CT Perfusion: How to do it right

Rajiv Gupta, PhD, MD

Neuroradiology
Massachusetts General Hospital
Harvard Medical School

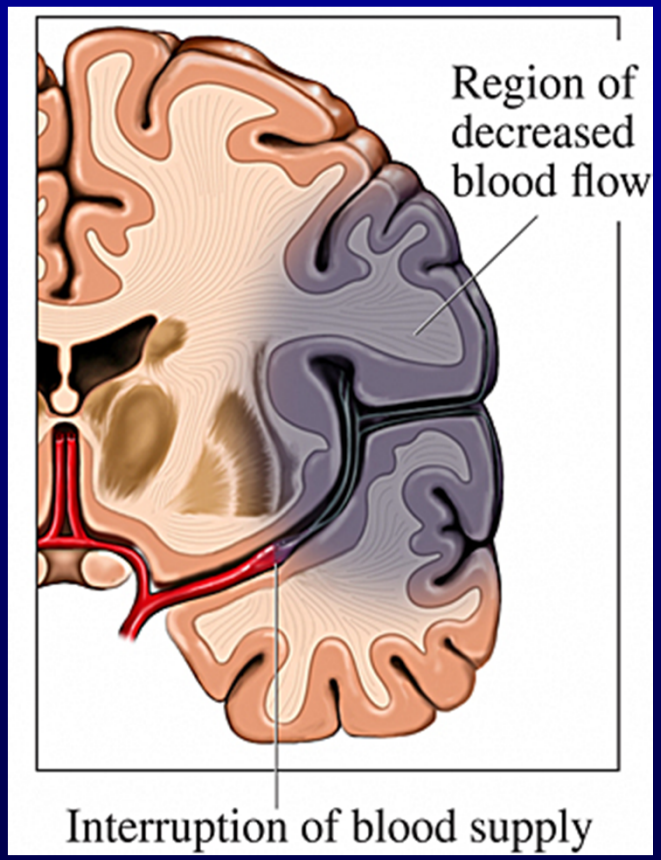
Outline

- Basic CT Perfusion Paradigm

- CT Perfusion for Stroke Imaging
  - Motivation
  - Technique and protocol
  - Artifacts and Pitfalls
  - Dose Issues

Courtesy of Prof. Lee Schwamm, MGH

Time *is* Brain



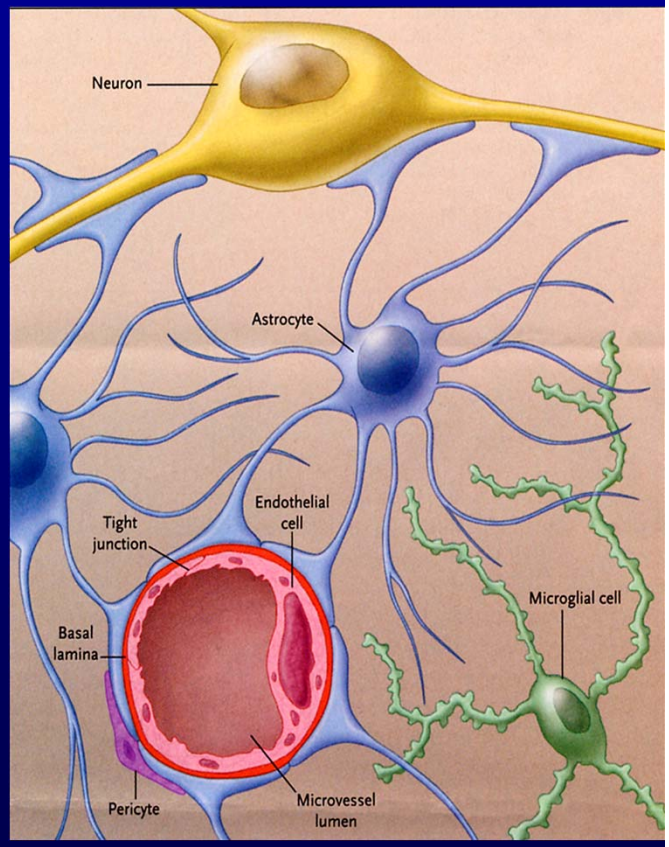
Lost per minute

Neurons: 1.9 x 10^6

Synapses: 14 x 10^9

Myelin fibers: 7.5 miles

Saver JL, *Stroke* 2006; 37: 263-266

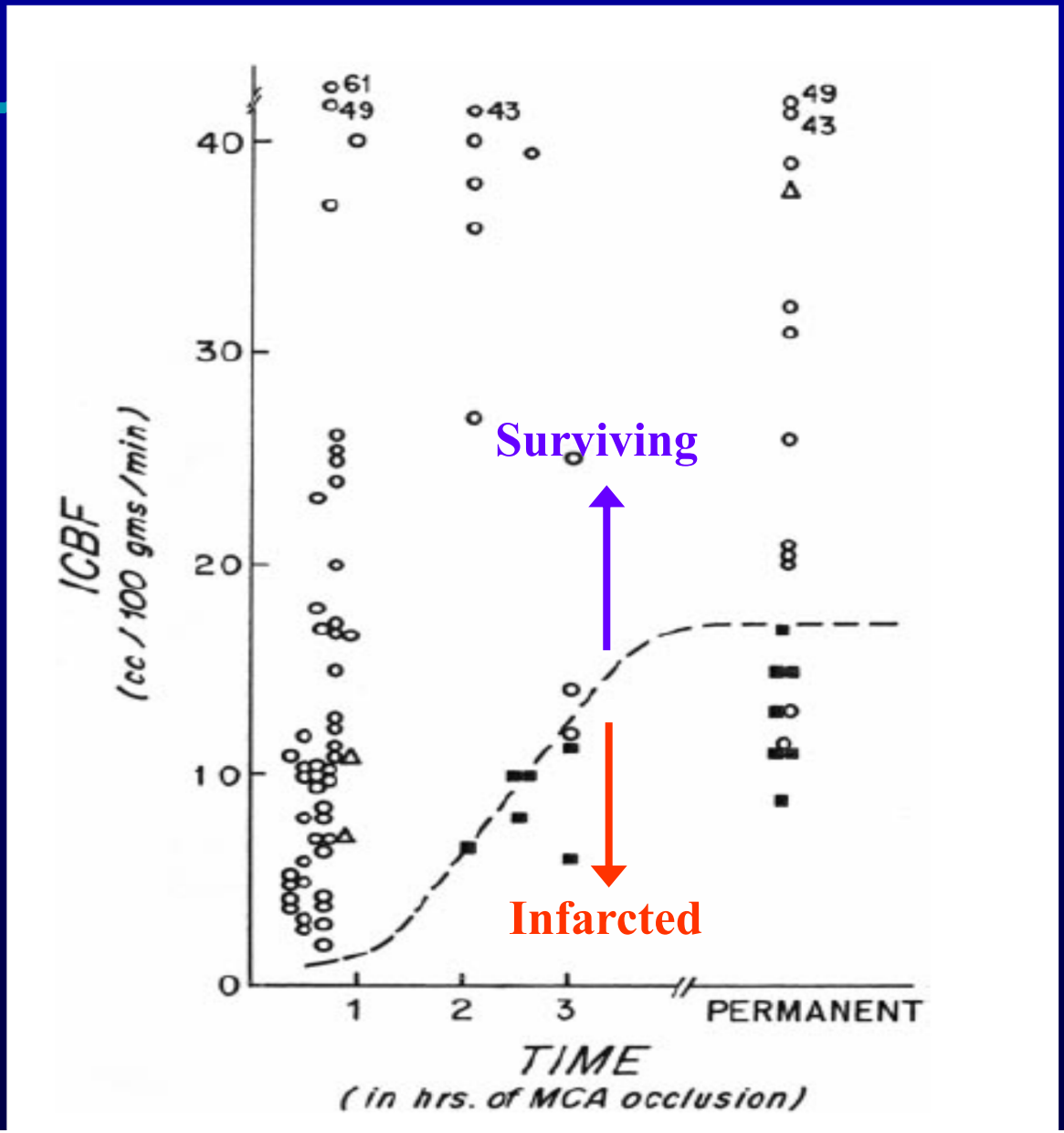


NEJM Feb 2006: del Zoppo

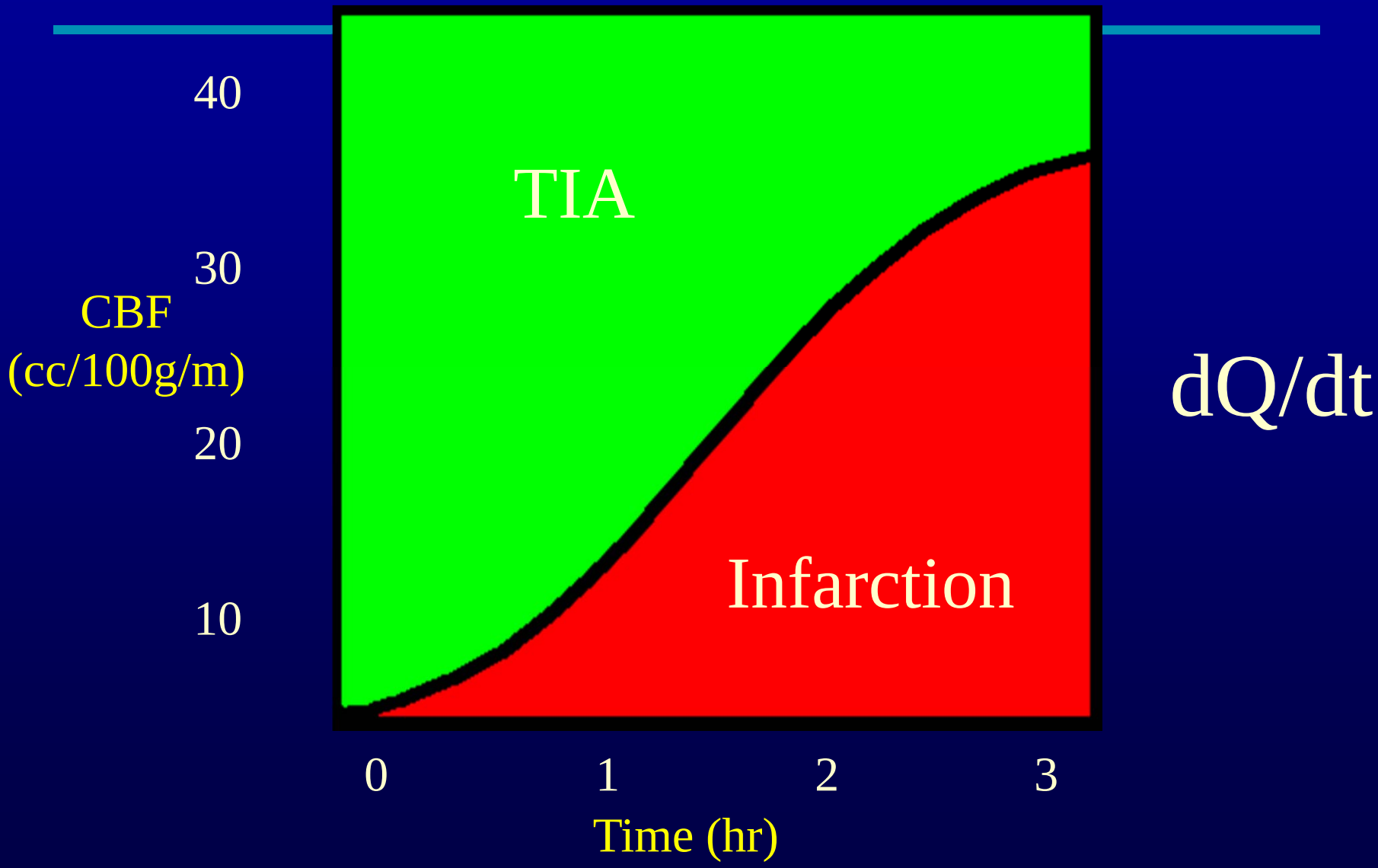
MHL / MGH

Rate of neuronal loss α CBF

Jones TH, et al. *J Neurosurg* 1981;54:773-782.



