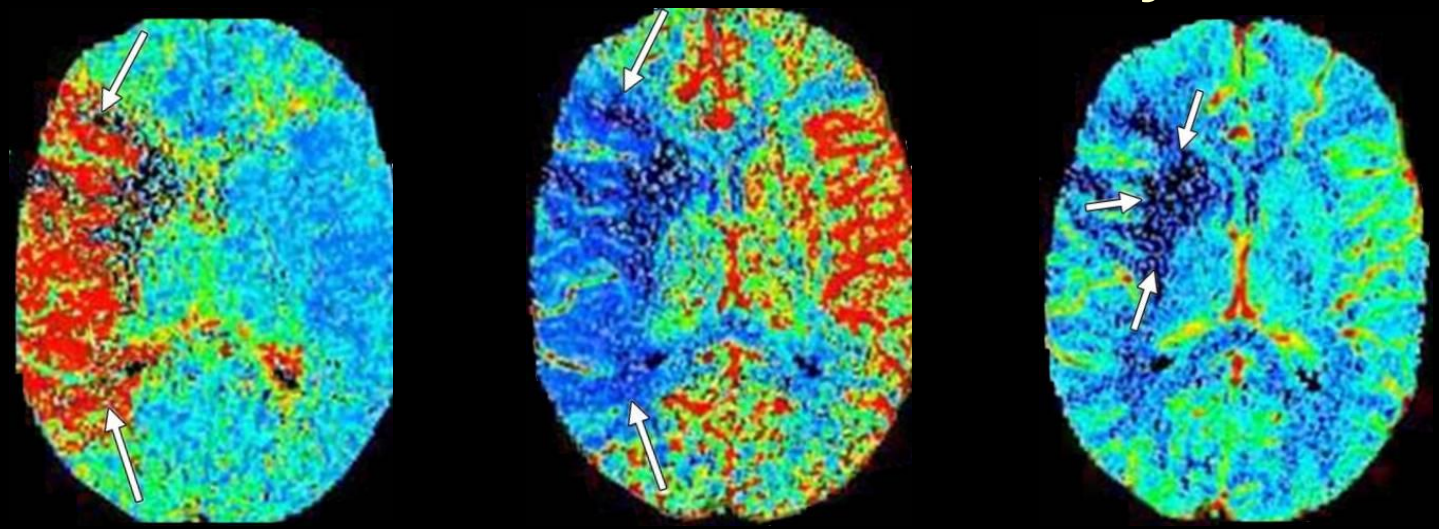
# Cerebral Autoregulation




Medhok, Debbie et. al. Current Neurology and Neuroscience Reports 18 (2018)

# “Old Time” CT Perfusion

- MTT & CBF show decreased perfusion
- CBV shows smaller abnormality



MTT – CBV = penumbra  MTT / CBV = mismatch ratio

Srinivasan, Ashok, et.al. RadioGraphics 26:S75-95 (2006)

# Ischemic Penumbra

- Infarct core is dead brain
  - Measured by DWI
  - CBF (< 30%) on CTP
- Brain at risk is ischemic
  - Tmax (> 6 sec)
- Brain at risk – Core = Mismatch volume or Ischemic penumbra

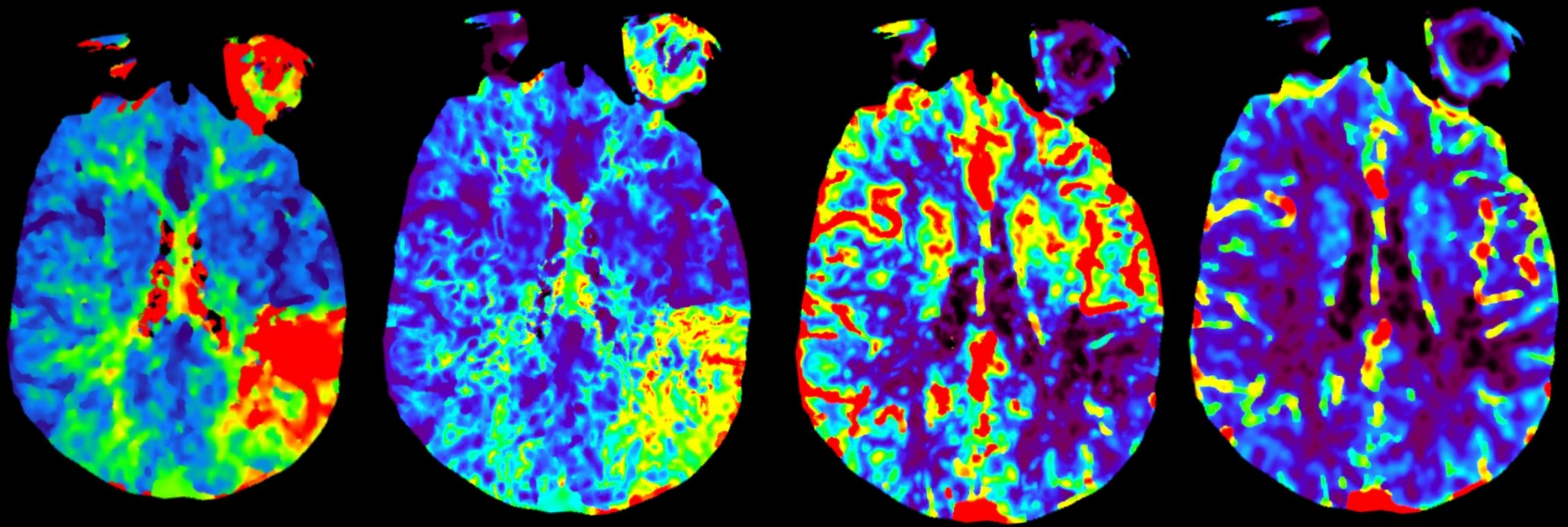

Summers, Debbie, Malloy, Rachel. Journal of Radiology Nursing 30(3):104-115 (2011)

# CT: Aphasia & R Hemiparesis

- No hemorrhage
- Decreased cortical density in posterior L MCA distribution
- Basal ganglia appear preserved
- ASPECTS = 8

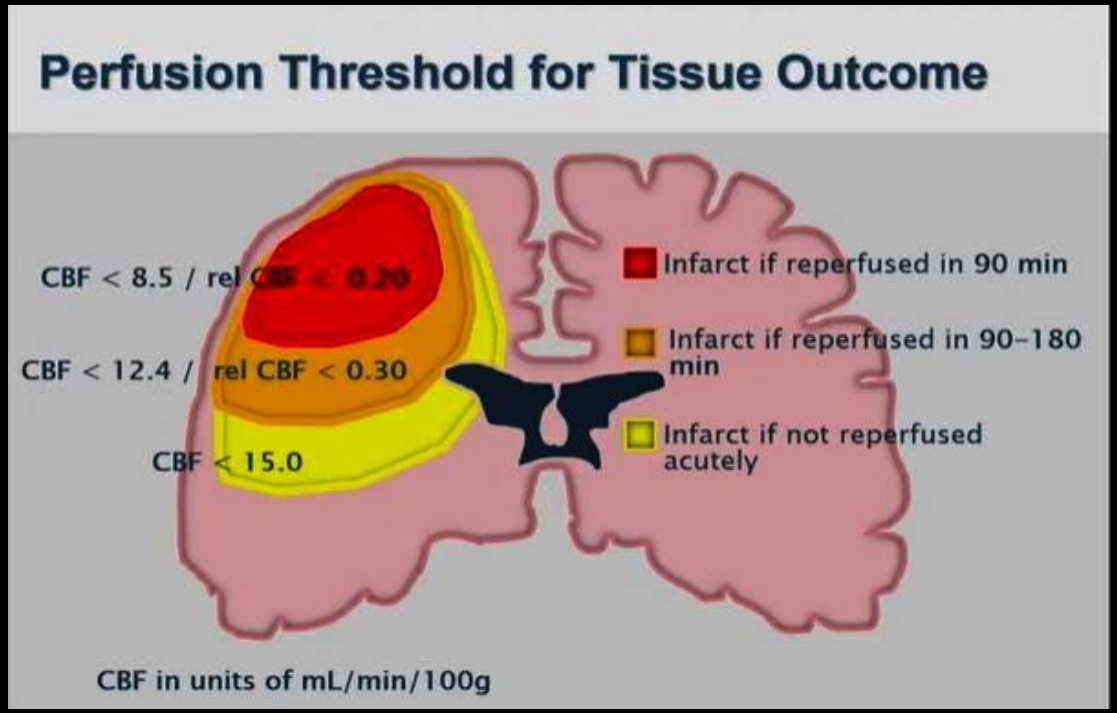
# CTP: Aphasia & R Hemiparesis

- TTP, MTT, CBF, CBV parameter maps
- MTT - CBV = penumbra (“Old Time”!)



# CTP: Aphasia & R Hemiparesis

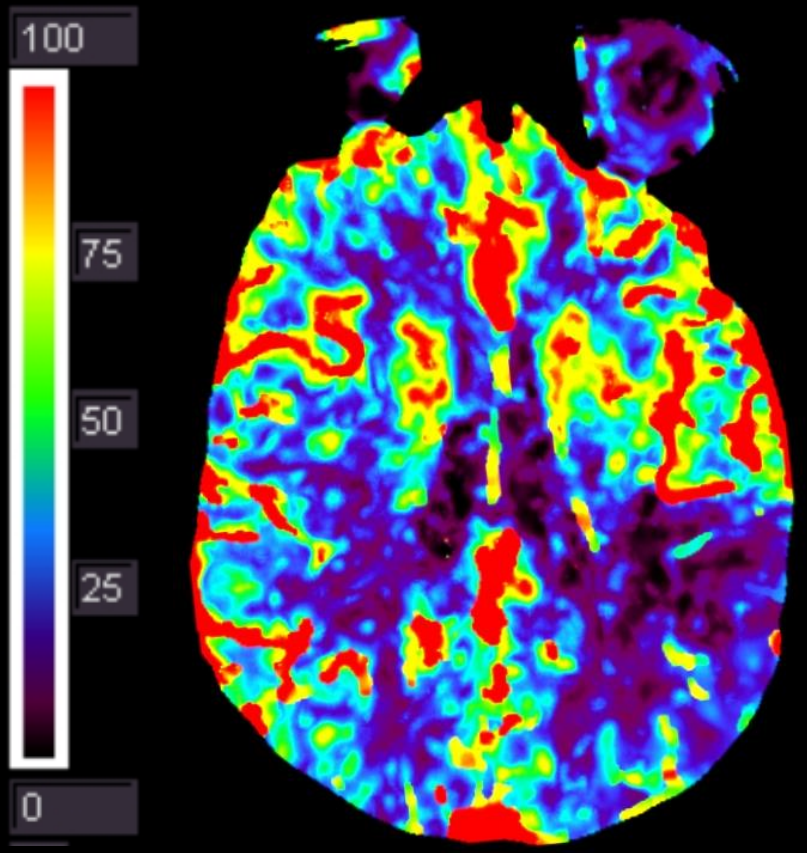
- More modern protocols use a decrease of CBF by 30% to estimate infarct core




d'Esterre, CD et al. Stroke 46:3390-3397 (2015)

# CTP: Aphasia & R Hemiparesis

- CBF map shows decreased perfusion on L
- Use the decreased perfusion to estimate infarct core?!