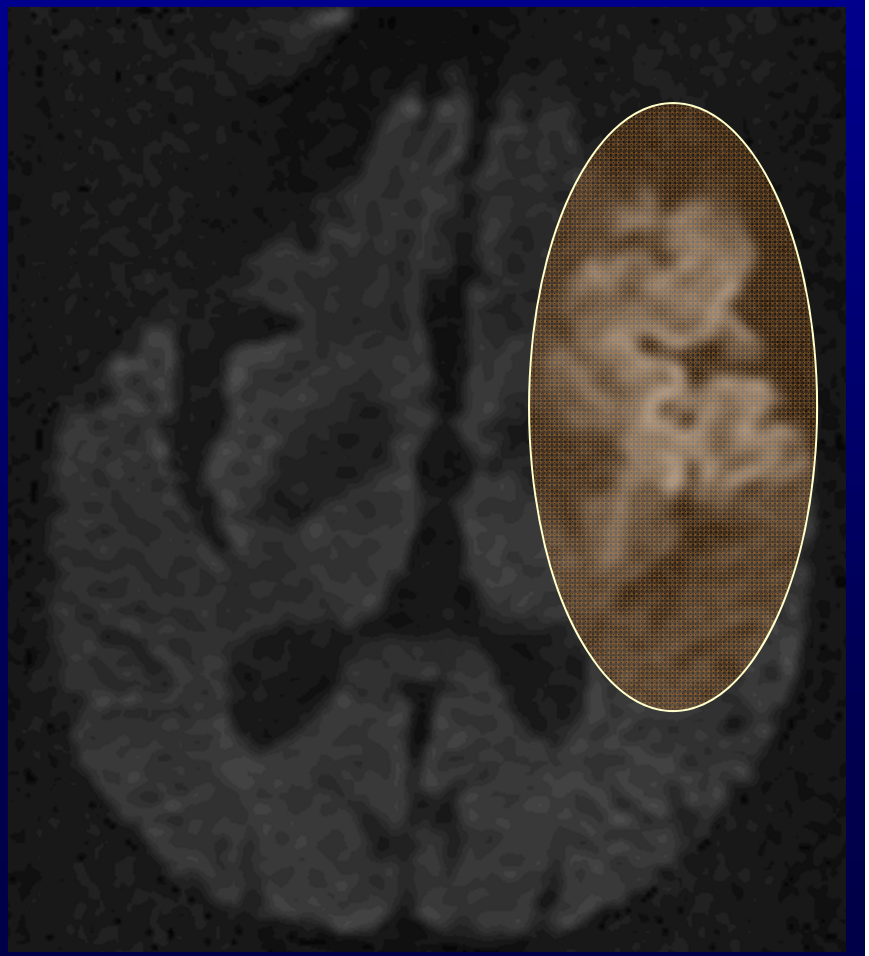
Ischemia = *f* (flow vs. time)

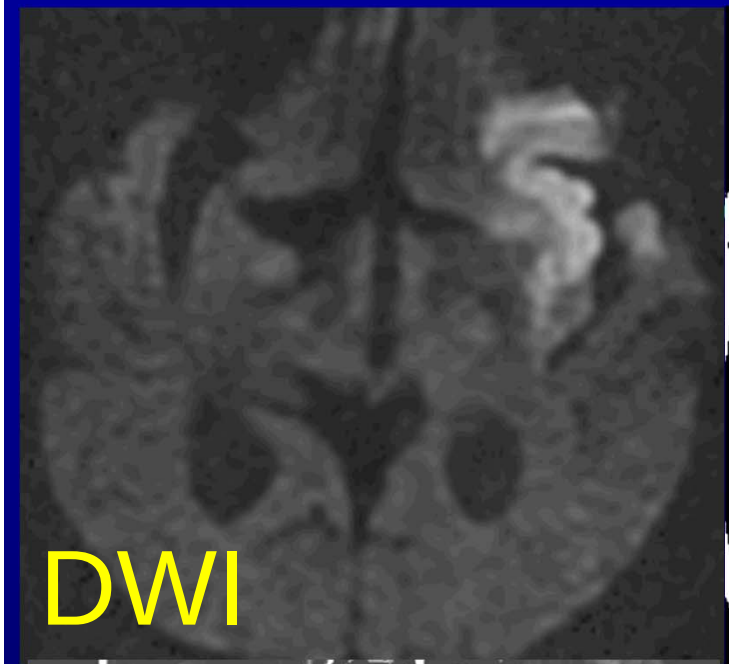


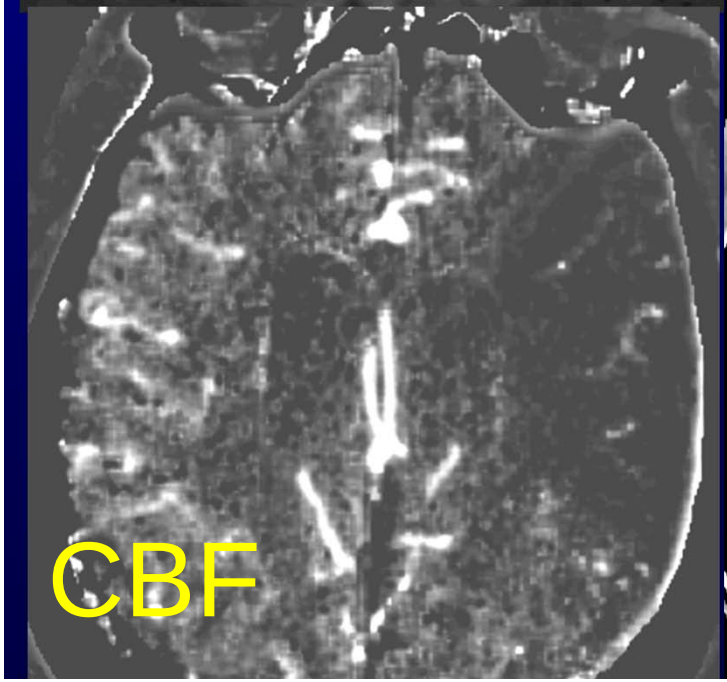
Central Dogma: Diffusion-Perfusion Mismatch

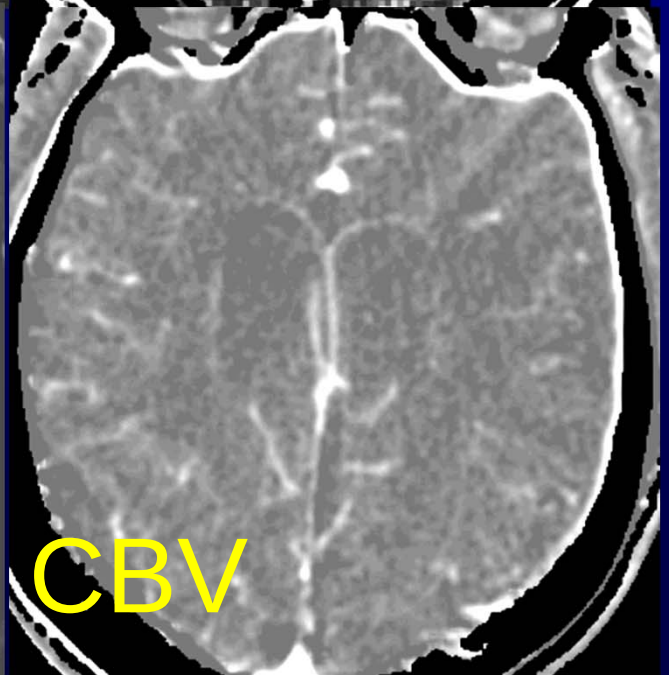
Can CT show both the core and the penumbra of the infarct?

- Diffusion Abnormality
  - Permanently infarcted
  - Infarct core or dead tissue
- Perfusion Abnormality
  - Overall tissue at risk
  - Includes the core
- (Perfusion – Diffusion)
  - Potentially salvageable Tissue
  - Ischemic penumbra