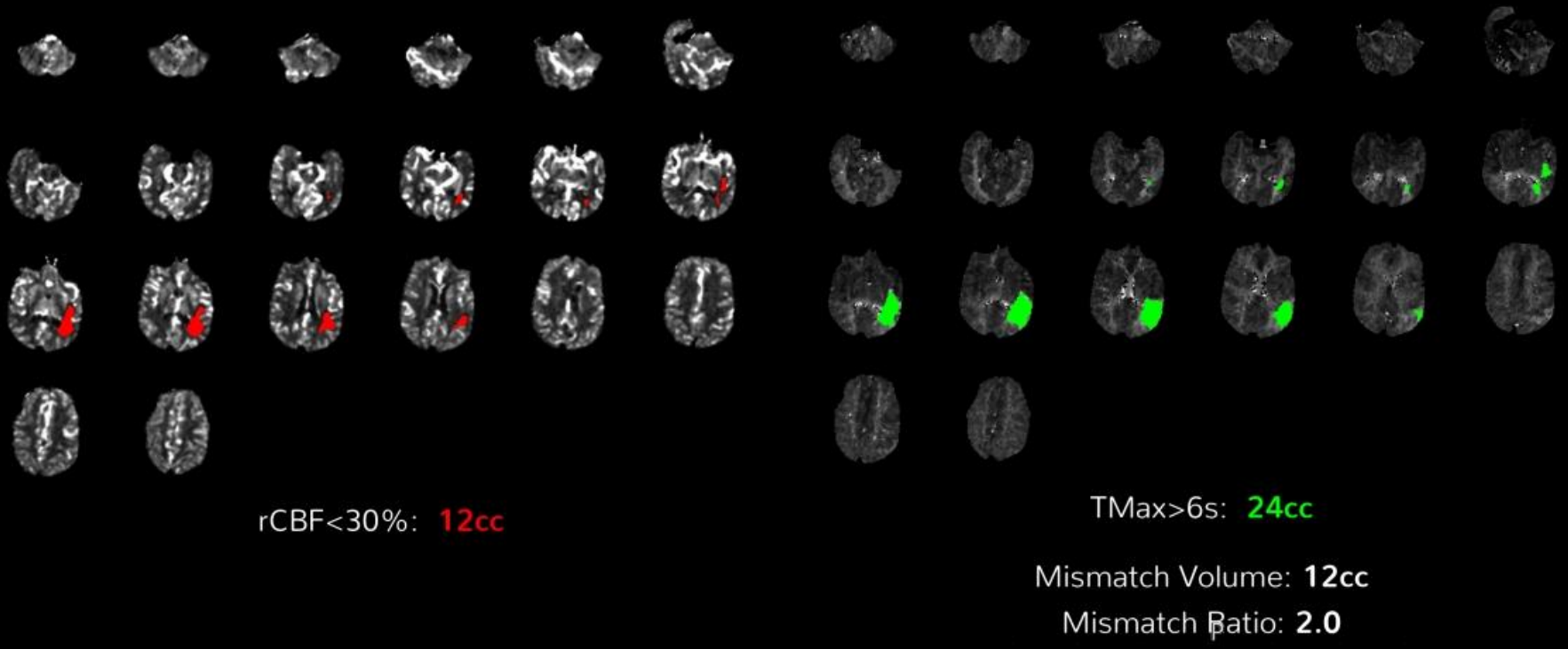


# CTP: Aphasia & R Hemiparesis

- Most modern protocols estimate the ischemic penumbra by comparing the increased TMAX (> 6 seconds), brain at risk, with the decreased CBF (< 30%), core
- TMAX = Time for contrast to move from proximal large vessel to brain parenchyma
- TMAX (> 6 s) – CBF (< 30%) = penumbra
- Really need AI!

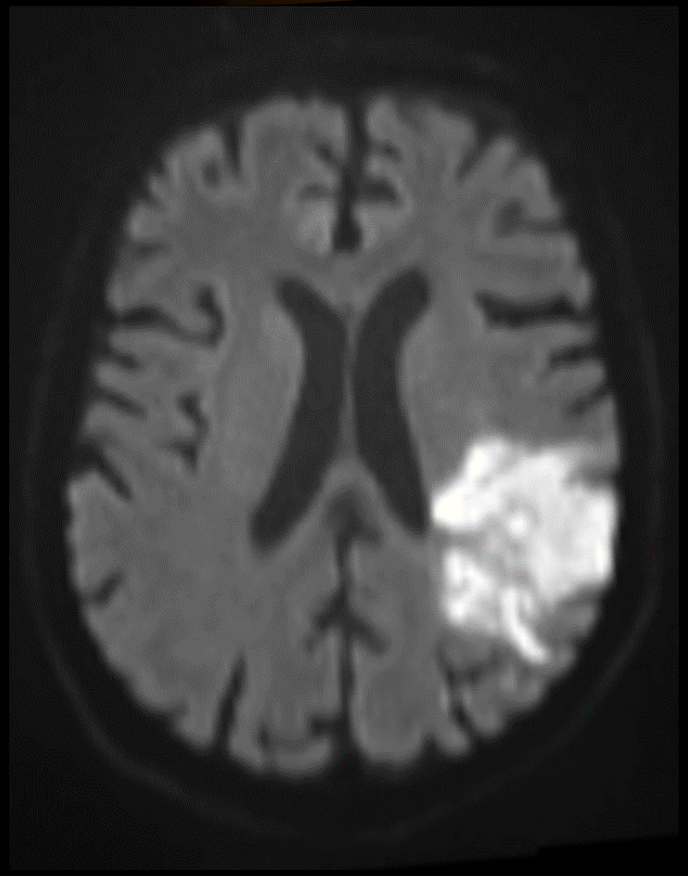
# AI: Aphasia & R Hemiparesis

- Calculates the relative CBF decreased 30%
- Calculates TMAX thresholded at 6 seconds



# Aphasia & R Hemiparesis

- Small mismatch volume 12 cc
- Target mismatch volume to treat > 15 cc
- Stroke not treated
- Follow-up DWI shows infarct

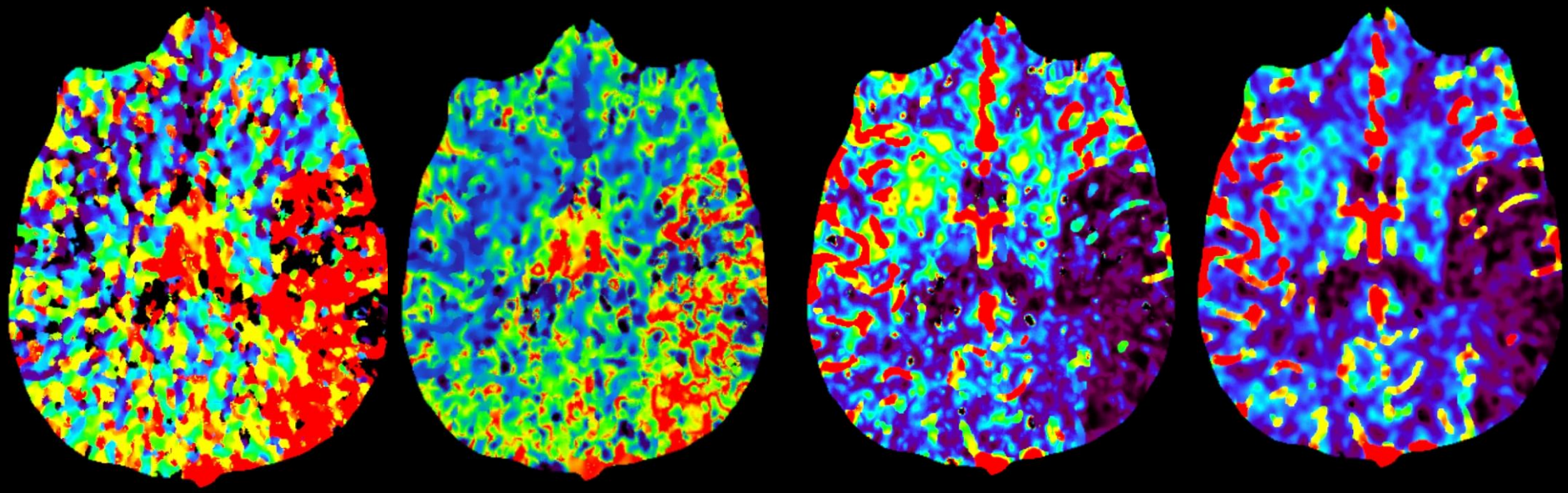


# CT: AMS

- No hemorrhage
- Decreased cortical density in posterior L MCA distribution
- Basal ganglia appear preserved
- Insula involved
- ASPECTS = 5

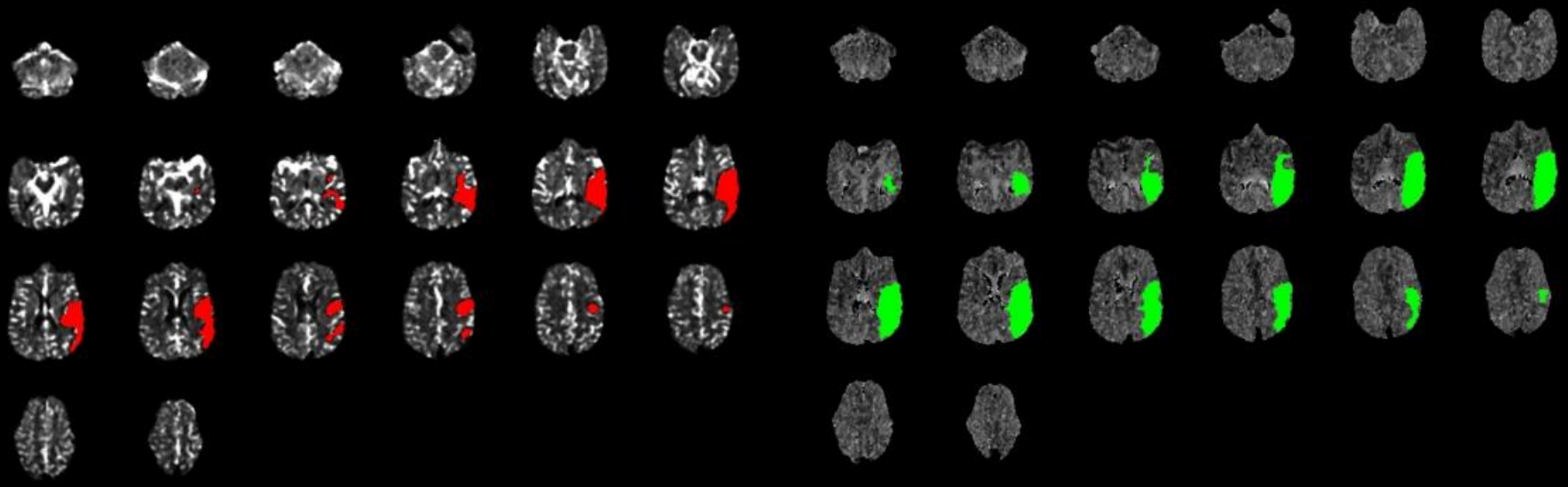
# CTP: AMS

- TTP, MTT, CBF, CBV parameter maps
- MTT - CBV = penumbra (“Old Time”!)



# AI: AMS

- Calculates the relative CBF decreased 30%
- Calculates Tmax thresholded at 6 seconds



# CTA: AMS

- CTA shows no large vessel occlusion (LVO)

# AMS

- CTA showed no LVO
- Patient was outside the time window for IV thrombolysis
- Follow-up CT shows evolving infarct

# Imaging: Ischemic Penumbra

- Is there “salvageable” brain?
  - –CTP, MRP
  - –If there is no substantial (usually > 15 ml) of ischemic penumbra (mismatch volume); not rational to risk hemorrhage due to thrombolytic therapy
  - –If there is a large penumbra; is therapy indicated outside the accepted “time window”?

# Treatment: IV Thrombolysis

- IV t-PA within 3.0 hrs.
  - NINDS trial
- IV t-PA within 4.5 hrs.
  - ECASS-3 trial
- IV t-PA within 9.0 hrs.
  - “Guided by perfusion imaging”
  - EXTEND trial

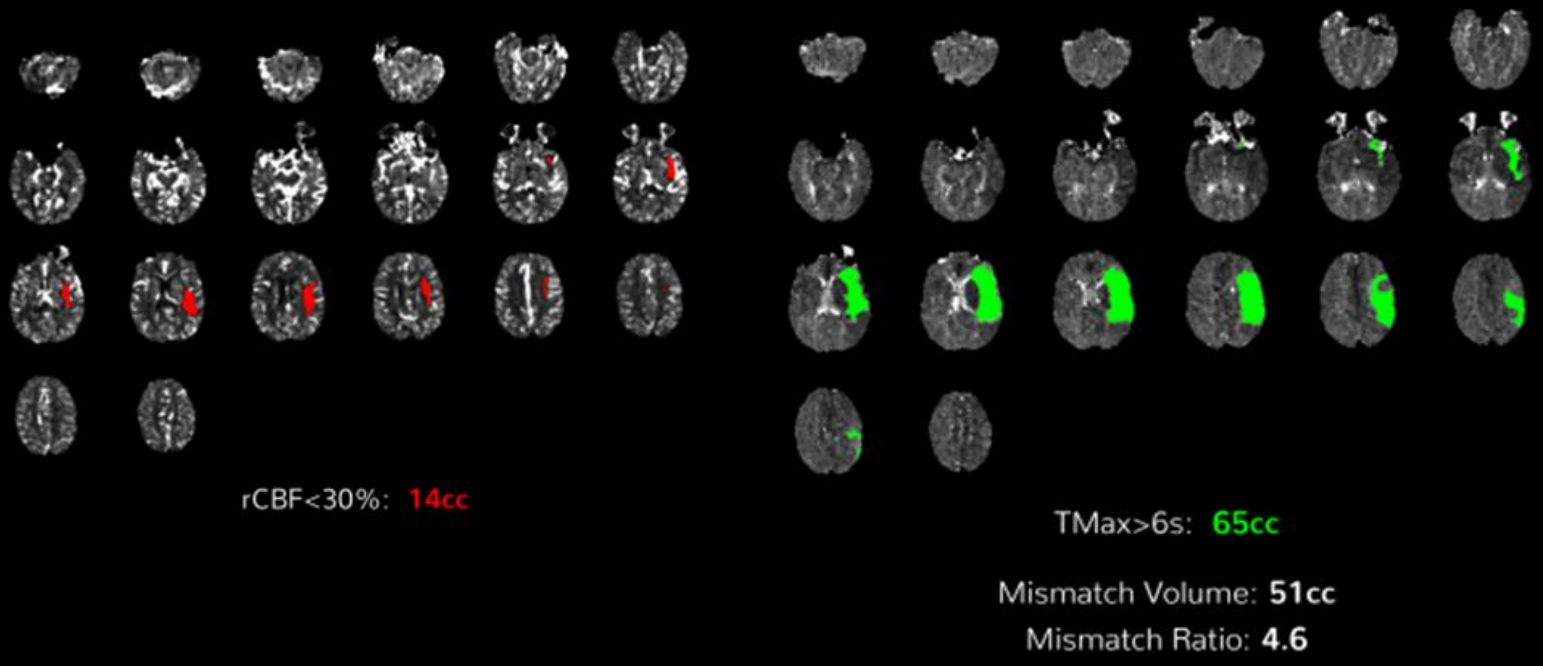
Ma H et al. NEJM 380:1795-1803 (2019)

# Stroke Alert: NCCT

- CT showed a left MCA infarct
- ASPECTS = 4
- CTA showed an M2 branch occlusion

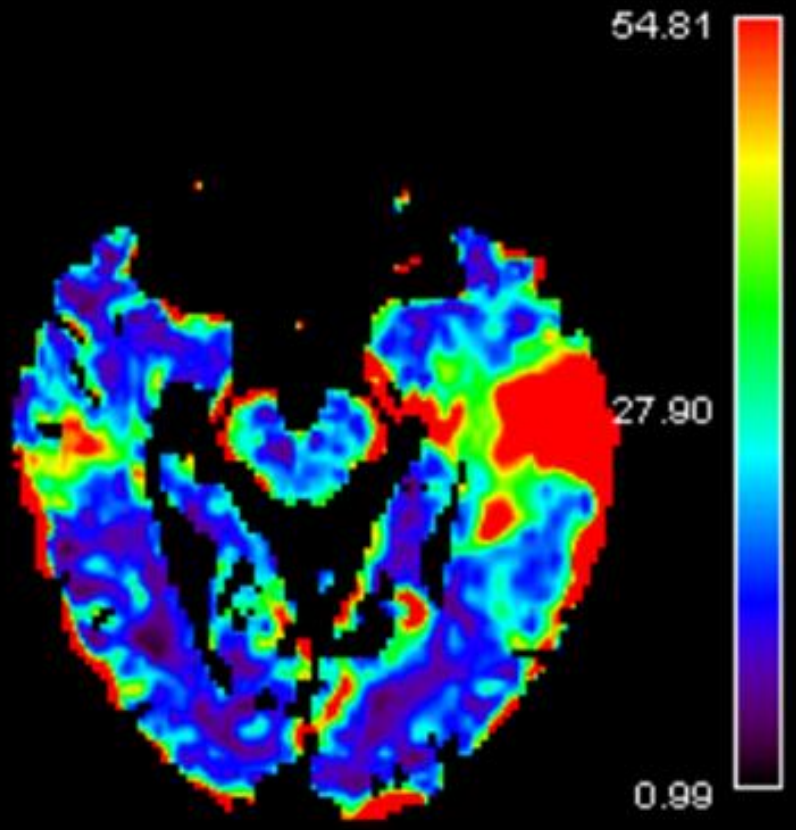
# Stroke Alert: CTP

- Core infarct of 14 cc
- Brain at risk of 65cc



# Treatment follow-up with MR

- MRA showed restoration of flow in L M2 branch
- MRP shows increased CBF in L temporal lobe
- “Luxury perfusion”
- No hemorrhagic conversion



# Treatment Beyond 4.5 Hours

- IV thrombolysis (perfusion imaging)
- Clot retrieval (up to 8 hrs)
- Possibly in select populations determined by imaging (is there no time limit?)
  - Imaging is brain
  - No benefit from thromboembolectomy (2013)
  - Endovascular treatment was found to result in better clinical outcomes (5 studies 2014-15)

Kidwell T et al. NEJM 368:914-23 (2013) Dippel et al. World Stroke Conf. (2014)

# IA Intervention Trials 2014-15

| TRIAL | INCLUSION CRITERIA | IMAGING |
|---|---|---|
| MR CLEAN | Vessel occlusion | CT, CTA |
| ESCAPE | Vessel occlusion, Good collaterals | CT, CTA |
| EXTEND IA | Vessel occlusion, Small core < 70cc, Mismatch > 1.2 | CT, CTA, CTP |
| SWIFT PRIME | Vessel occlusion, Small core < 70cc, Mismatch > 1.8 | CT, CTA, CTP/MRP |
| REVASCAT | Vessel occlusion | CT, CTA/MRA |

All 5 trials showed benefit from thromboembolectomy
Each trial used different selection criteria

# IA Intervention Trials 2014-15

- Since the goal of these trials was to show benefit from thromboembolectomy in appropriately selected patients, were some patients excluded who might have benefitted?
- What about late thromboembolectomy?
- The selection criteria are controversial and are a topic for continuing research.

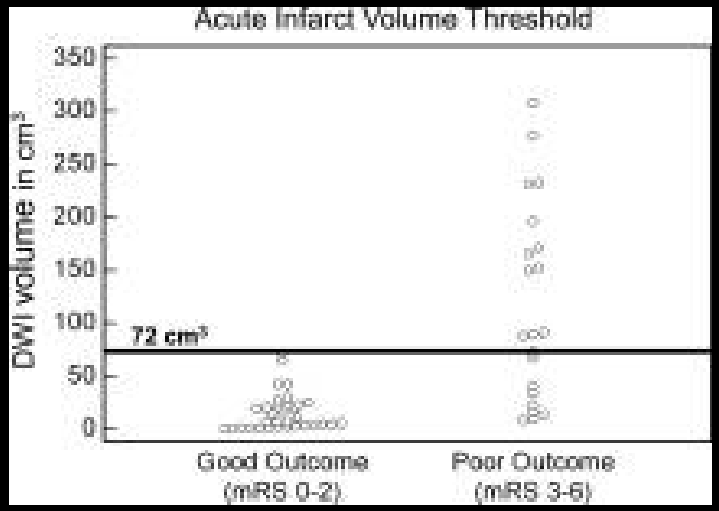
# IA Intervention Trials 2018

| TRIAL | INCLUSION CRITERIA | IMAGING |
|---|---|---|
| DAWN (2018) | 6-24 hours post ictus<br>Core volume to clinical mismatch | CTP, DWI, MRP |
| DEFUSE 3 (2018) | 6-16 hours post ictus,<br>Small core volume < 70cc,<br>Core volume to ischemic volume mismatch > 1.8 | CTP, DWI, MRP |

Trials showed benefit from late thromboembolectomy in appropriately selected patients.
Let's focus on infarct size.

# Imaging: Infarct Size

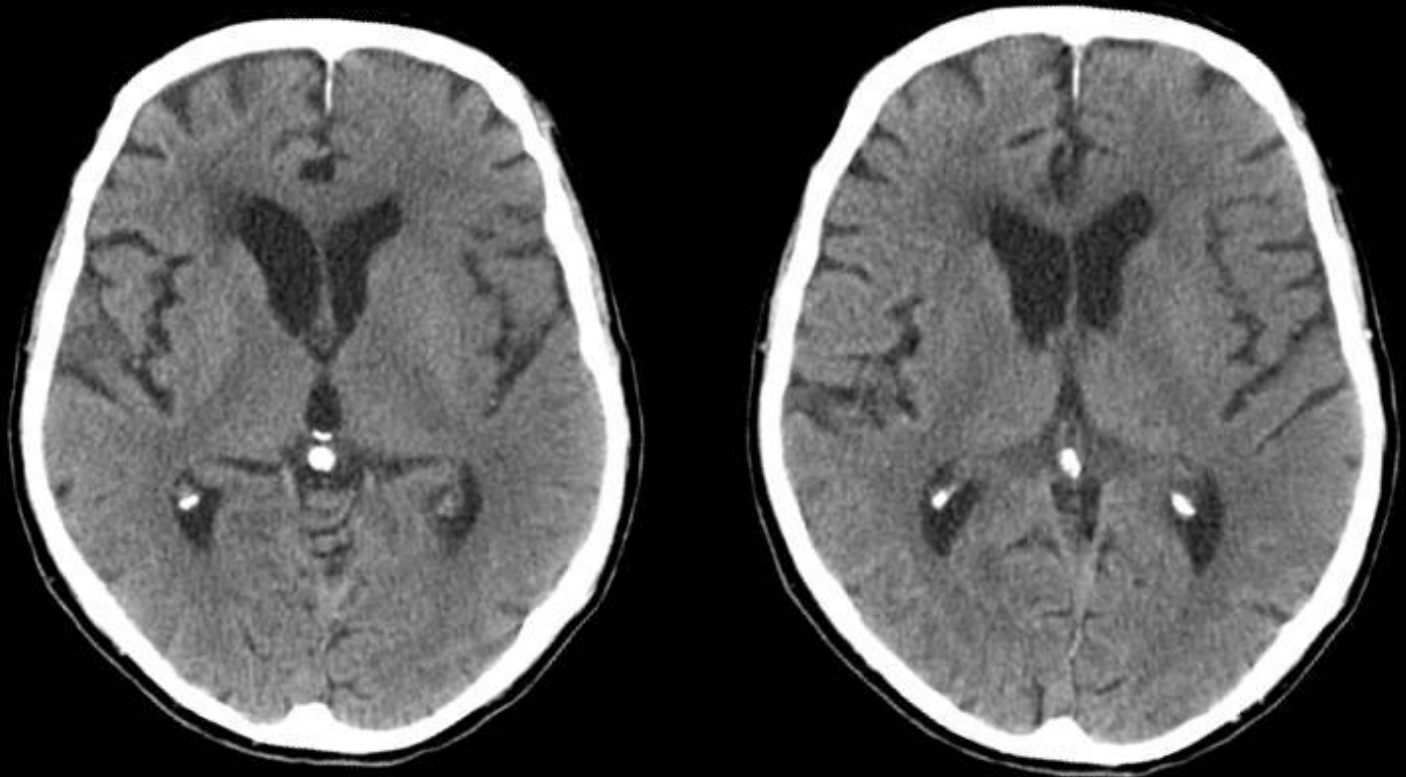
- Is there a large infarct core?
  - –CT (ASPECTS), CTP (CBF < 30%), DWI
  - –Greater than 1/3 MCA territory
  - –Greater than 72 cc of tissue
  - –If large infarct
    - •Poor outcome despite Rx



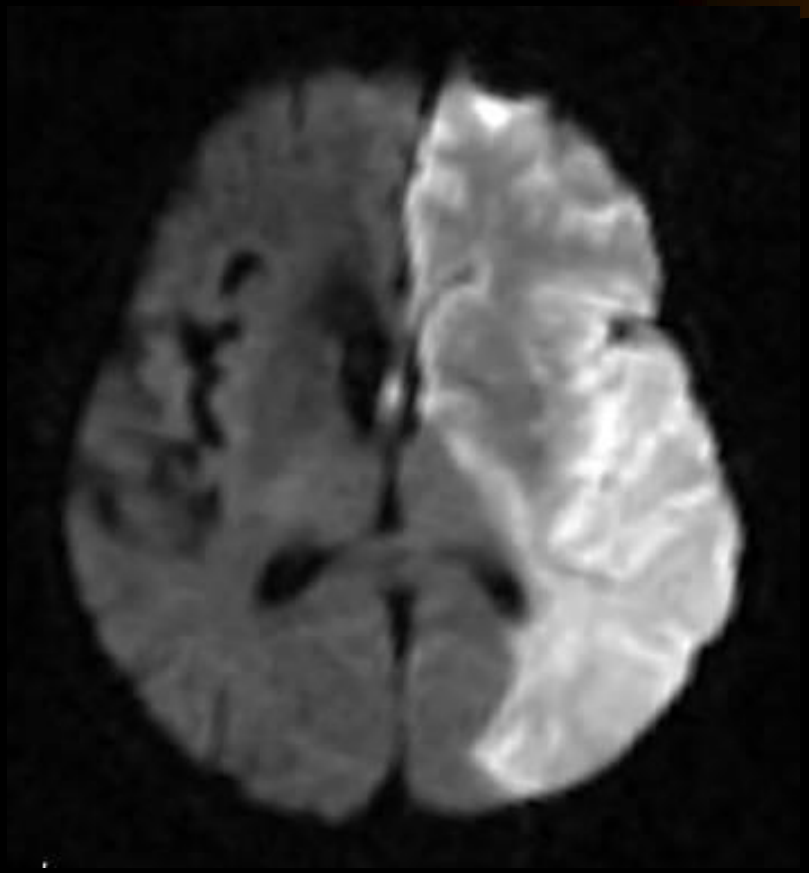

Gonzalez. J of MRI 36:259-271 (2012)

# Right Sided Weakness: CT

- L insular ribbon sign (loss of gray-white)
- How big is the infarct?