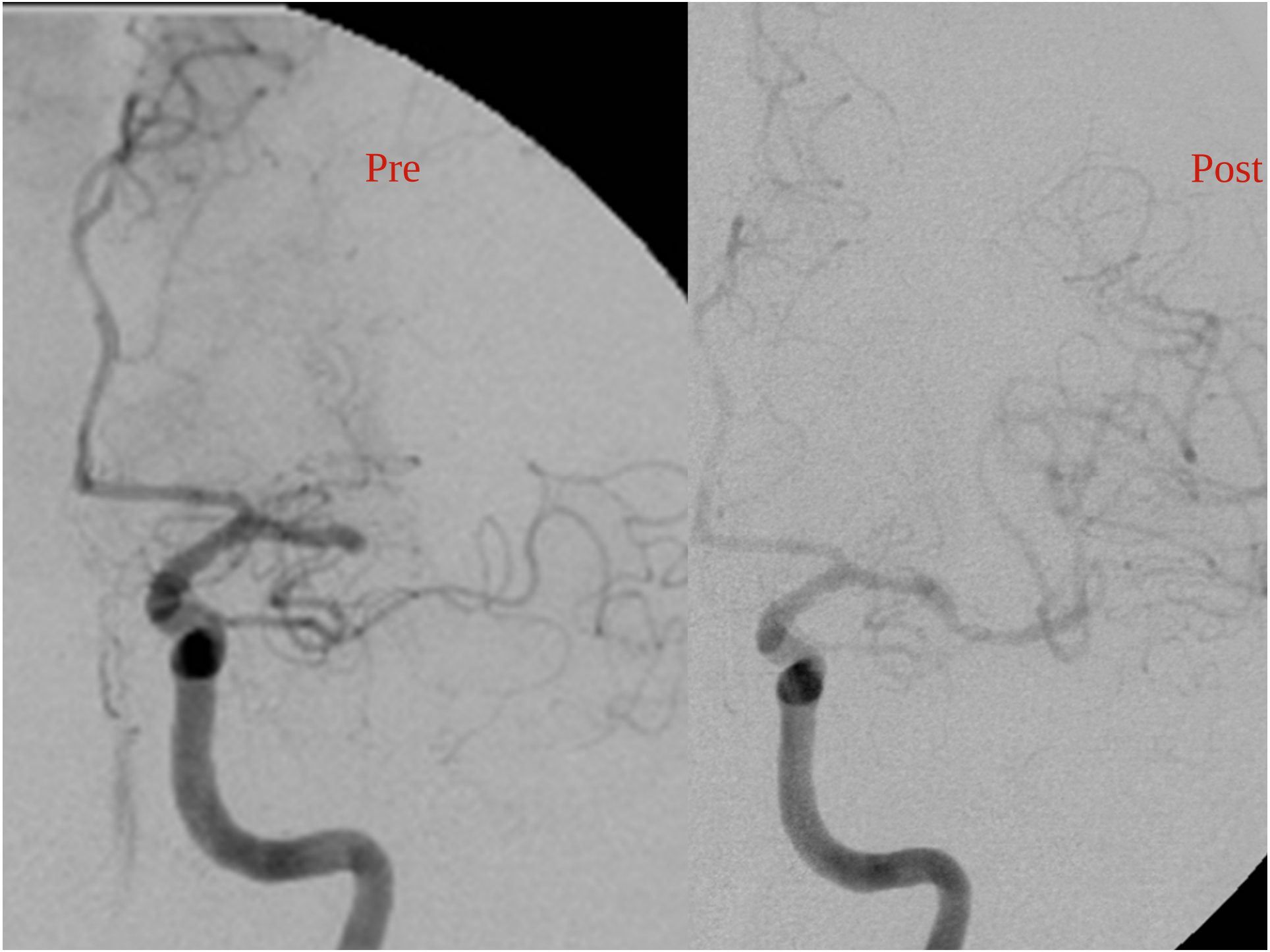




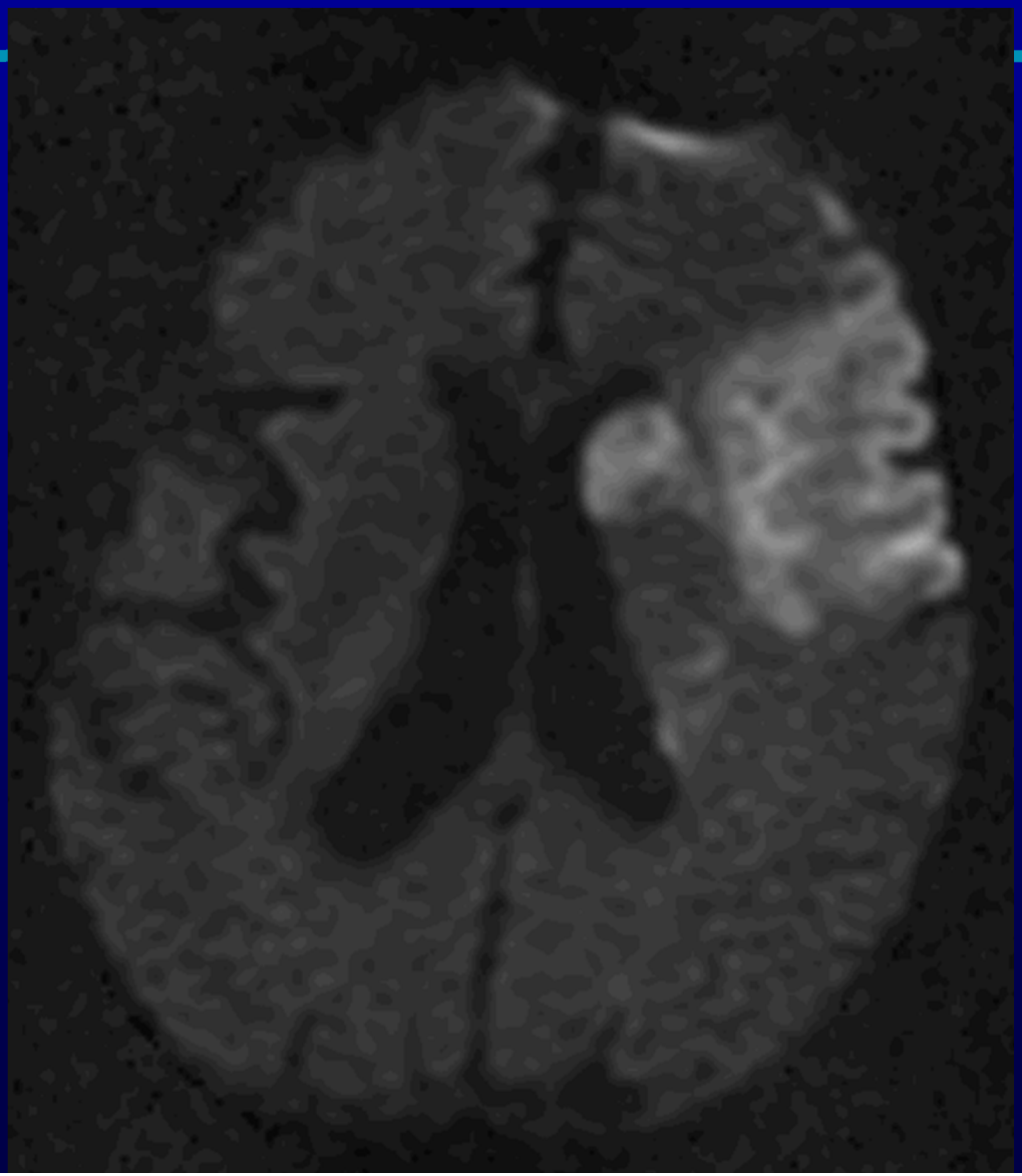


CTP Example

- Small infarct
- Proximal occlusion
- Large mismatch


Pre
Post

DWI: Post IA Tx

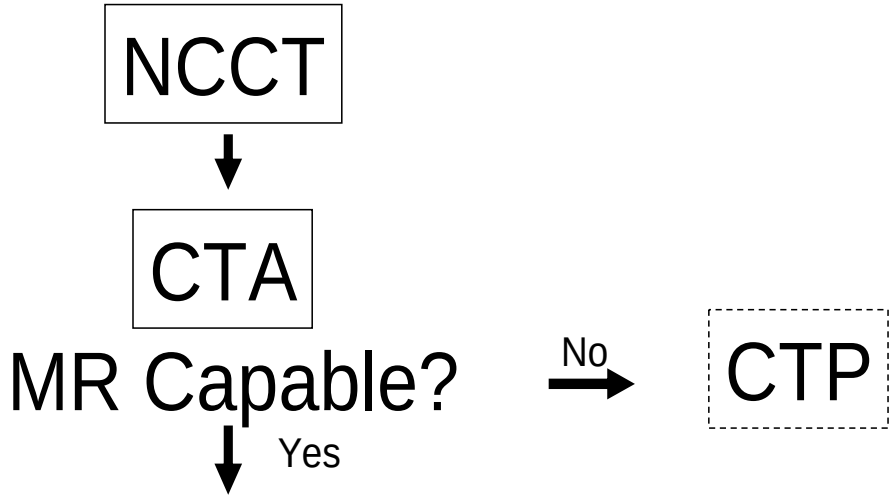


Key Questions in Stroke Imaging

- Brain Attack Protocol
  - IV tPA: Is there hemorrhage? (CT)
  - IA tx: Is there large vessel occlusion? (CTA)
  - IA tx: How much brain is already dead? (DWI)
    - Infarct "core"
    - < 1/3 MCA territory or <70-100 ml
  - Other mgmt: "True-at-risk" vs "benign oligemia"?

- **Perfusion imaging CAN'T REPLACE MR DWI**
  - **but … if DWI is not available …**
  - **CT-CBF (*not CBV*!) is the next best test for "core"**

MGH Neuroradiology Acute Ischemic Stroke
Recommended Imaging Algorithm

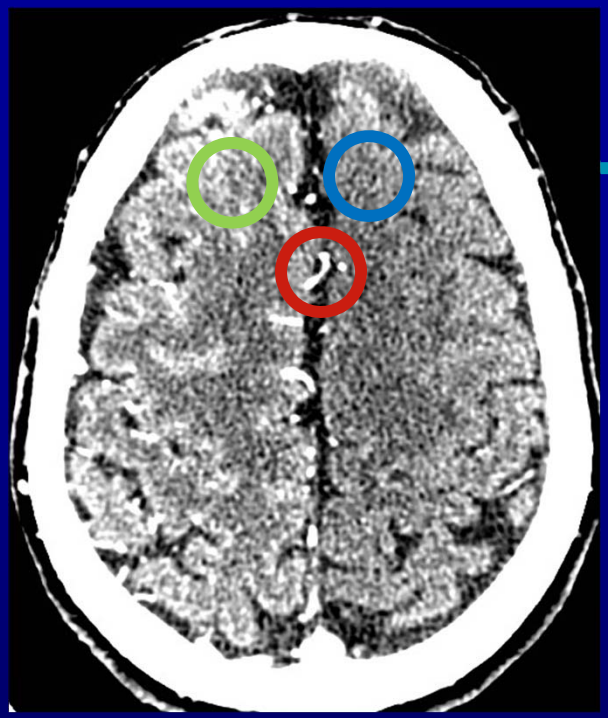


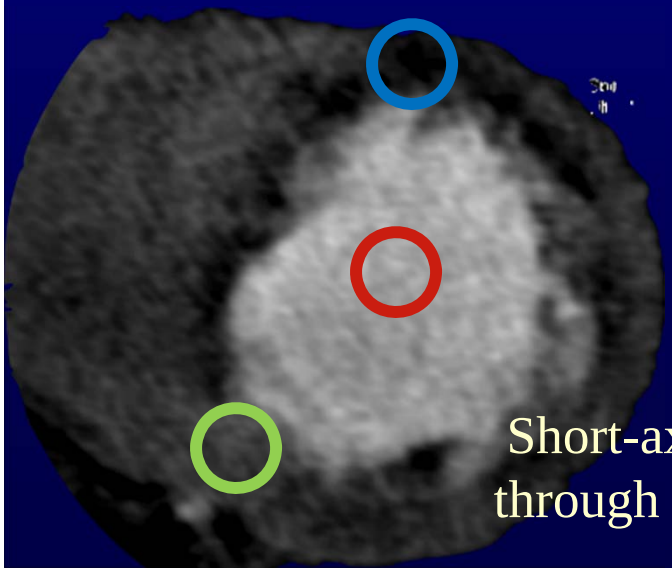
Includes TIA

"Angina of the Brain"

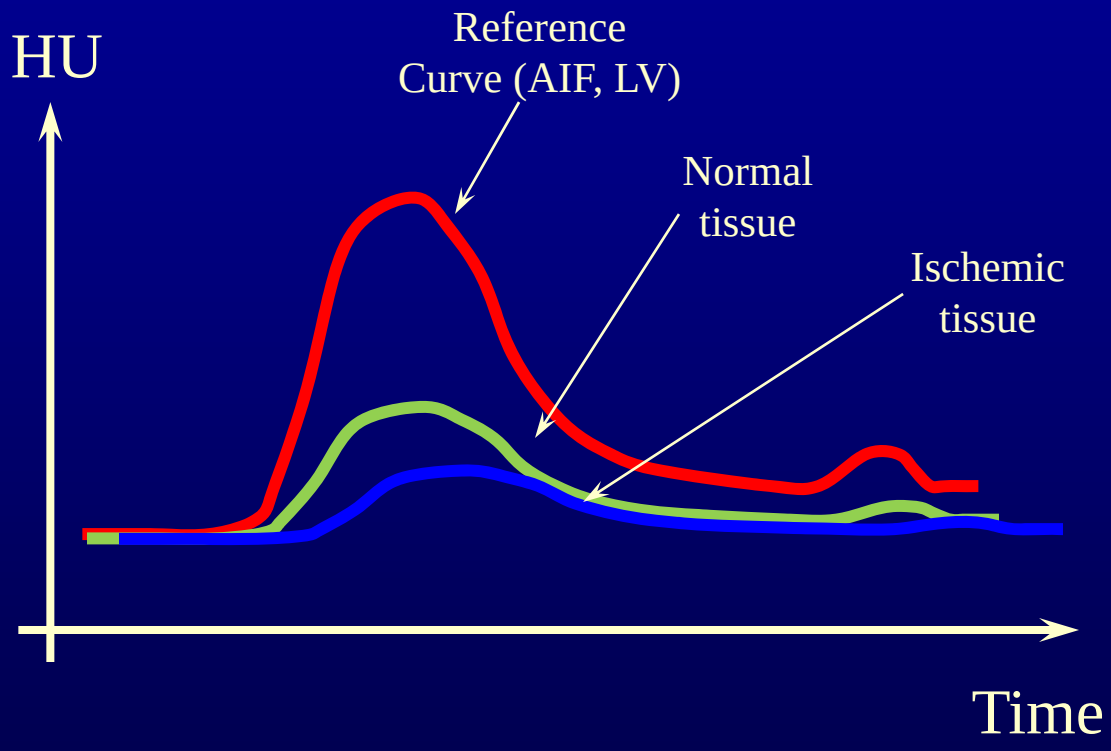
Courtesy of Gil Gonzalez, MD

Basic Paradigm



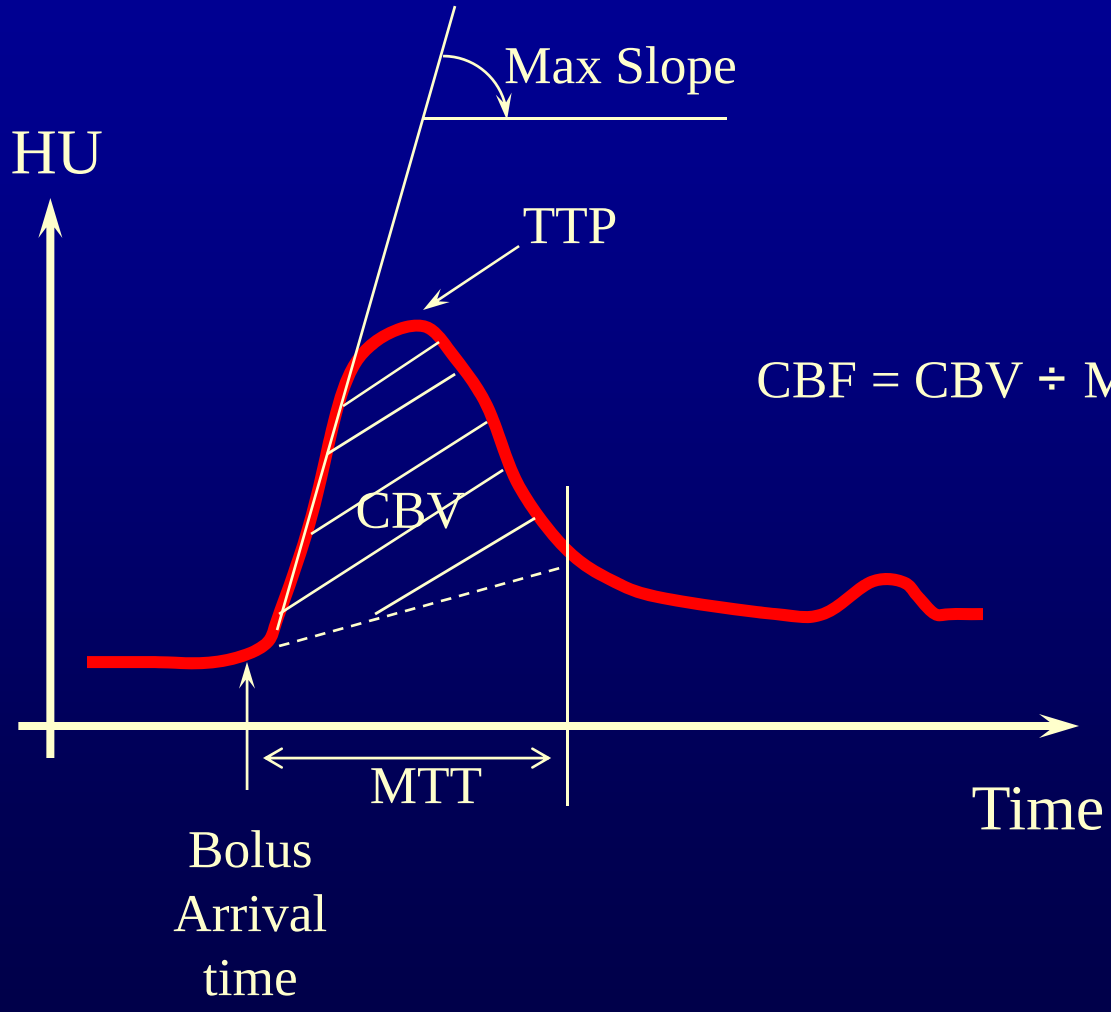


Short-axis
through LV



Observe dynamic blood flow as
the contrast washes in and out

Parameterization

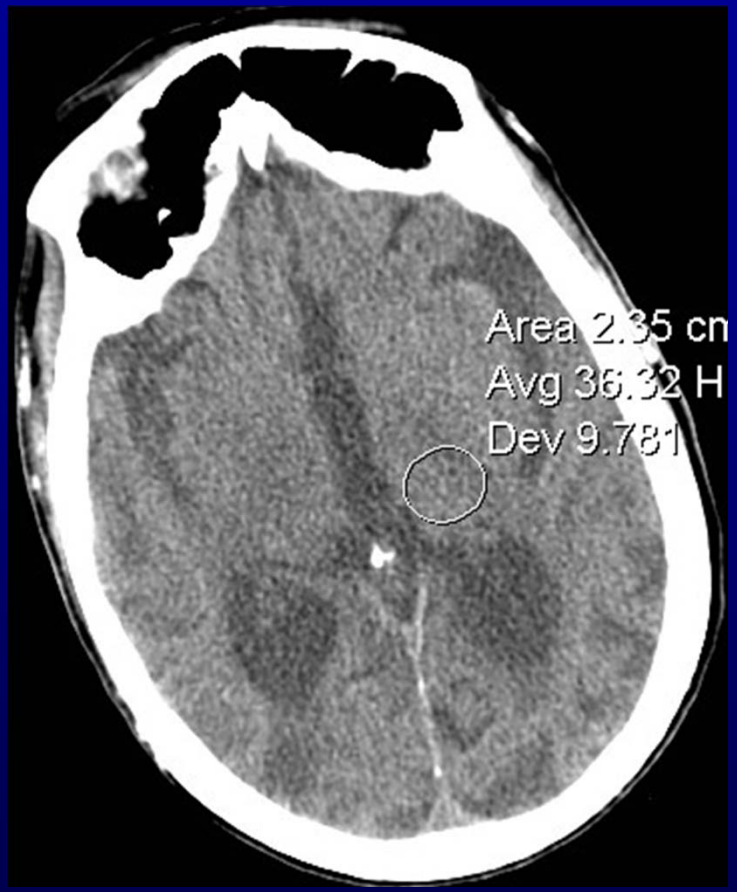


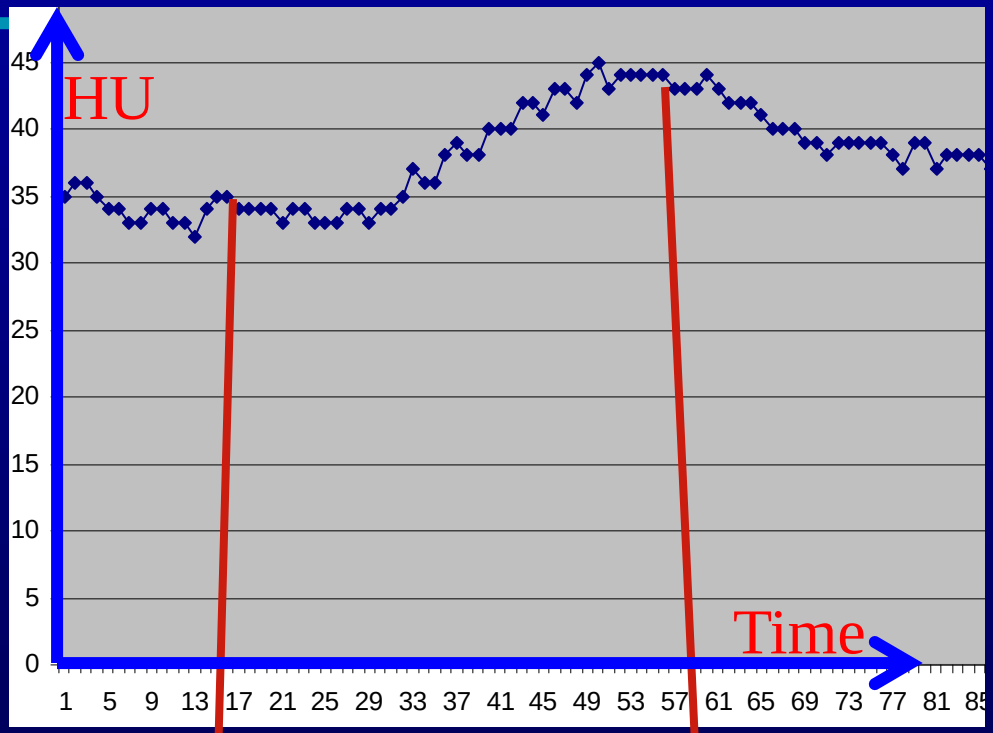
Main Challenges

- Too many technologies and processing algorithms
- CNR and SNR are low
- Dose can be very high
- Clinical applications are still being worked out

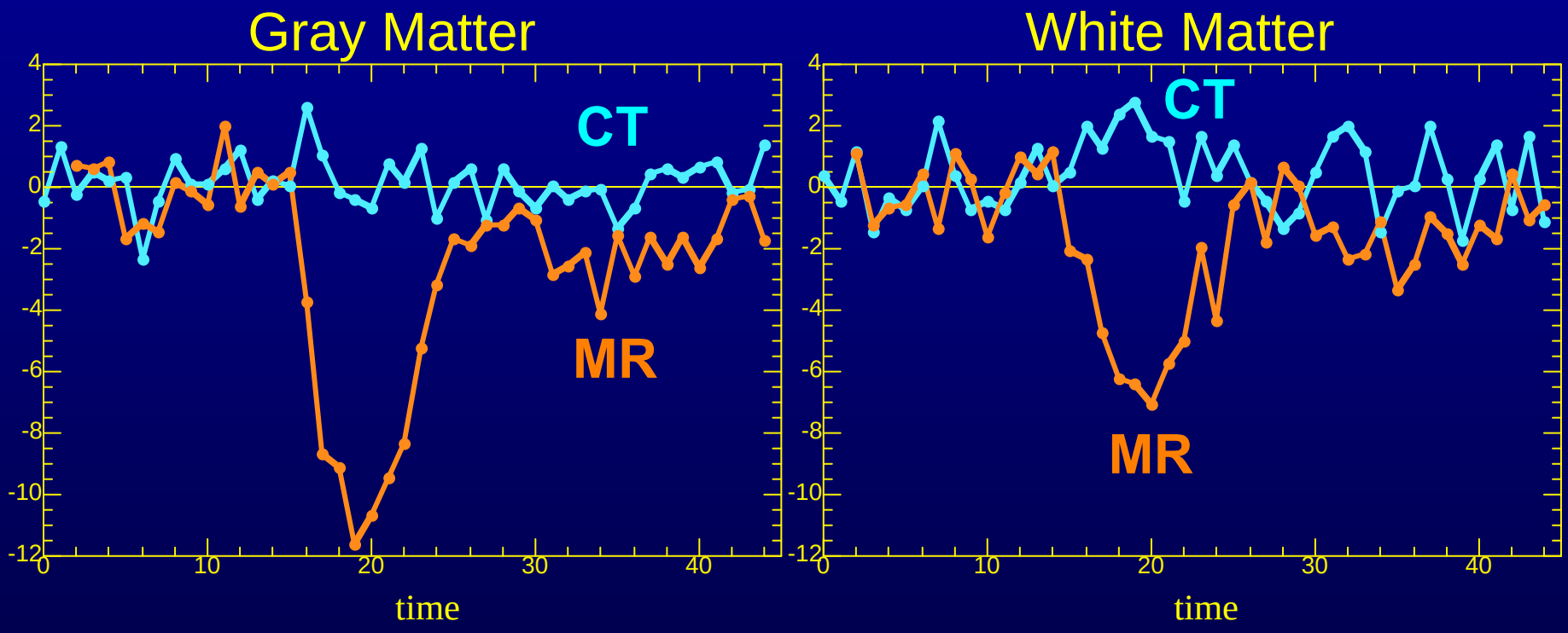
Other than that, life is good!

Low CNR and SNR

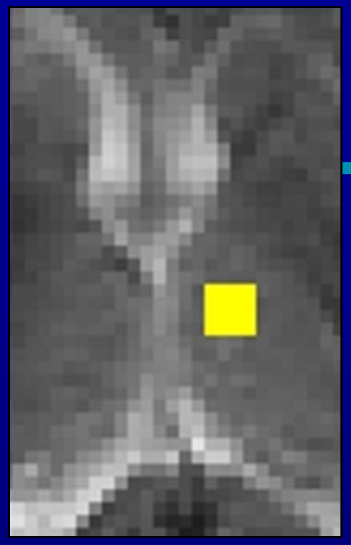




Single pixel intensity as a function of time

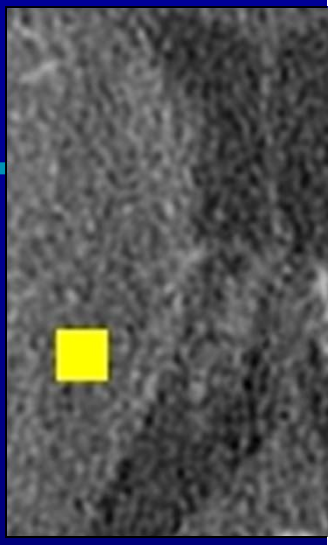


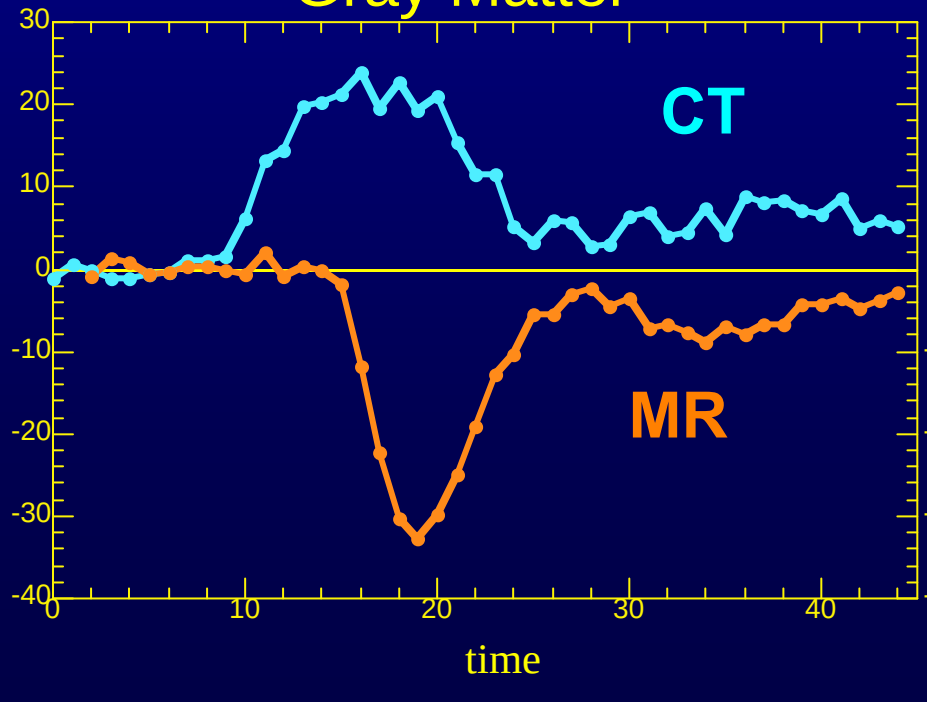
Dr. Bill Copen, MGH

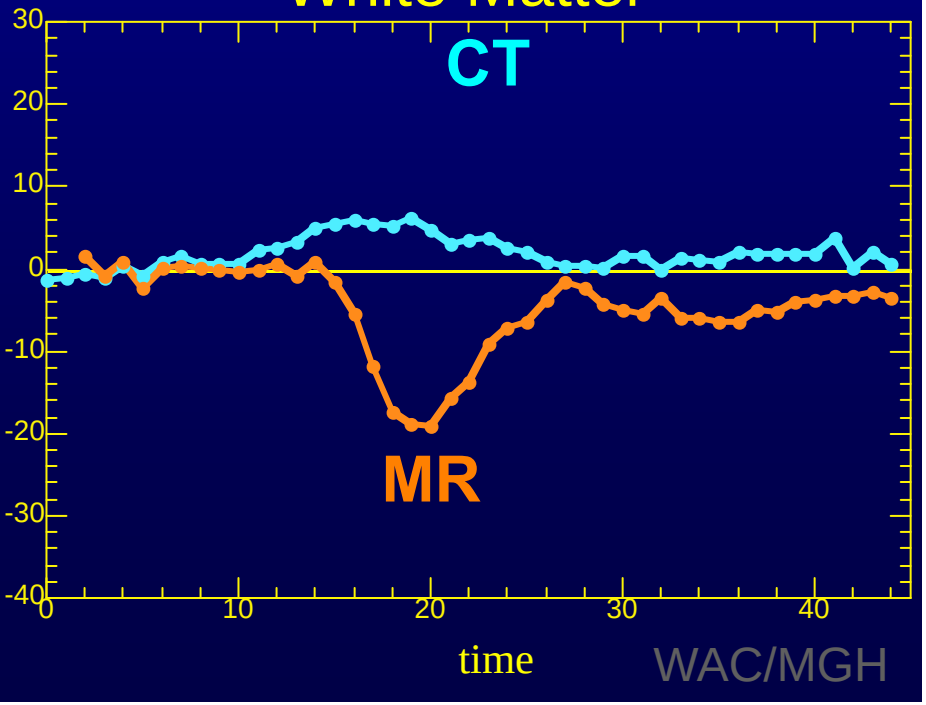


Average intensity over time

Must thicken the slice and aggregate pixels for good CNR and SNR







Radiation Dose

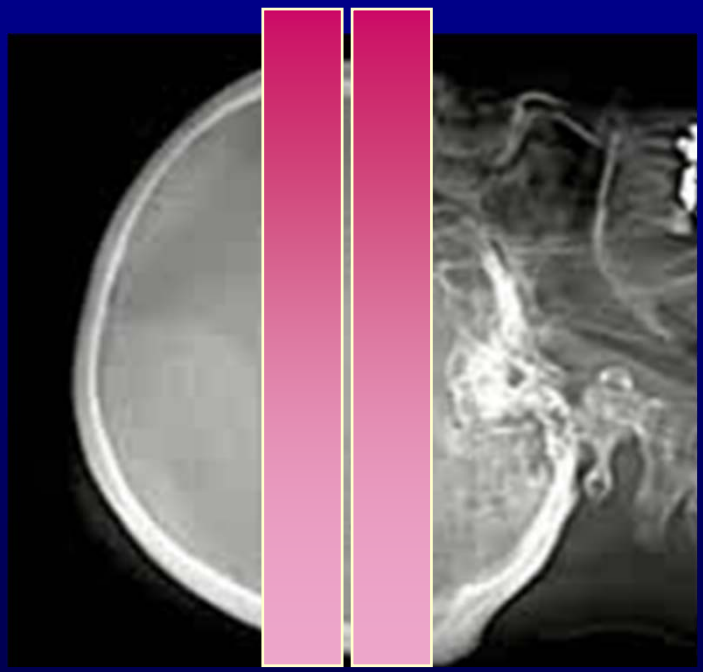
Day 37 after 1st CTP: four CTA/CTP and two DSA exams in 2 weeks