# Right Sided Weakness: DWI



# Diffusion Imaging (DWI)

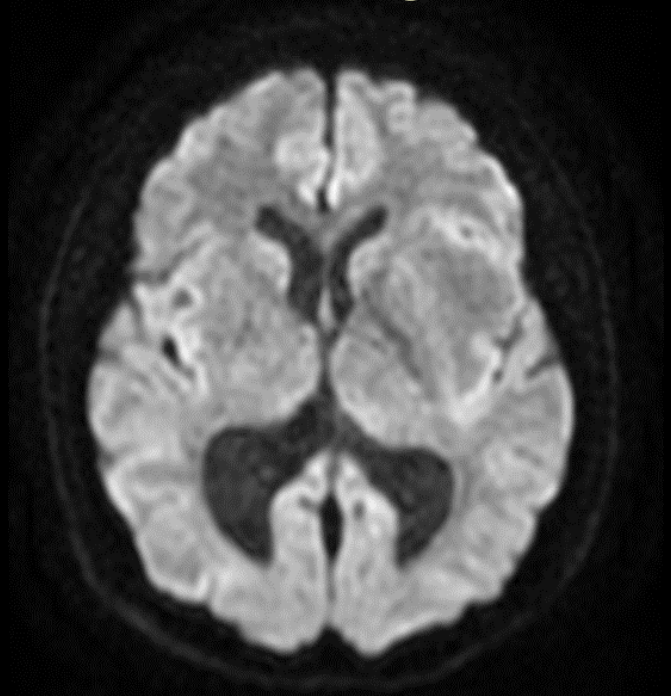
- DWI is based on measurements of the diffusion of water molecules
  - Water molecules move more freely in the interstitial space than in the intracellular space
  - When water moves from the interstitial space to the intracellular space diffusion becomes restricted
  - We see this change as cytotoxic edema

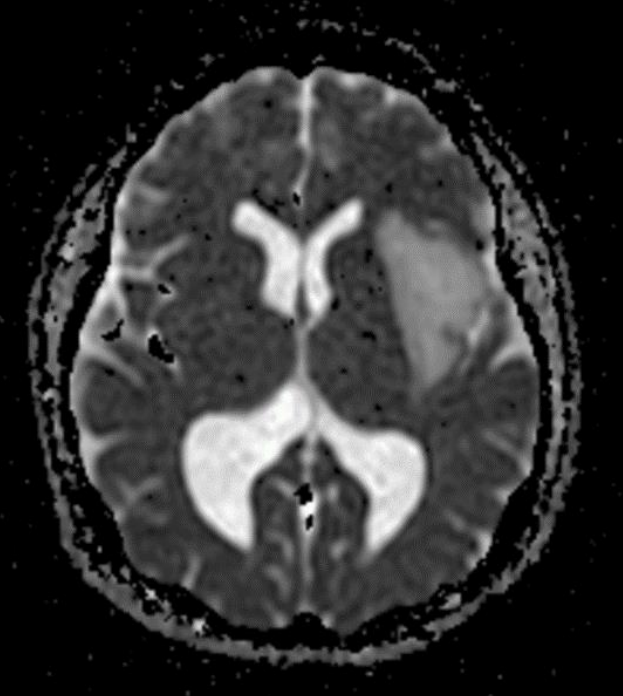
# New Seizure: NCCT

- Is this an MCA infarct?
- Let's get an MRI

# New Seizure: DWI & ADC

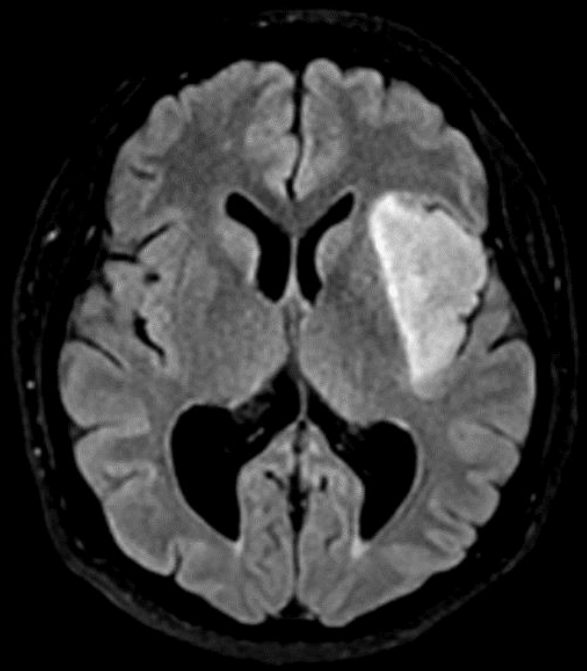
- DWI is not all that bright!?
- ADC is bright; no restricted diffusion

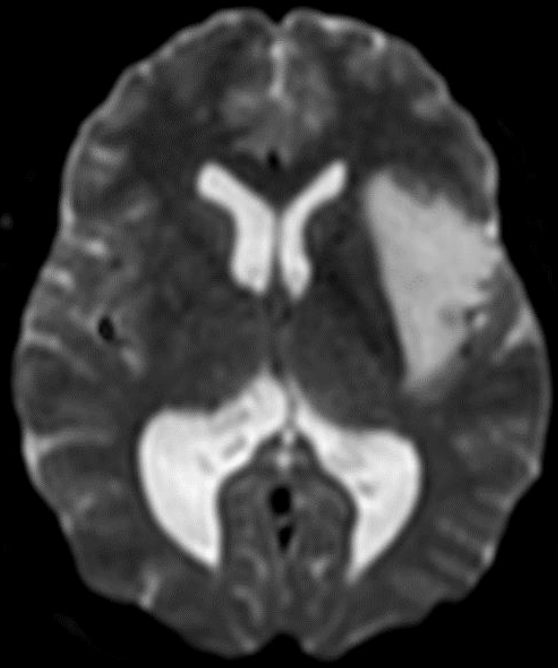




# New Seizure: FLAIR & T2

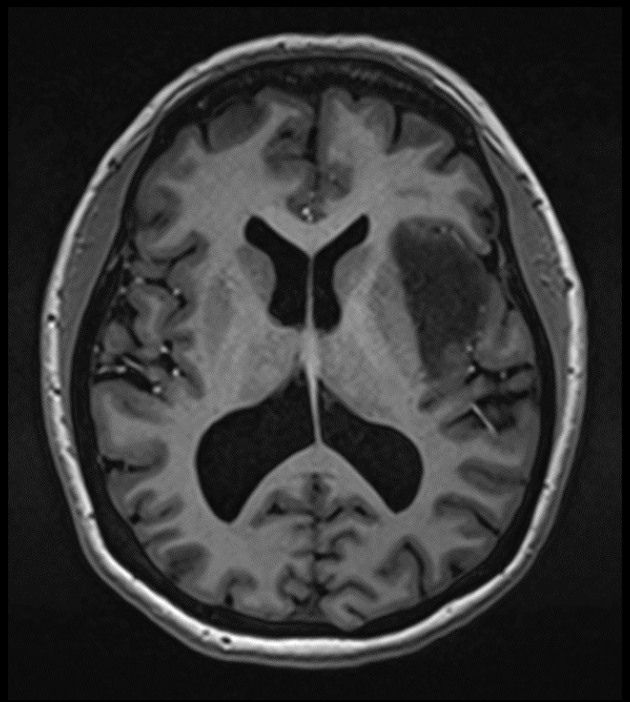
- T2 is bright while FLAIR has some dropout
- T2/FLAIR mismatch sign indicates a glioma

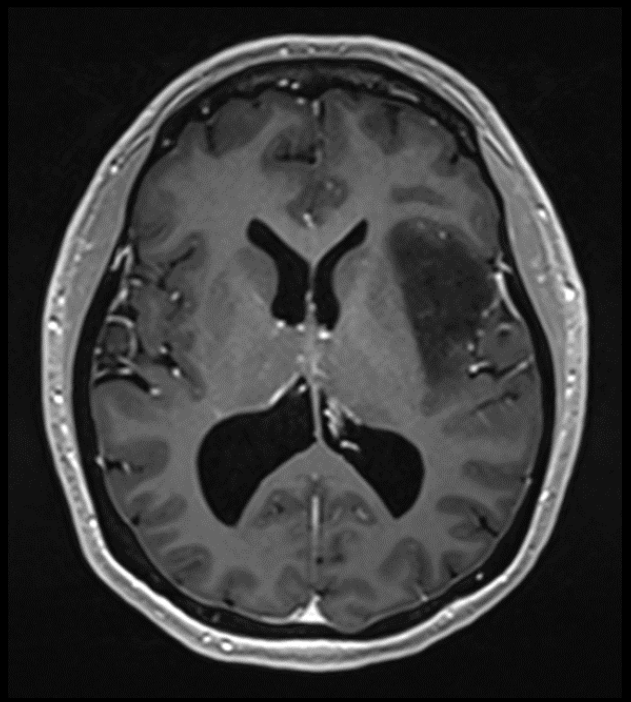




# New Seizure: Pre & Post T1

- There is no contrast enhancement
- Findings consistent with low grade glioma





# Imaging with DWI, MRP, MRA

- Acute stroke protocol
  - 6-7 minutes imaging time
- DWI, ADC, T2, FLAIR, and GRE
- CE MRA
- MR perfusion
  - TTP, MTT, CBF, CBV, T max
- CE T1

Nael et al. Radiology 242:600-09 (2007)

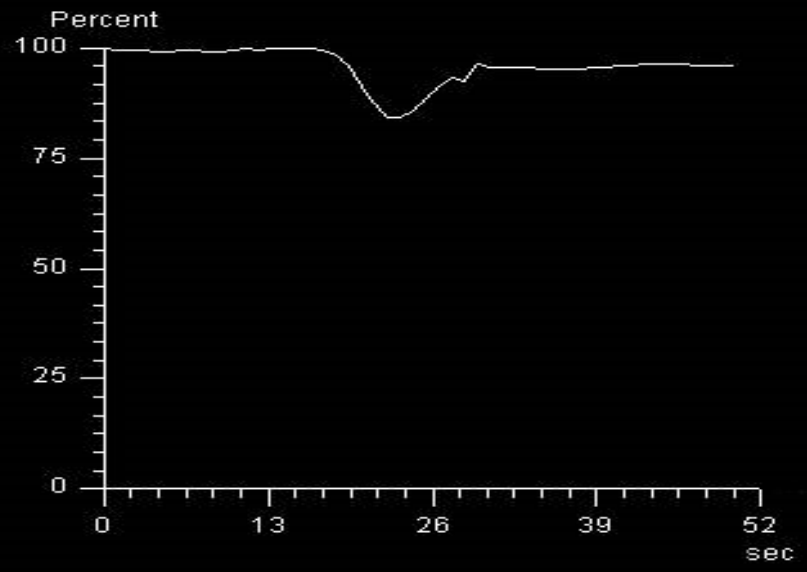
Nael et al. Stroke 44:664-70 (2013)

# Imaging with MR

- DWI / ADC
  - Confirm infarct, infarct size
- GRE
  - Subtle hemorrhage, venous thrombosis
- FLAIR
  - Infarct age; useful in “wake up strokes”
- MRA of brain and neck
- MR perfusion

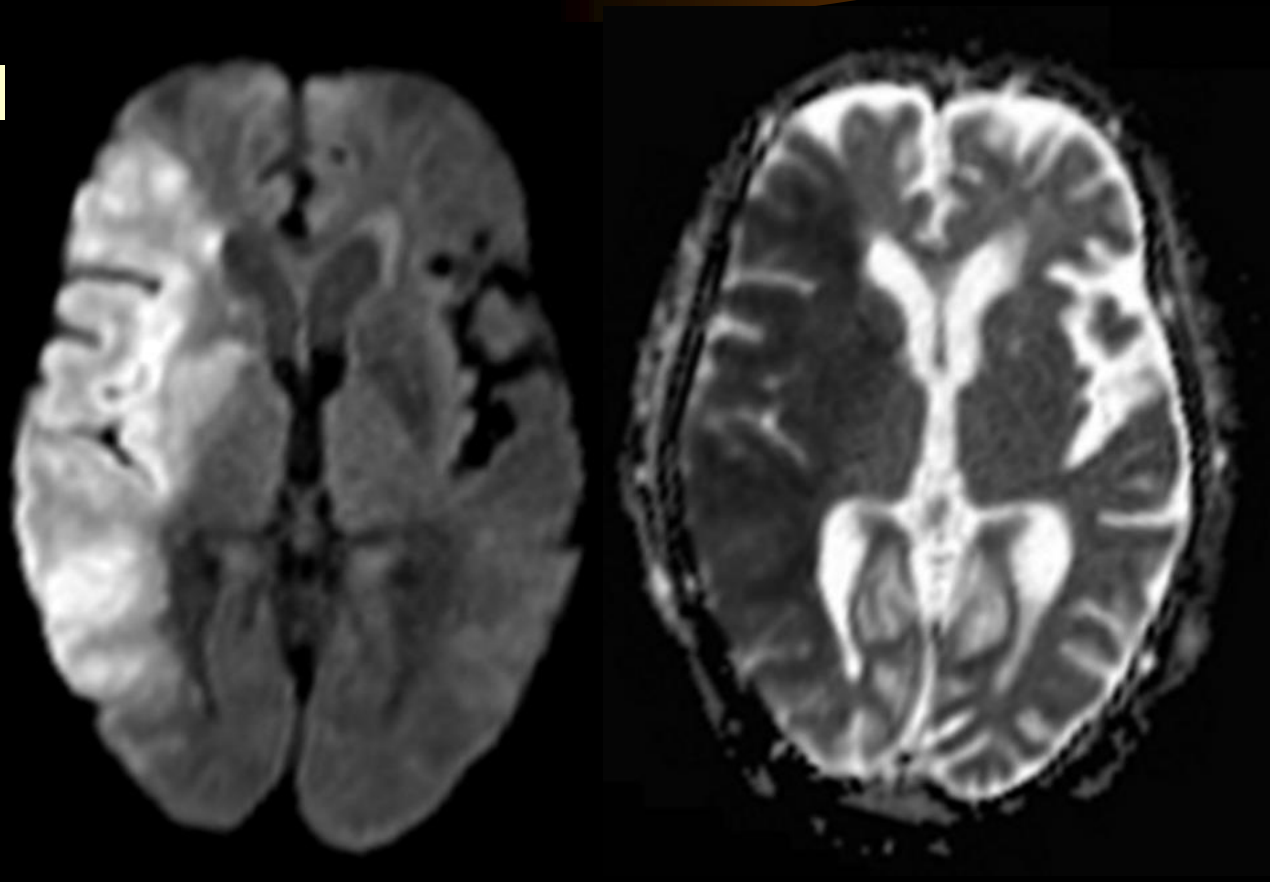
# MR Perfusion: Dynamic Susceptibility Contrast (DSC)

- Infuse IV (Gadolinium) contrast
- T2* sequence to scan whole brain
- Contrast induces a hypointense signal



# L Weakness: DWI & ADC

- DWI & ADC are abnormal in entire R MCA including the lentiform nucleus
- Infarct volume > 72 ml.

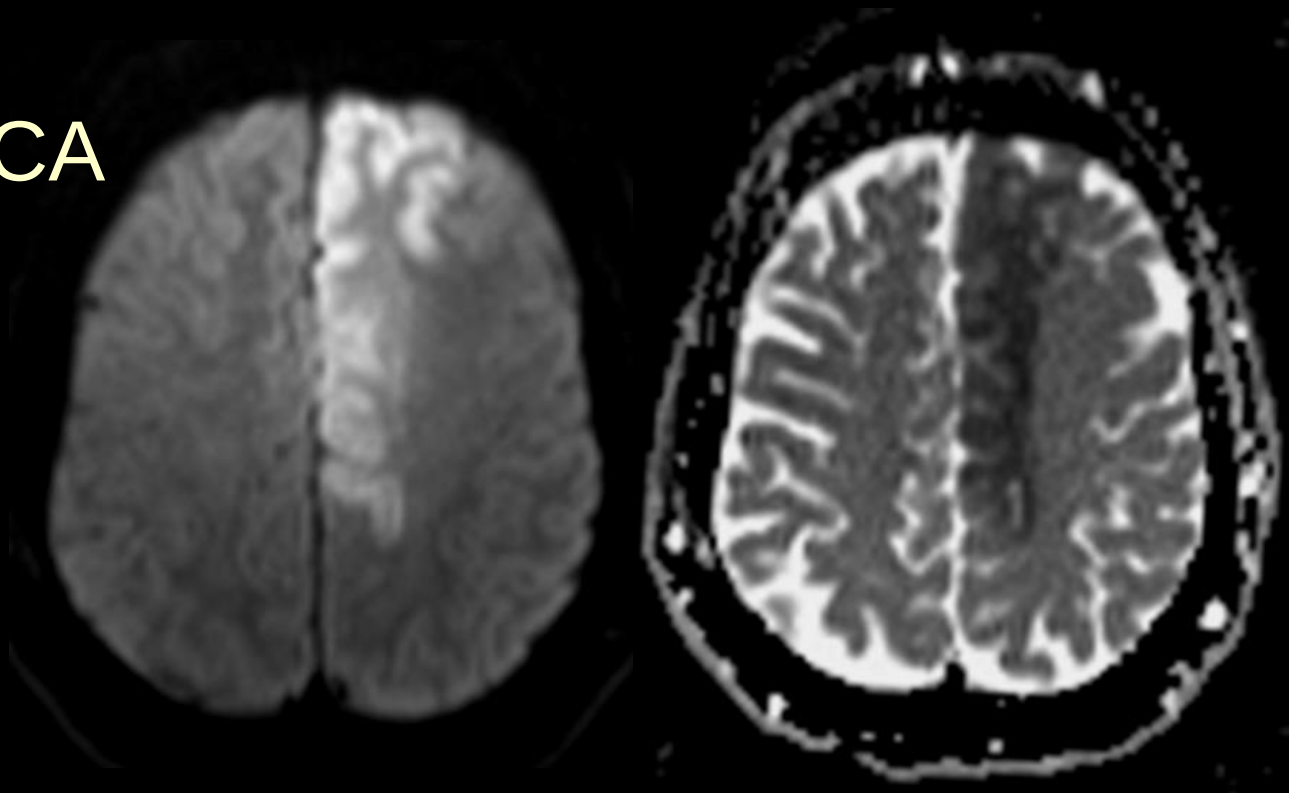


# L Weakness: MRA

- MRA shows no flow in R MCA c/w LVO
- There are a few distal collaterals
  - Poor collaterals

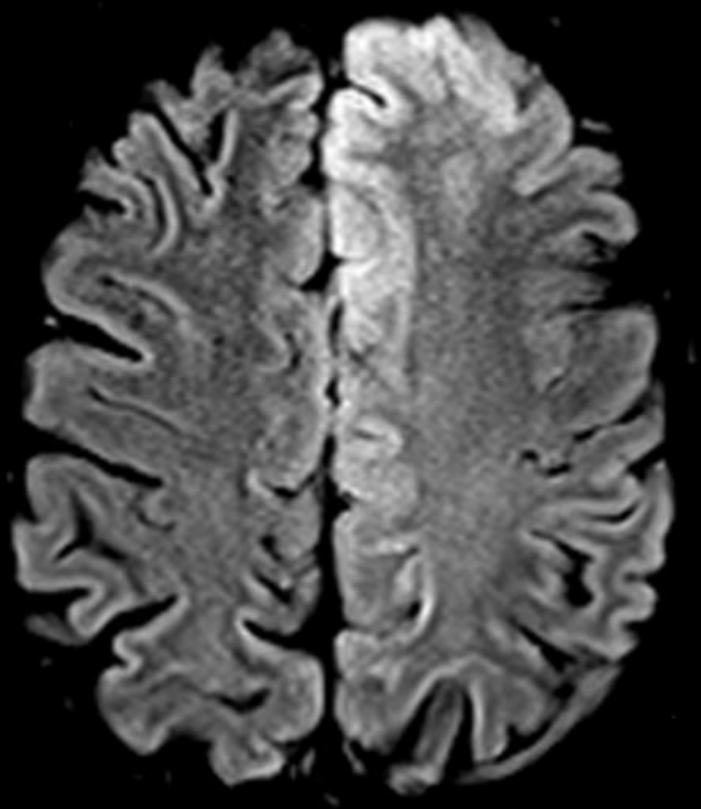
# AMS, R/O Stroke: DWI & ADC

- Abnormal DWI and ADC in L ACA territory
- ? Acuity



# AMS, R/O Stroke: FLAIR

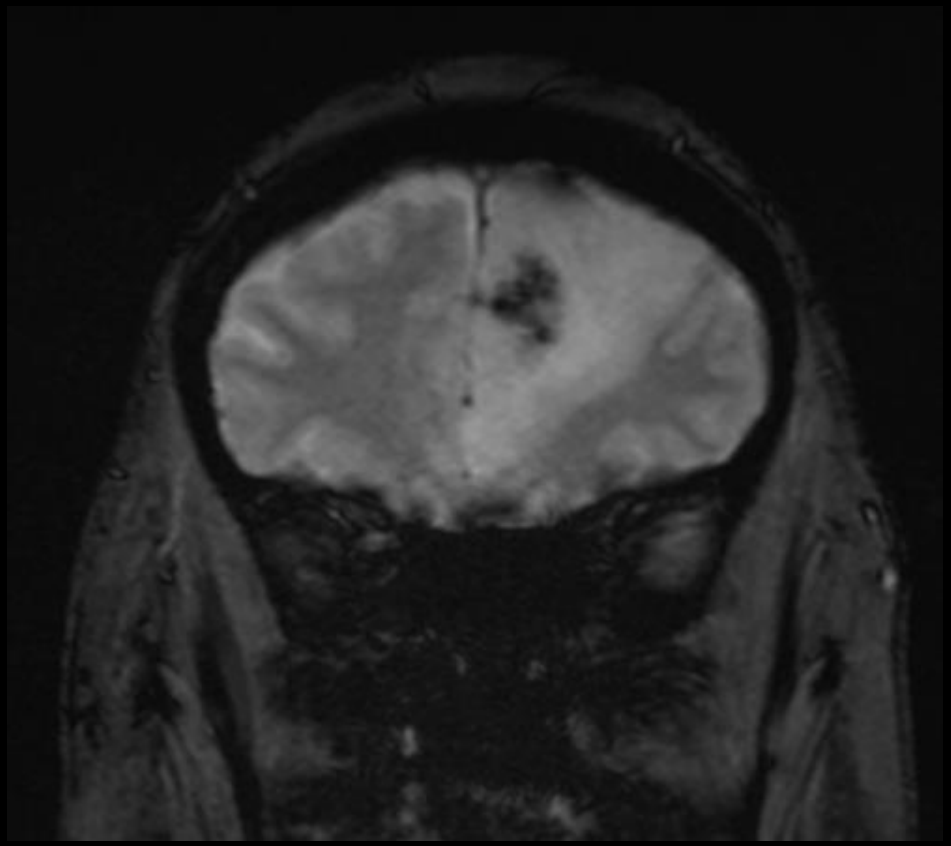
- FLAIR abnormality is similar to the DWI abnormality
- Infarct is likely subacute
- More likely to hemorrhage if treated