120 kV, 100 mAs, and 50 rotations

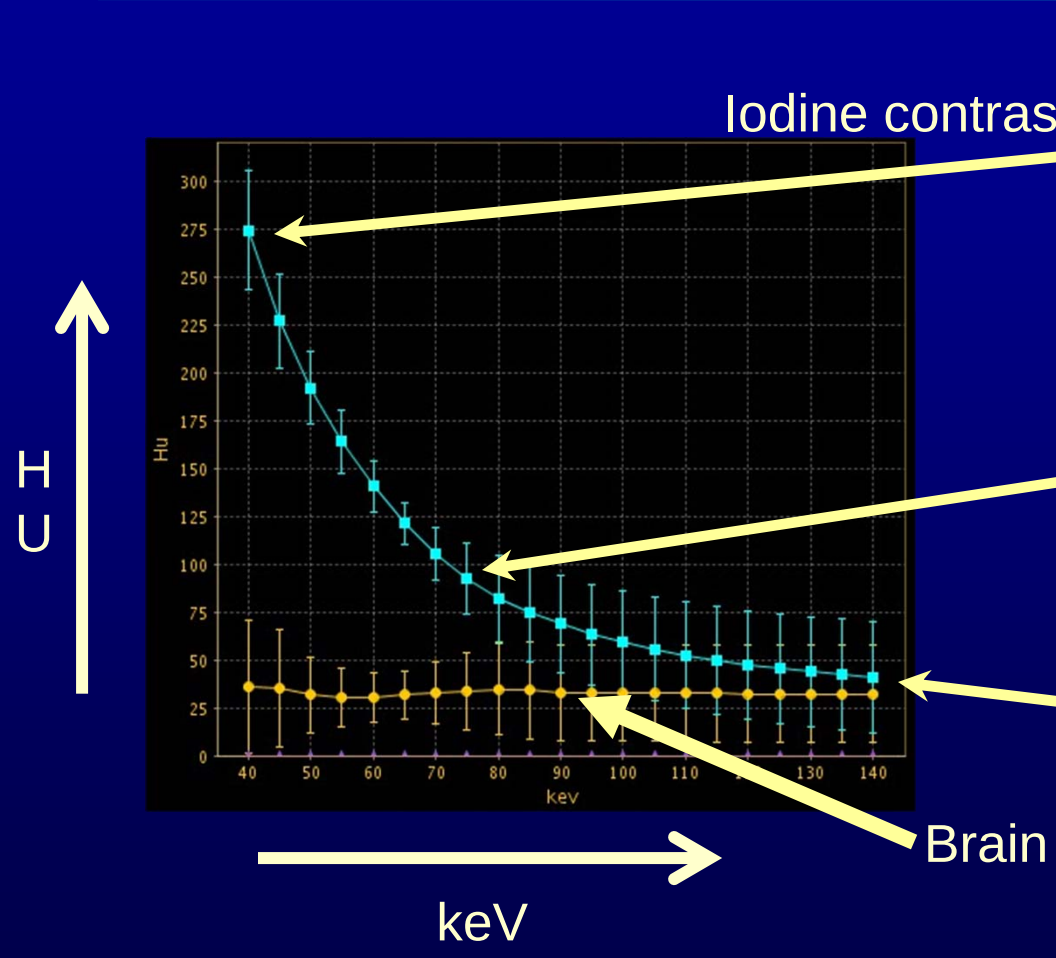
Eur Radiol (2005) 15:41–46

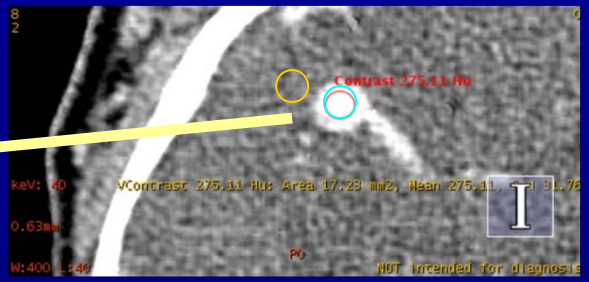
MGH Single Slab Perfusion Protocol

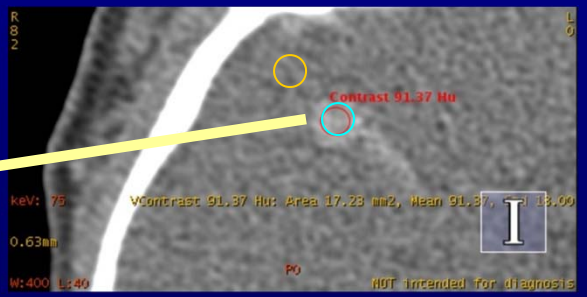
- Perfusion (single slab, cine)
  - 80 kVp 200 mA, 1 second rotation, 8 x 5 mm slices
  - **Phase I (cine):** 1 image every second for 40s (0.5s recon interval)
  - **Phase II (axial):** 1 image every 3 seconds for 27 s
  - Total duration = 67 s
  - Total X-ray exposure = 49 s
- CTDIvol=470 mGy
- DLP = 1890 mGy-cm
- CTP protocol well within the 0.5 Gy CTDI (vol)
- Further 25% reduction with 150mA

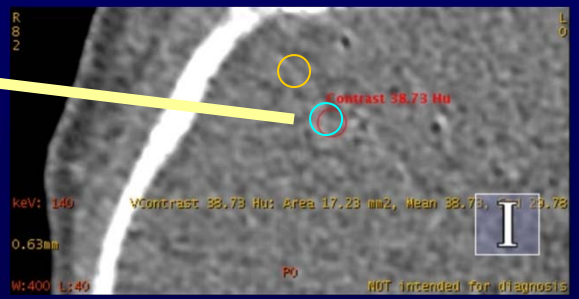


kVp Pitfall: Tissue spectral response









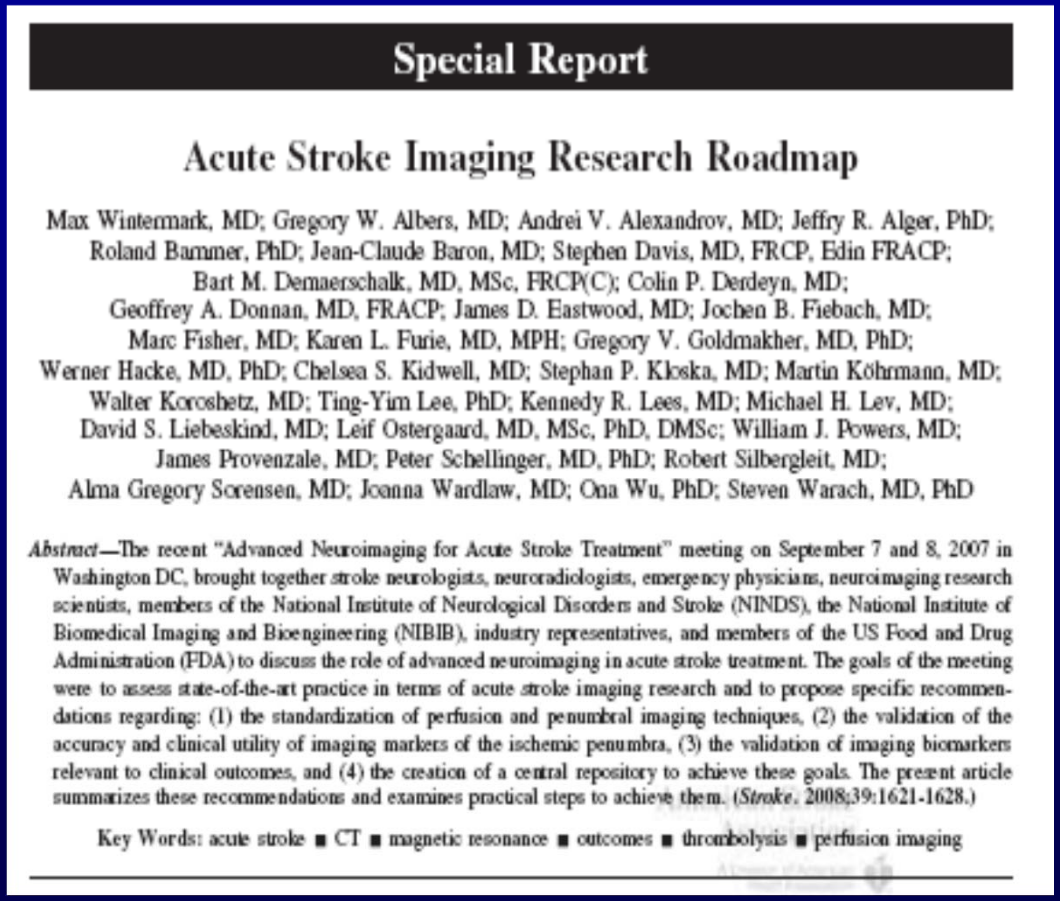
CT Perfusion Dose vs kVp

- Low kVp is desirable
- 80 kVp standard
  - Less radiation dose
  - More iodine conspicuity

kVp	mA	CTDI (mGy)	Eff dose (mSv)	Num Rot	Total organ dose (mGy)	Total Effective dose (mSv)
80	200	16.1	0.19	40	644	7.6
100	200	28.6	0.35	40	1144	14
120	200	43.4	0.55	40	1736	22
140	200	59.6	0.67	40	2384	26.8

mAs Pitfall

- CT Perfusion is NOT, and should not be a standard head CT protocol
- Low mAs is sufficient
  - < 200
  - As low as 100; "*roadmap*"
- Epilation threshold
  - ~ 3 Gy, ~ 3 wk delay
  - If CTP is 8x the .5 Gy max, dose at least 4 Gy!