Kufner et al. European Journal of Neurology 20:281-285 (2013)

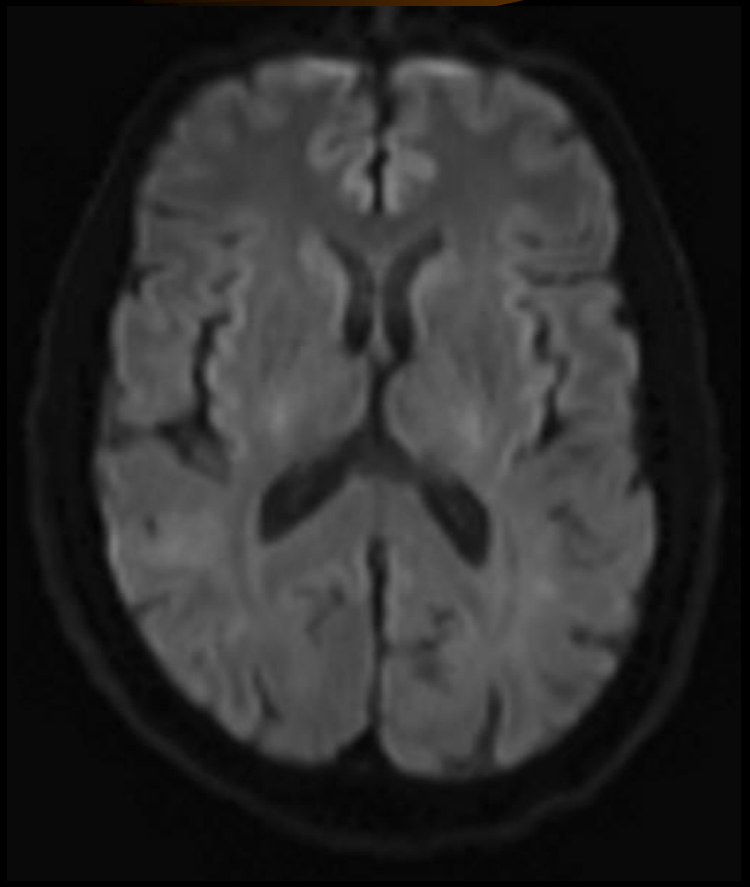
# AMS, R/O Stroke: GRE

- Despite the imaging findings, the patient was treated with IV tPA
- Follow-up GRE shows hemorrhagic conversion



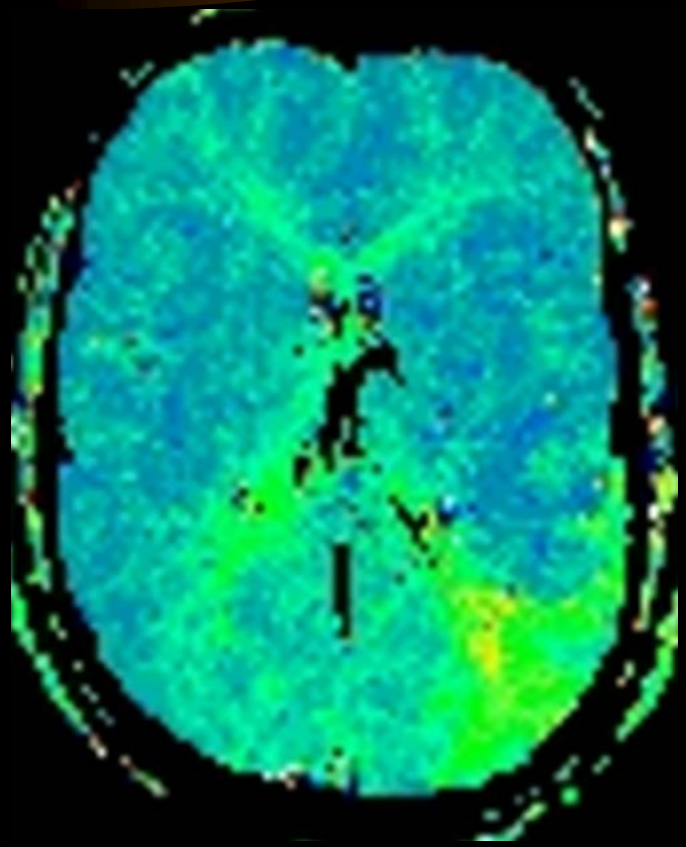
# TIA, R/O Stroke: DWI

- DWI is normal
- Are we done?
- No!
- Look for poorly perfused brain at risk



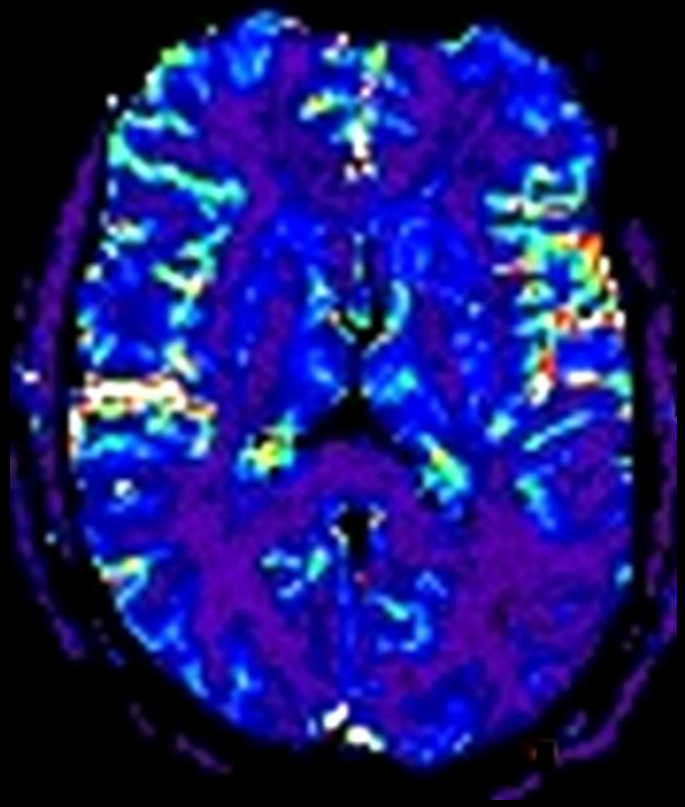
# TIA, R/O Stroke: TTP

- TTP map shows delayed perfusion in the left posterior watershed



# TIA, R/O Stroke: CBF

- CBF is nearly symmetric
- There is delayed perfusion on the left, but no significant decreased flow



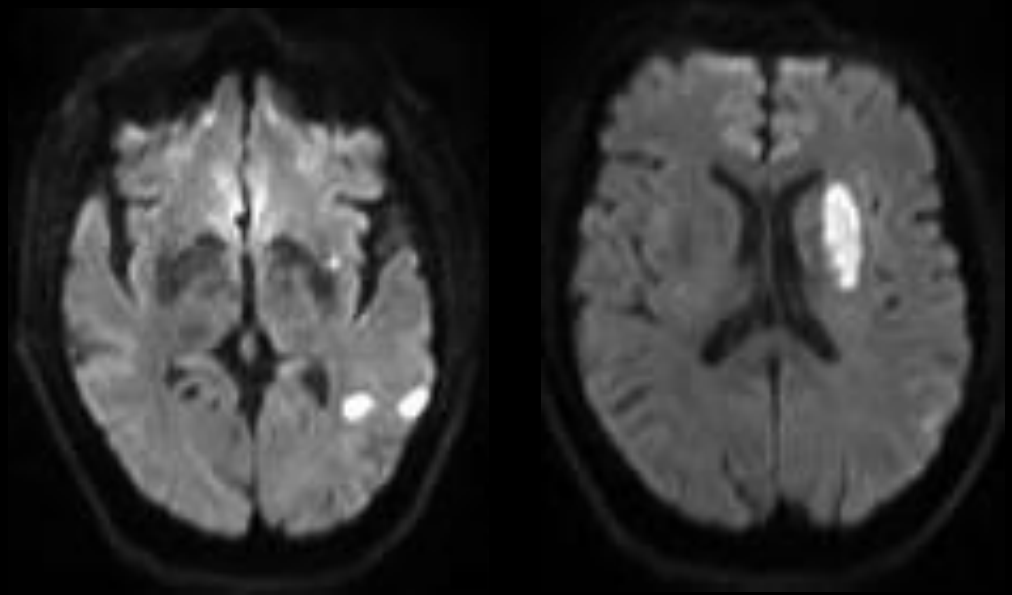
# Cases of Acute Stroke

- Currently using Tmax as the perfusion parameter to estimate brain at risk
  - Most predictive of tissue viability and outcome
  - Threshold (>6 sec) helps us to be consistent
- Compare with DWI to determine penumbra
  - T max – DWI = volume mismatch (penumbra)

Olivot et. al. Stroke 40:469-75 (2009)

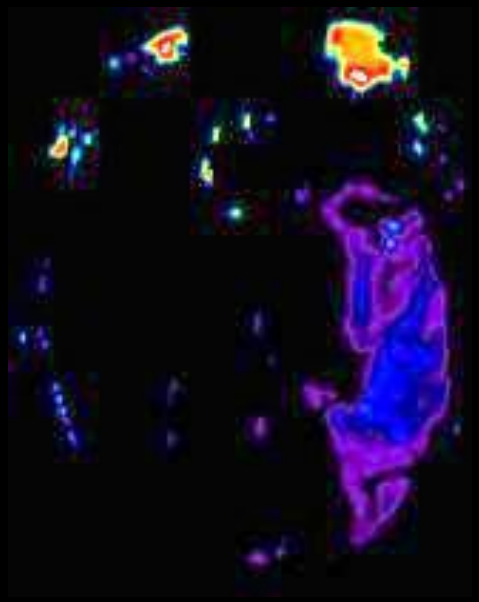
# Acute Stroke #1

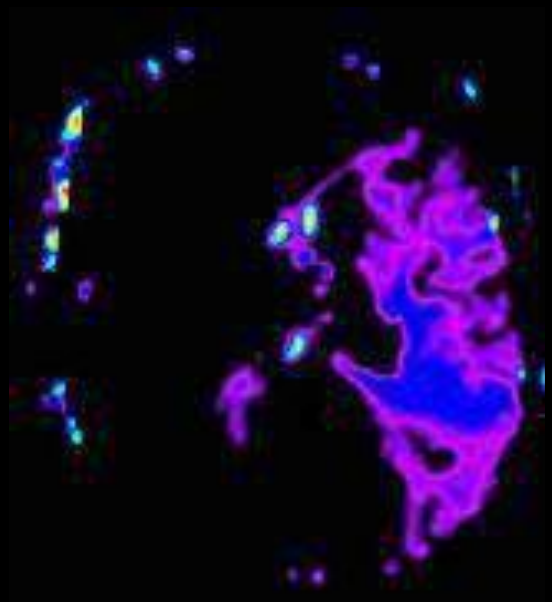
- DWI shows L basal ganglia and L posterior watershed infarcts
- Look for hypoperfused brain at risk



# Acute Stroke #1

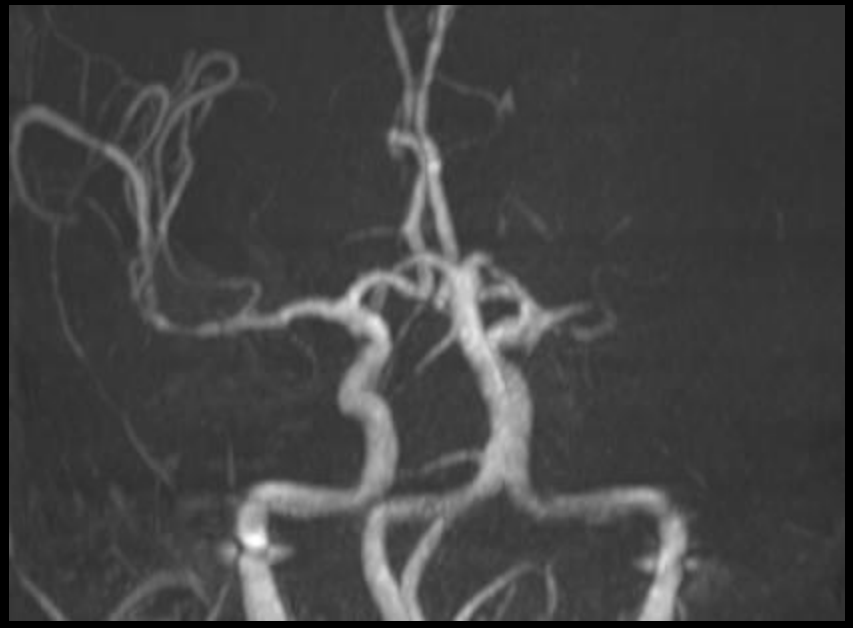
- Tmax shows extensive area at risk
- Tmax – DWI = Large mismatch
- Suspect L MCA abnormality