Special Report

Acute Stroke Imaging Research Roadmap

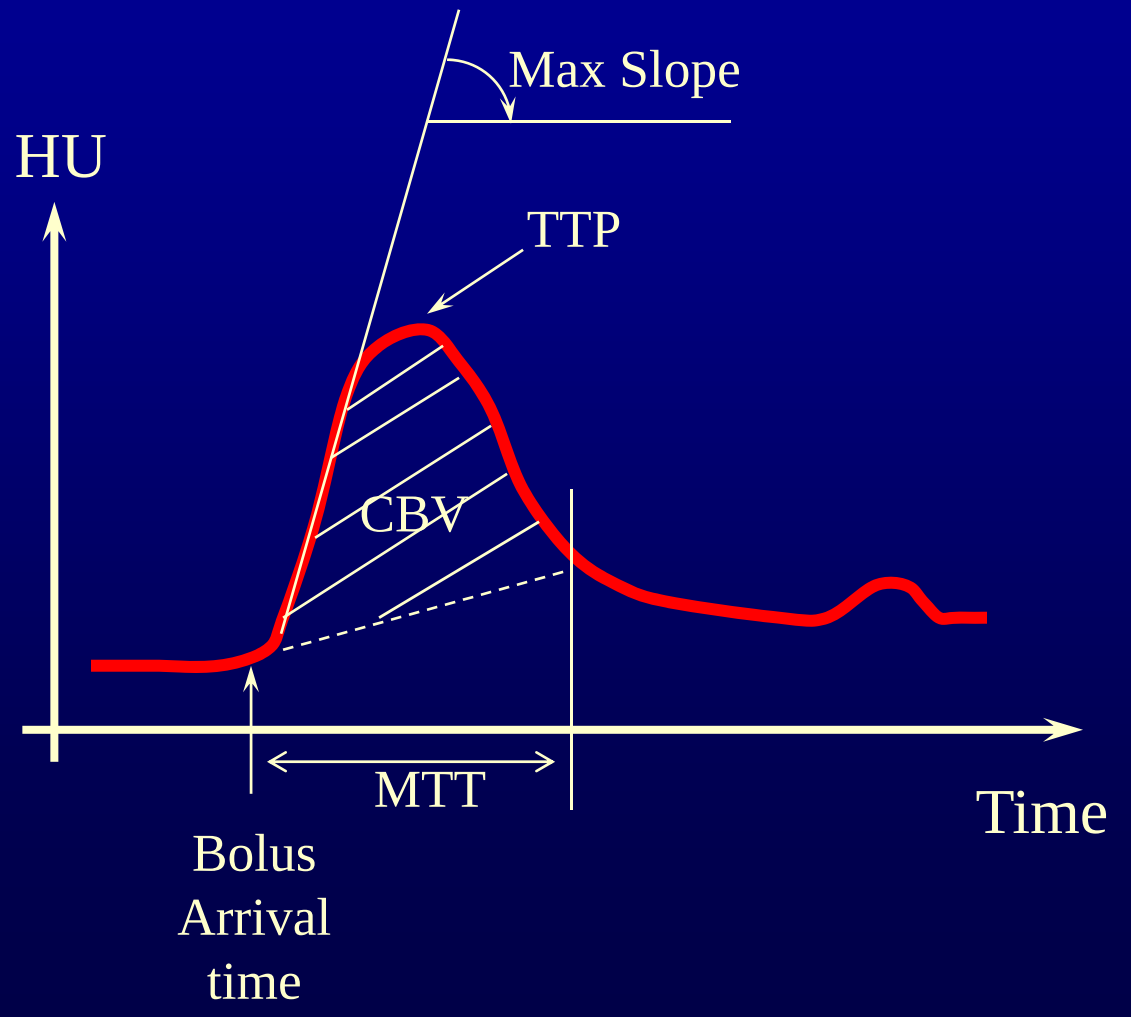
Max Wintermark, MD; Gregory W. Albers, MD; Andrei V. Alexandrov, MD; Jeffry R. Alger, PhD; Roland Bammer, PhD; Jean-Claude Baron, MD; Stephen Davis, MD, FRCP, Edin FRACP; Bart M. Demaerschalk, MD, MSc, FRCP(C); Colin P. Derdeyn, MD; Geoffrey A. Donnan, MD, FRACP; James D. Eastwood, MD; Jochen B. Fiebach, MD; Marc Fisher, MD; Karen L. Furie, MD, MPH; Gregory V. Goldmakher, MD, PhD; Werner Hacke, MD, PhD; Chelsea S. Kidwell, MD; Stephan P. Kloska, MD; Martin Köhrmann, MD; Walter Koroshetz, MD; Ting-Yim Lee, PhD; Kennedy R. Lees, MD; Michael H. Lev, MD; David S. Liebeskind, MD; Leif Ostergaard, MD, MSc, PhD, DMSc; William J. Powers, MD; James Provenzale, MD; Peter Schellinger, MD, PhD; Robert Silbergleit, MD; Alma Gregory Sorensen, MD; Joanna Wardlaw, MD; Ona Wu, PhD; Steven Warach, MD, PhD

Abstract—The recent "Advanced Neuroimaging for Acute Stroke Treatment" meeting on September 7 and 8, 2007 in Washington DC, brought together stroke neurologists, neuroradiologists, emergency physicians, neuroimaging research scientists, members of the National Institute of Neurological Disorders and Stroke (NINDS), the National Institute of Biomedical Imaging and Bioengineering (NIBIB), industry representatives, and members of the US Food and Drug Administration (FDA) to discuss the role of advanced neuroimaging in acute stroke treatment. The goals of the meeting were to assess state-of-the-art practice in terms of acute stroke imaging research and to propose specific recommendations regarding: (1) the standardization of perfusion and penumbral imaging techniques, (2) the validation of the accuracy and clinical utility of imaging markers of the ischemic penumbra, (3) the validation of imaging biomarkers relevant to clinical outcomes, and (4) the creation of a central repository to achieve these goals. The present article summarizes these recommendations and examines practical steps to achieve them. (*Stroke*. 2008;39:1621-1628.)

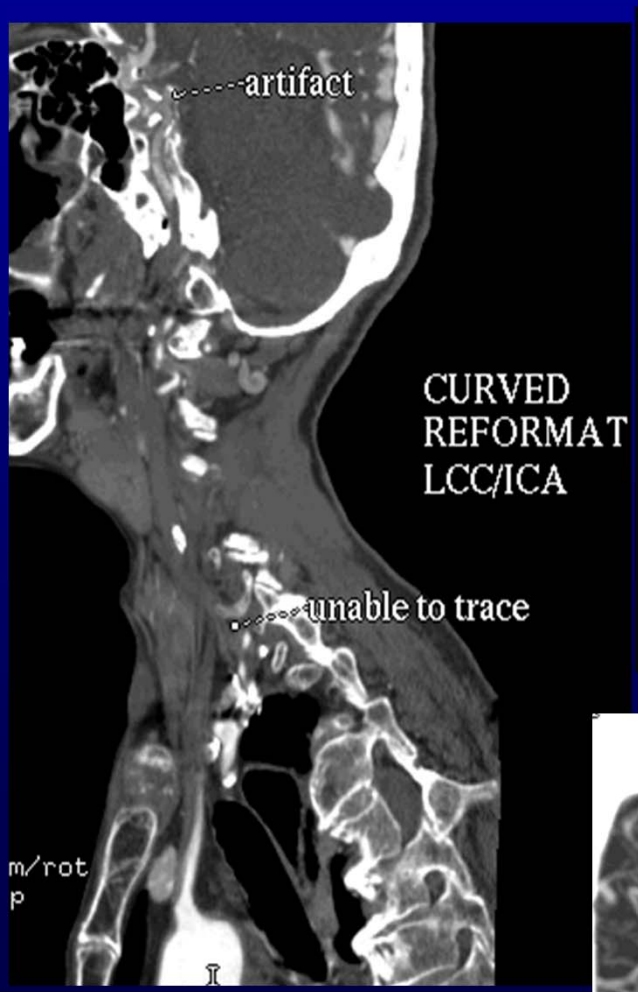
Key Words: acute stroke ■ CT ■ magnetic resonance ■ outcomes ■ thrombolysis ■ perfusion imaging

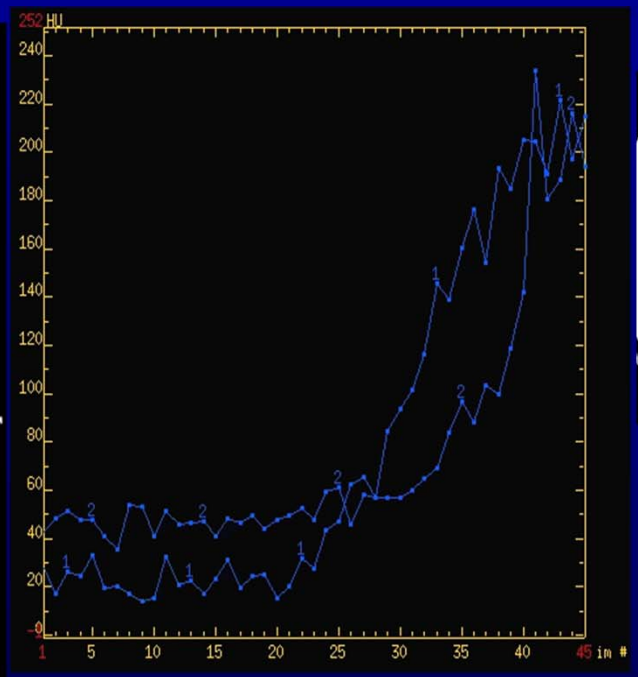
Sampling Frequency Pitfall

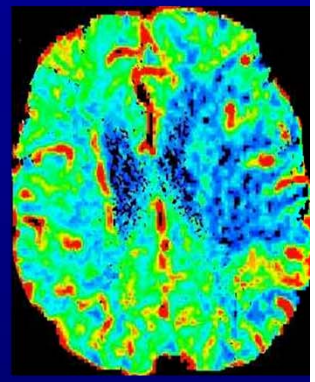
- Acquire adequate baseline
- Brain transit time (~5s) is fast
- Need at least 1.0s to 1.5s sampling in the arterial phase
- Slower sampling OK in venous phase
- Do not try to beat the Nyquist limit

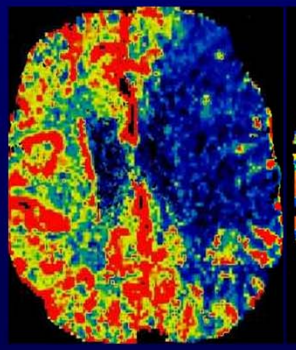


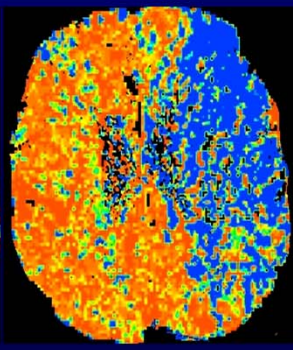
Sampling Duration Pitfall: Time-Opacification Curve Truncation with Slow Flow









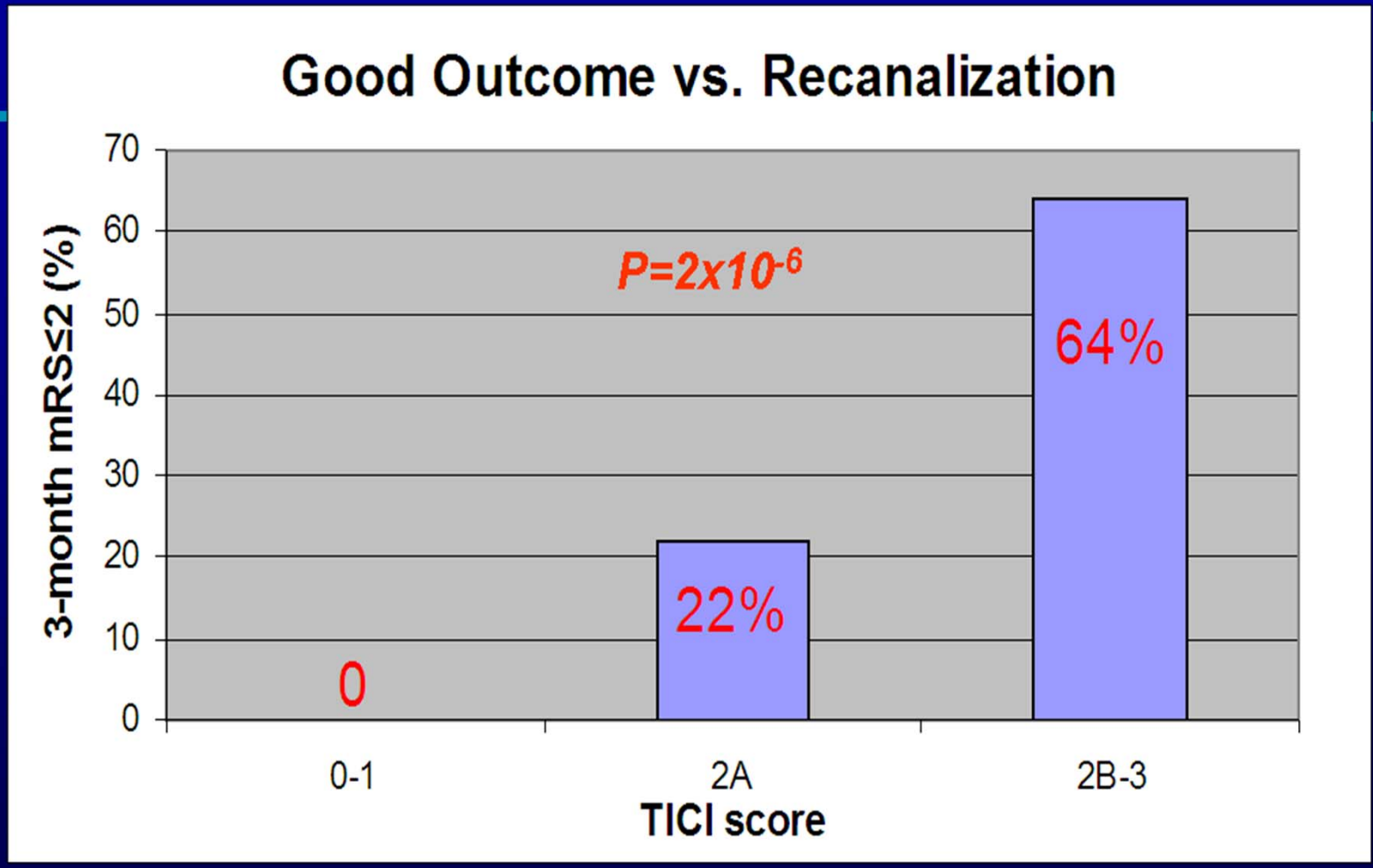


MHL / MGH

CTP Interpretation Pitfalls

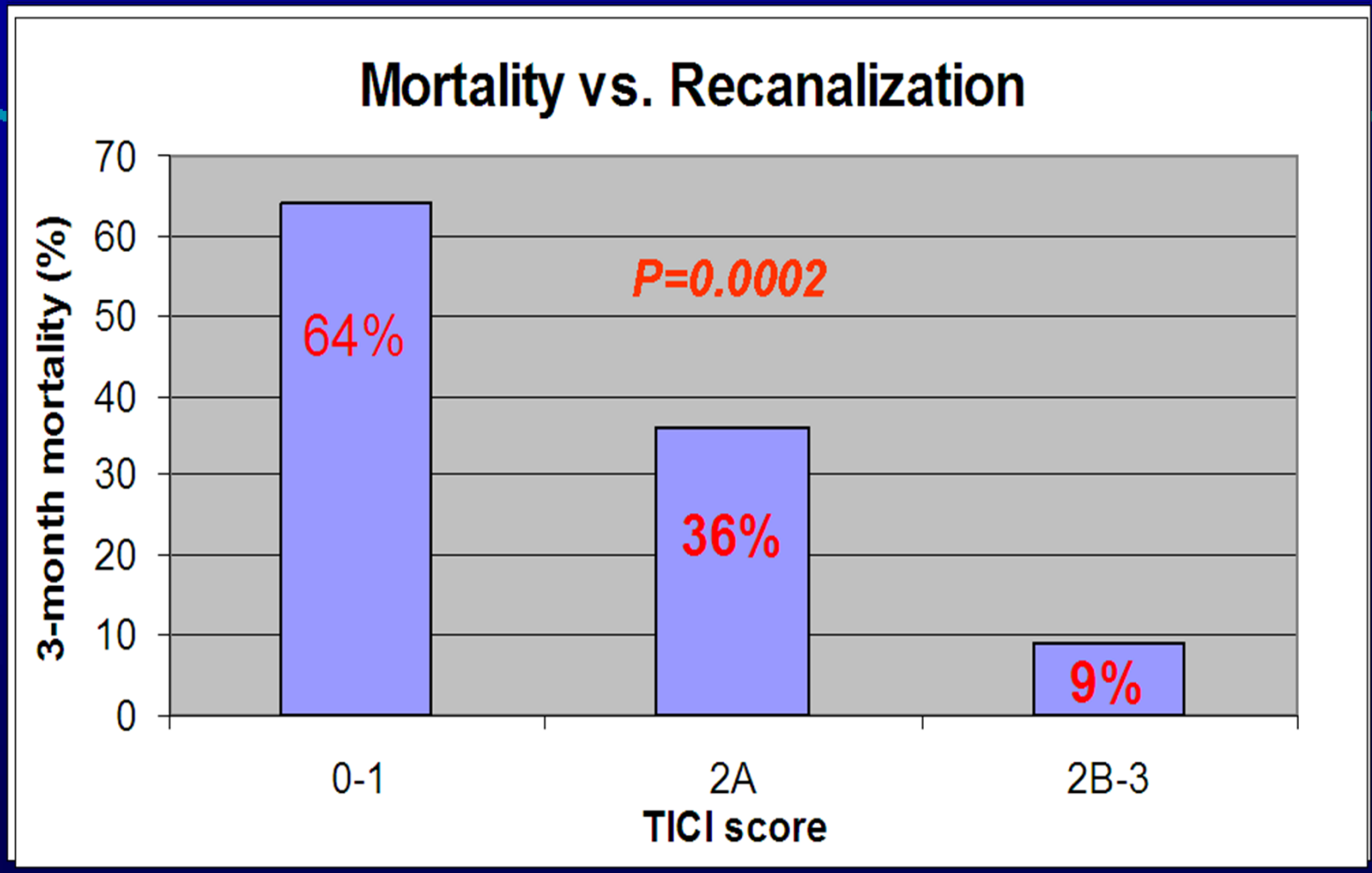
- Reperfusion is necessary but not sufficient for a good outcome
- Collateral circulation strongly influences treatment response
- Quantification of perfusion is not validated
- Core infarct volume is the best surrogate marker for patient selection

MGH experience, 2004-2008



No reperfusion → *Greater reperfusion*

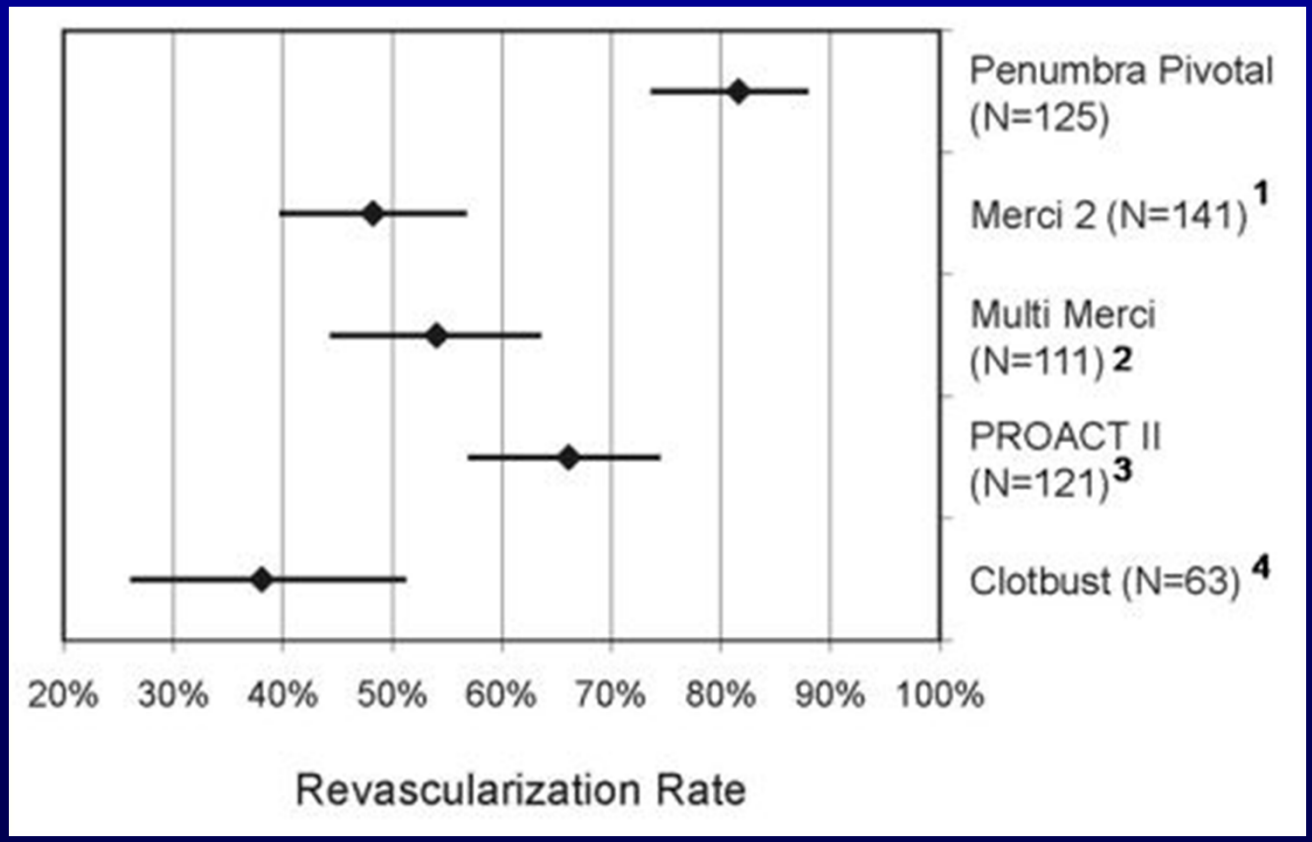
MGH experience, 2004-2008



No reperfusion → *Greater reperfusion*

- **Reperfusion is not sufficient for a good outcome**

Revascularization in Major Trials



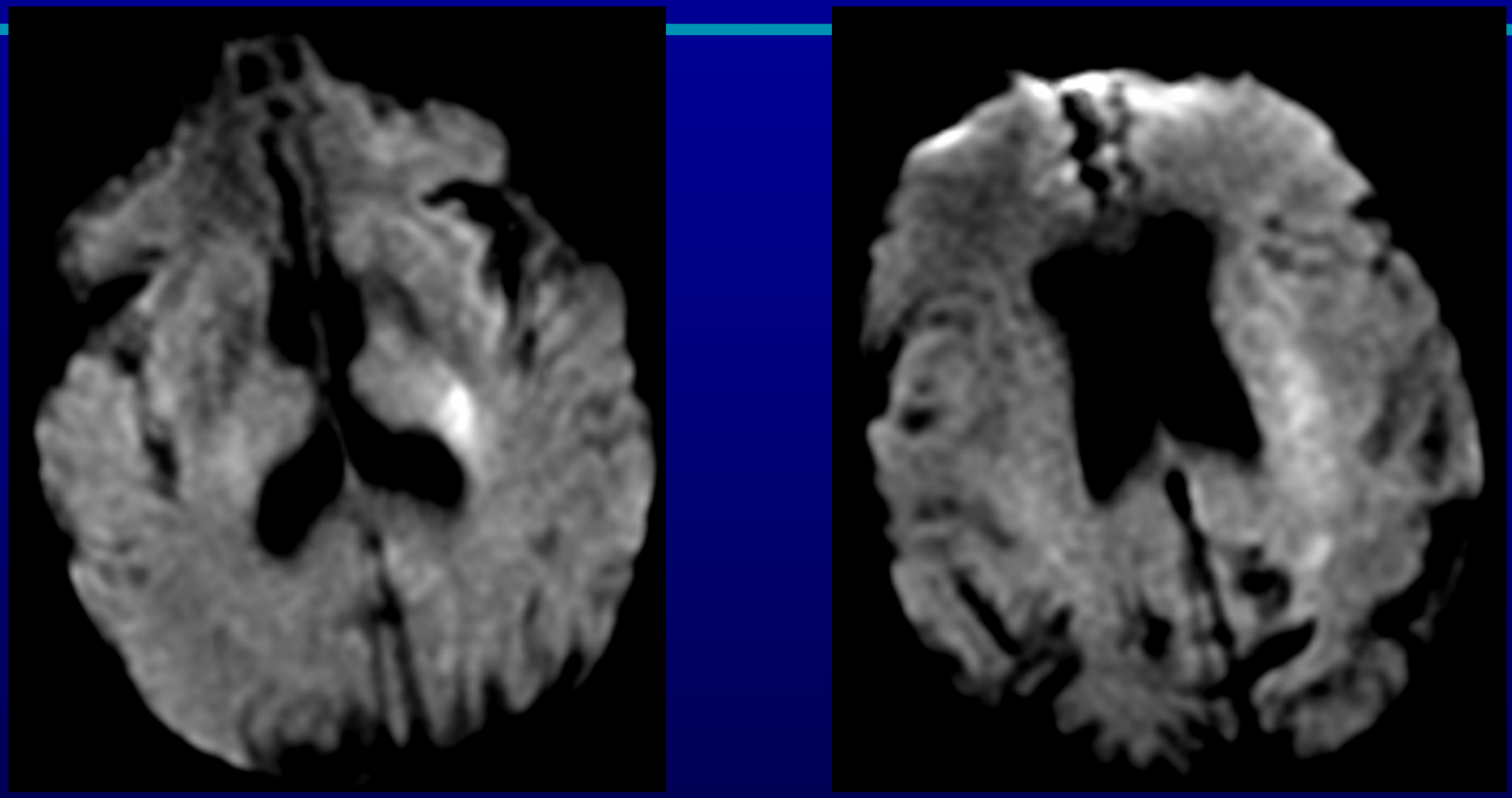
McDougall C, Penumbra Stroke Trial Investigators. The Penumbra Stroke Trial: Safety and Efficacy of a New Generation of Mechanical Devices for Clot Retrieval in Acute Ischemic Stroke. *ISC* 2008.

Revascularization = Good Outcome??