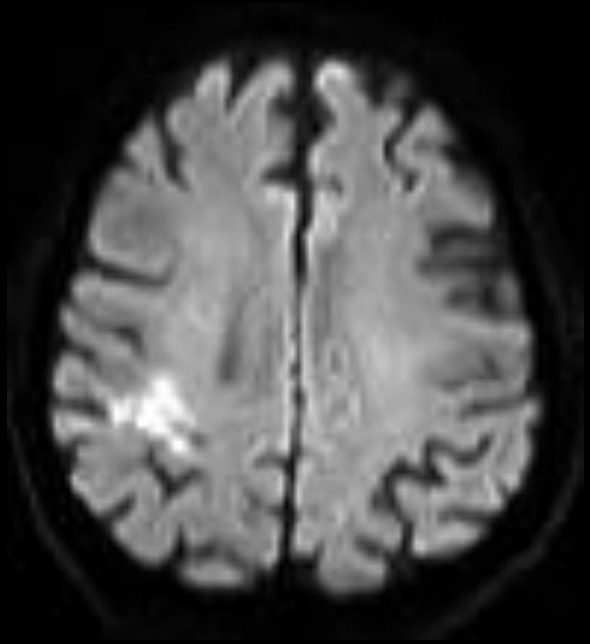
# Acute Stroke #1

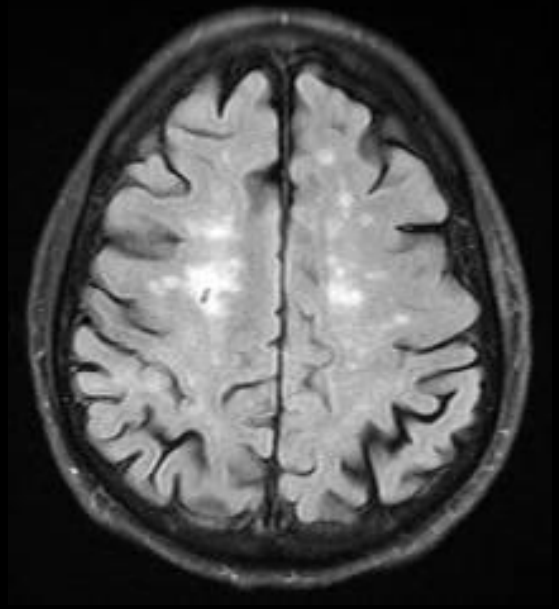
- MRA shows L M1 occlusion
  - Poor collaterals



# Acute Stroke #2

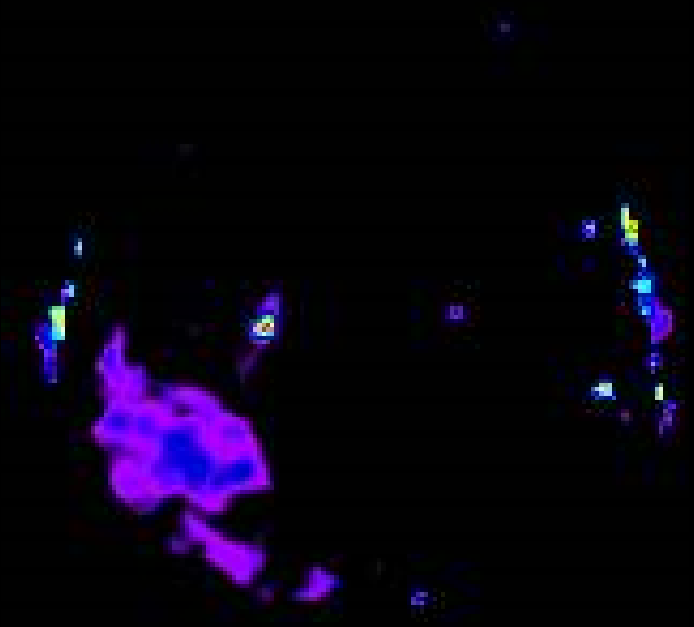
- DWI: small infarct involving R motor cortex
- FLAIR: WM disease but no hyperintensity at the acute infarct





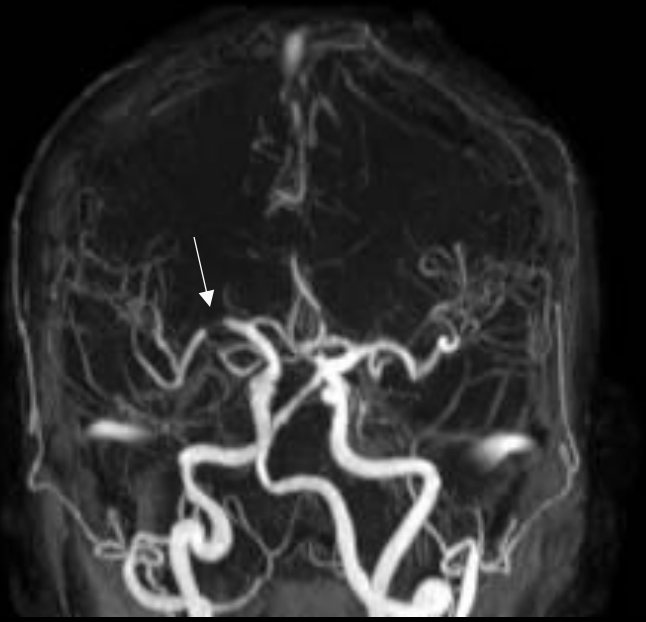
# Acute Stroke #2

- Tmax shows a small area at risk
- Tmax – DWI = small volume mismatch (penumbra)



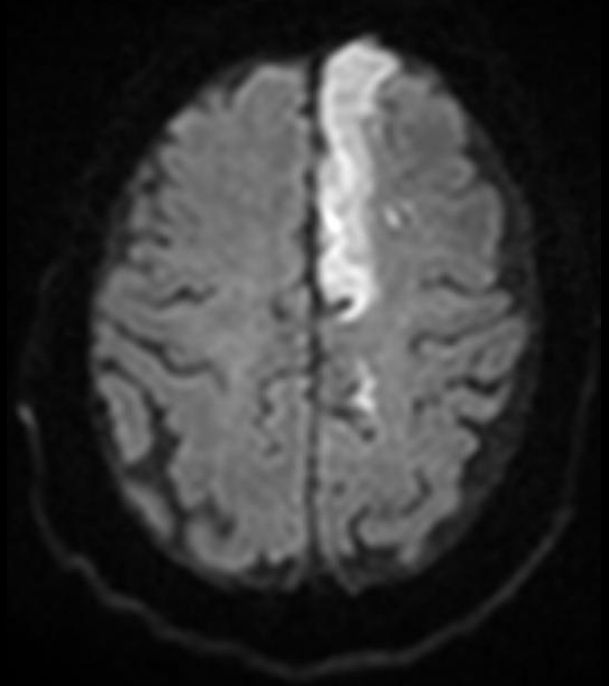
# Acute Stroke #2

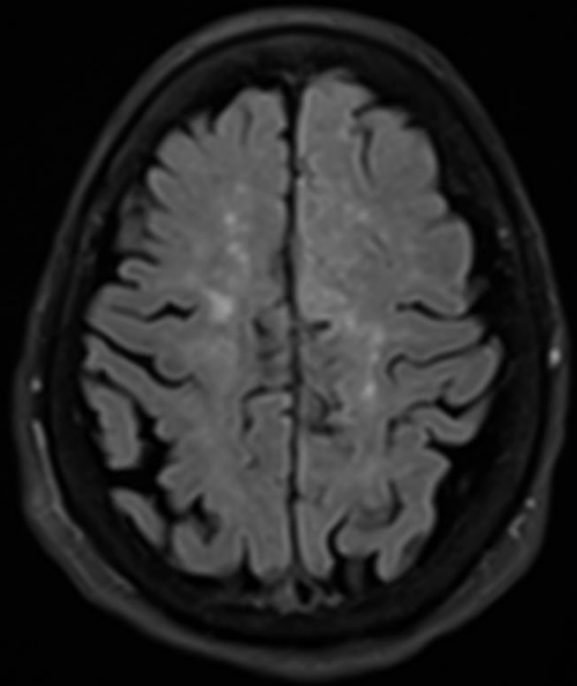
- Contrast enhanced MRA shows a critical R M1 stenosis



# Acute Stroke #3

- DWI shows L  ACA infarct
- Flair shows minimal hyperintensity



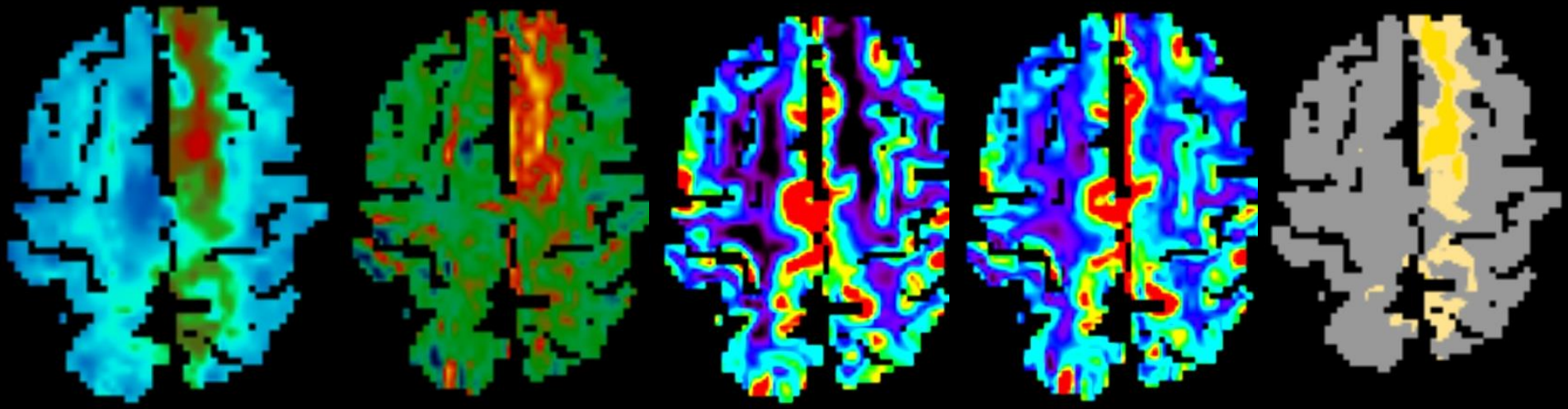


# Acute Stroke #3

- Contrast enhanced MRA shoes no LVO
- Hypoplastic R A1 is a common variant

# Acute Stroke #3

- TTP, MTT, CBF, CBV, Tmax parameter maps
- Matched defect?

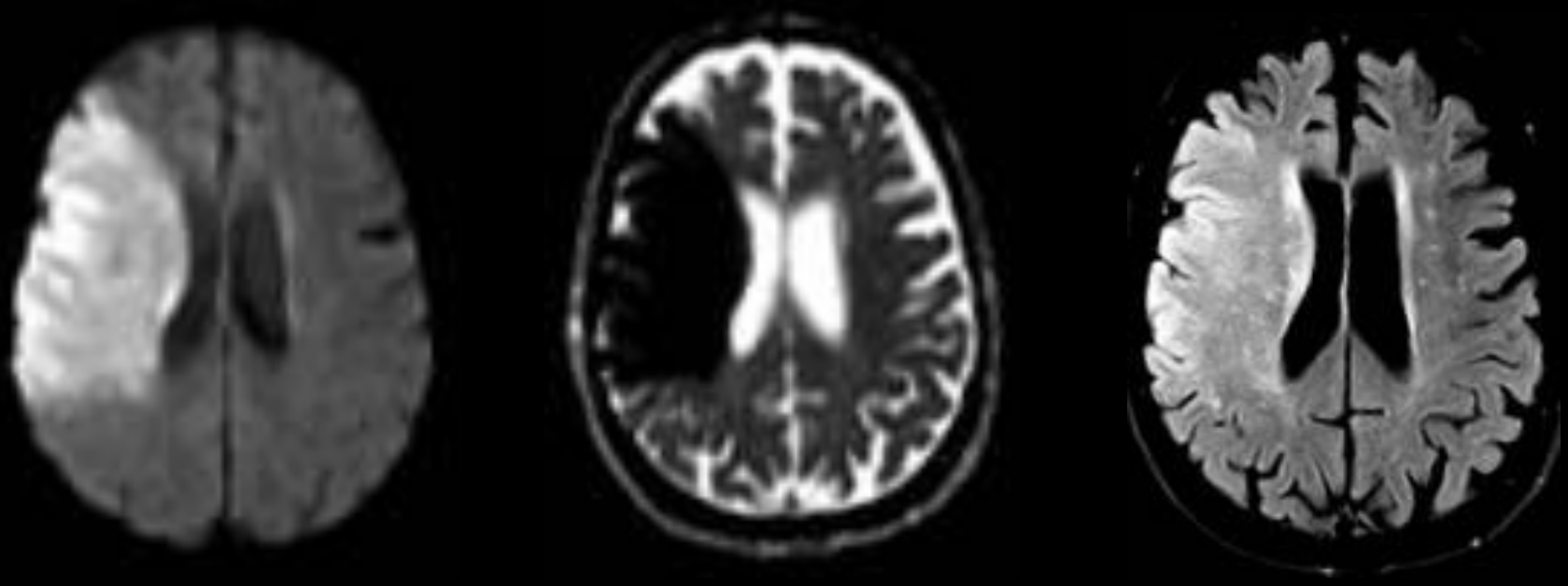


# Acute Stroke #3

- Mismatch volume is less than 1 cc.

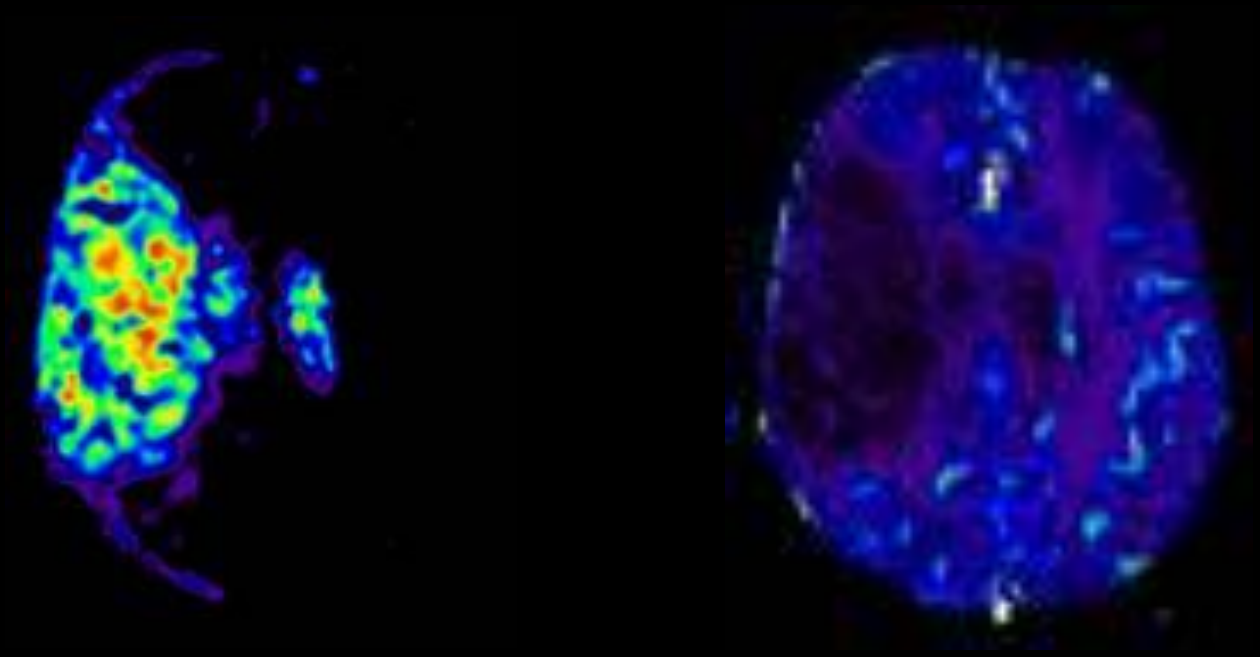
# Acute Stroke #4

- DWI & ADC show an R MCA infarct
- On FLAIR slight hyperintensity at the infarct



# Acute Stroke #4

- Tmax & CBF demonstrate a matched defect with no penumbra

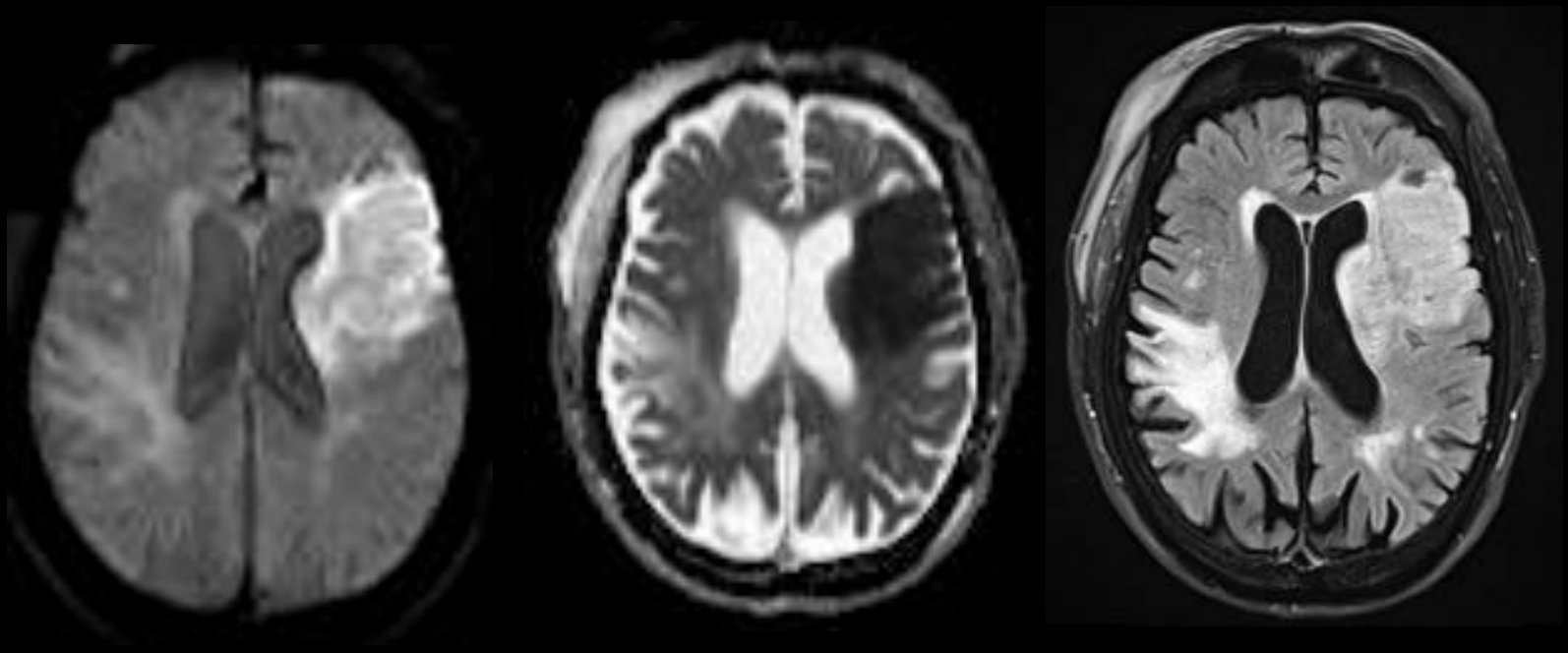


# Acute Stroke #4

- Contrast enhanced MRA shows a proximal R ICA occlusion

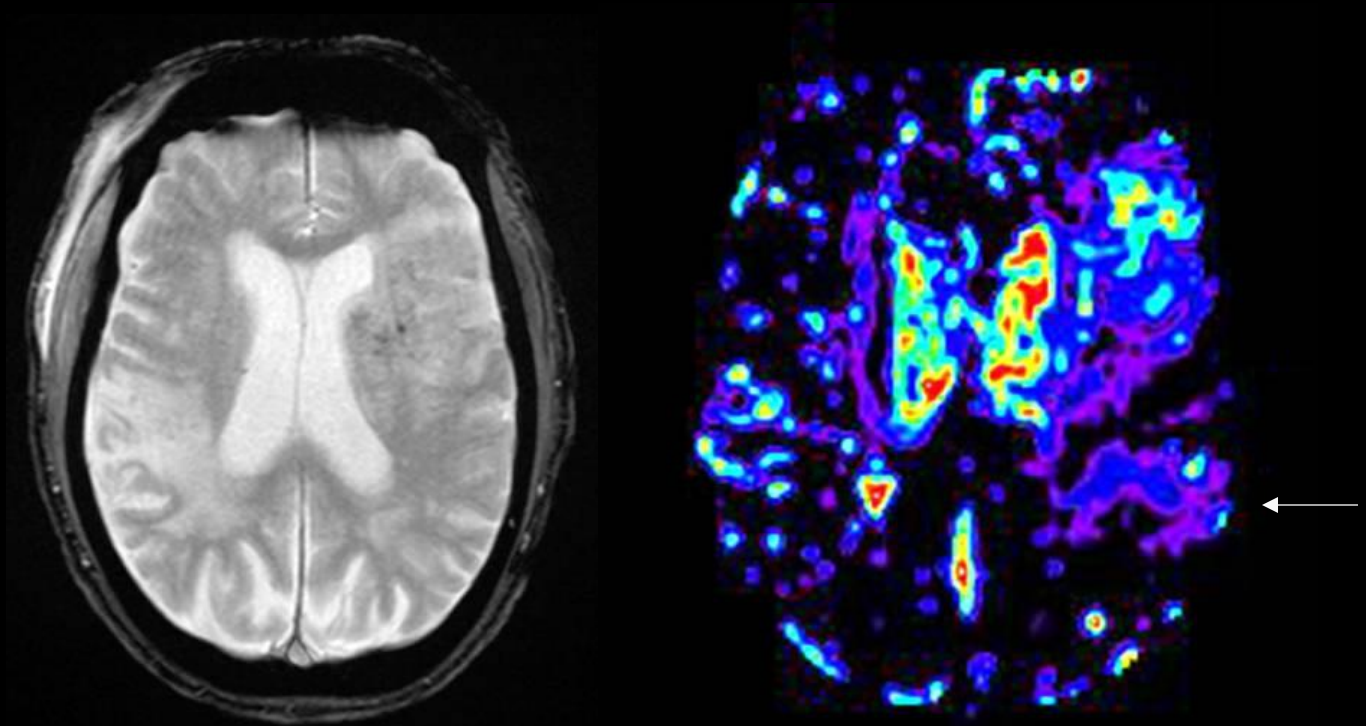
# Acute Stroke #5

- DWI & ADC show a L MCA infarct
- FLAIR shows contralateral WM disease and hyperintensity at the infarct



# Acute Stroke #5

- GRE: small petechial hemorrhage
- T max: small penumbra posterior to infarct



# Acute Stroke #5

- Contrast enhanced MRA shows a high-grade L M1 stenosis

# Summary

- NCCT: hemorrhage, large stroke, other dx
- CTA: proximal vs distal, collaterals
- CTP: penumbra = Tmax - CBF (< 30%)
- DWI/ADC: confirm stroke, stroke volume
- FLAIR: hyperintense?
- GRE: subtle hemorrhage?
- MRP: penumbra = Tmax (> 6 sec) – DWI
- MRA: proximal vs distal, collaterals

# Thanks!