	IMS II	PROACT II (treatment arm)	Multi MERCI	Penumbra
No. of patients	81	121	164	125
age (yrs)	64±11.5	64±14	68±16	63.5±13.5
NIHSS	19±5.3	17 (5-27)	19 (15-23)	17.6±5.2
% TIMI 2/3 recanalization	60	66	69.5	81.6
% good outcome (mRS≤2, 90 dd)	46	40	36	25
% mortality (90 dd)	16	25	34	32.8

↑Recanalization = ↓Outcomes

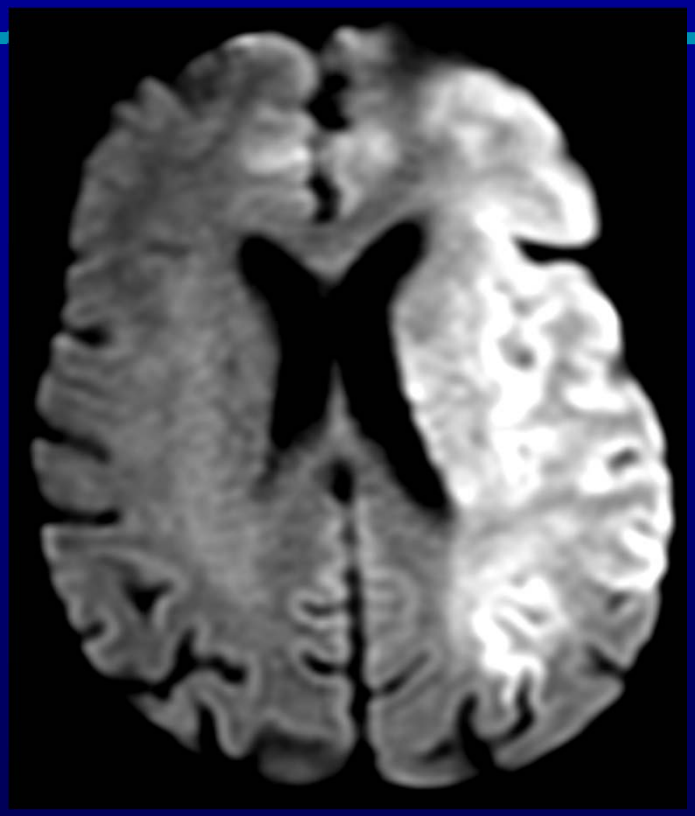
Time is Brain???

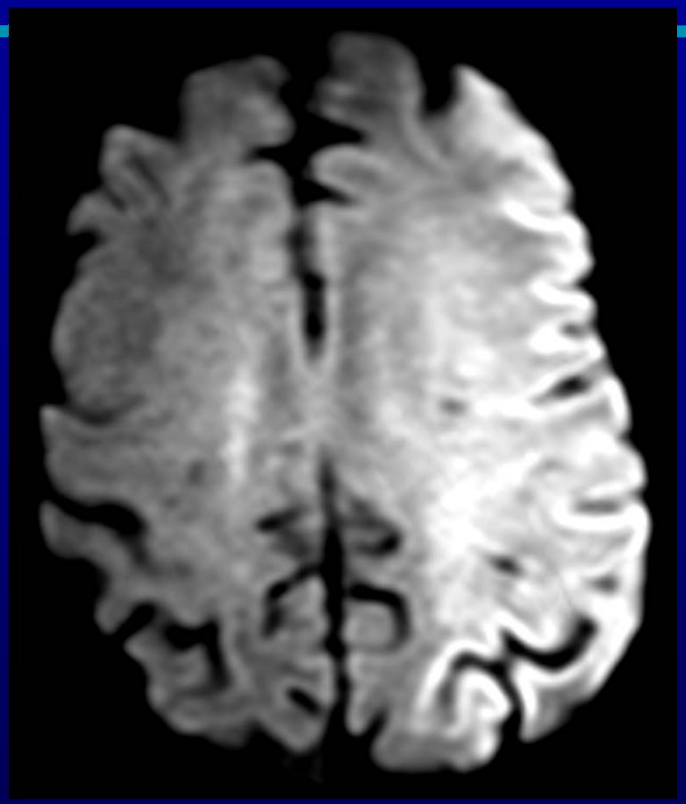


8 HOURS POST-ICTUS

79 year old female with right hemiparesis and seizure:
ICA-T occlusion

Time is Brain???





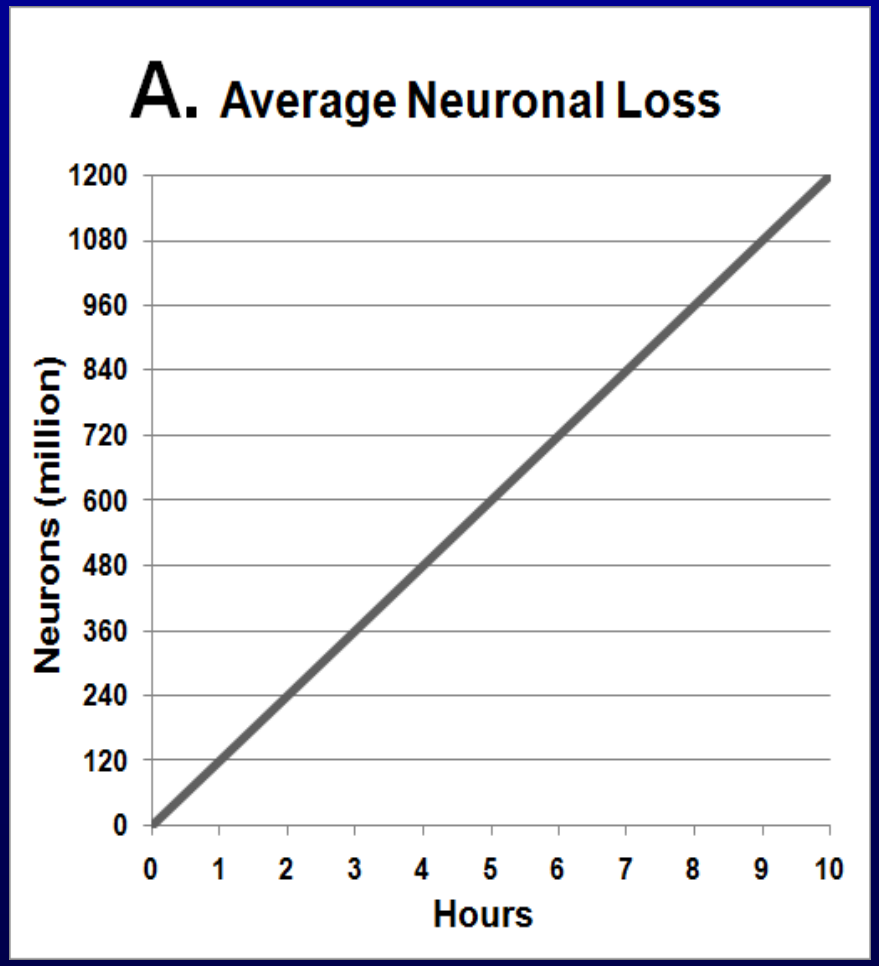
2.5 HOURS POST-ICTUS

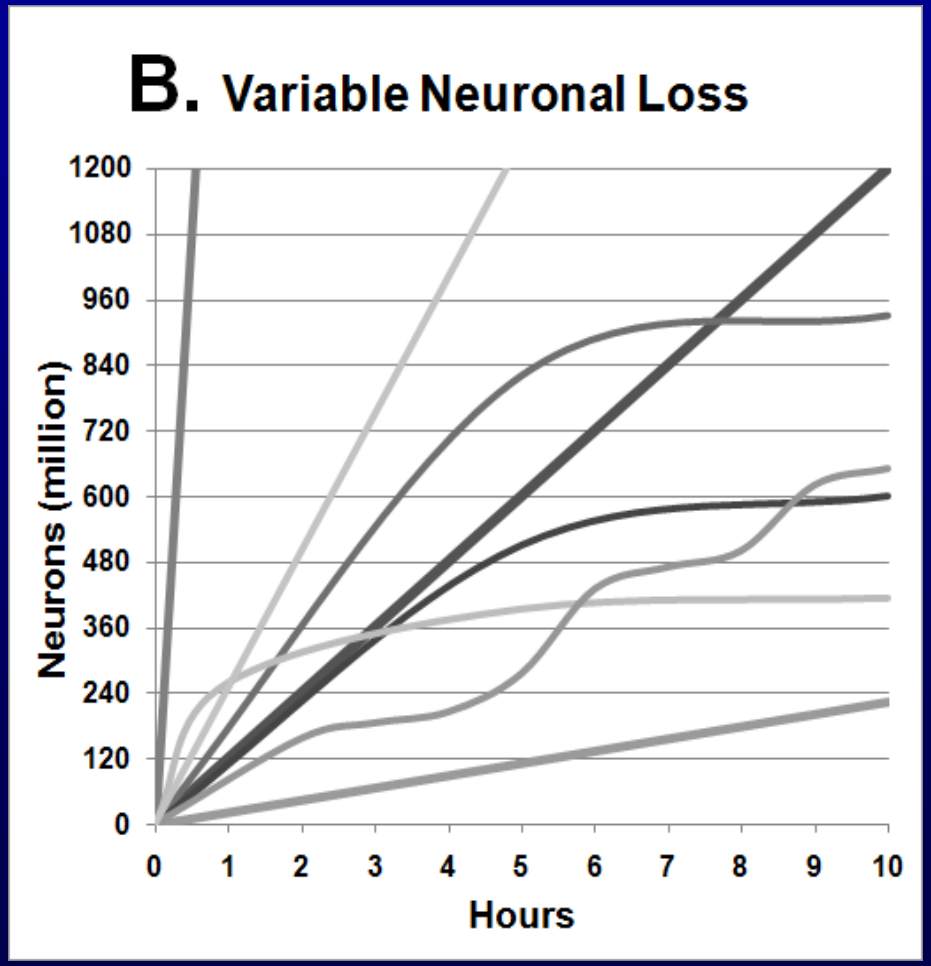
74 year old male with right hemiparesis and aphasia:
ICA-T occlusion

Why such variability in response?

- Different people's neurons behave differently to ischemia
- The collateral circulation, which varies enormously, strongly influences treatment response

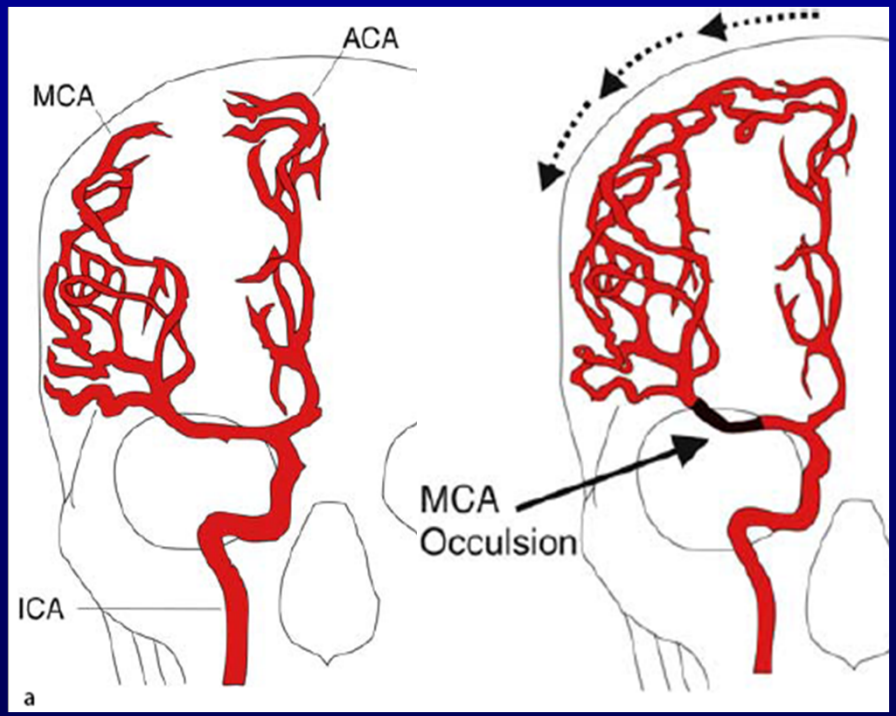
Infarct Size = Rate x Time



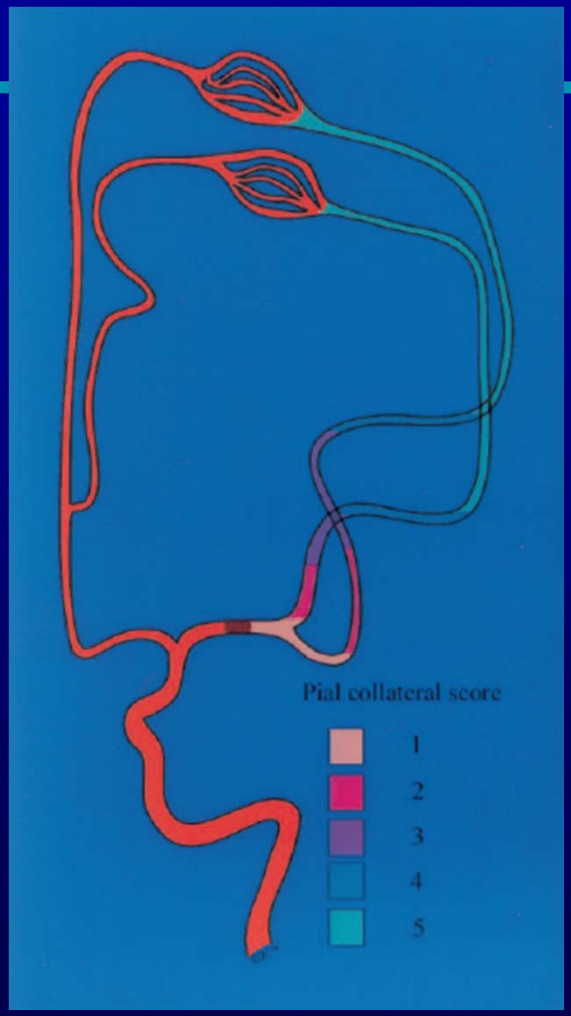


Courtesy of Reza Hakimelahi, MD

Collateral circulation

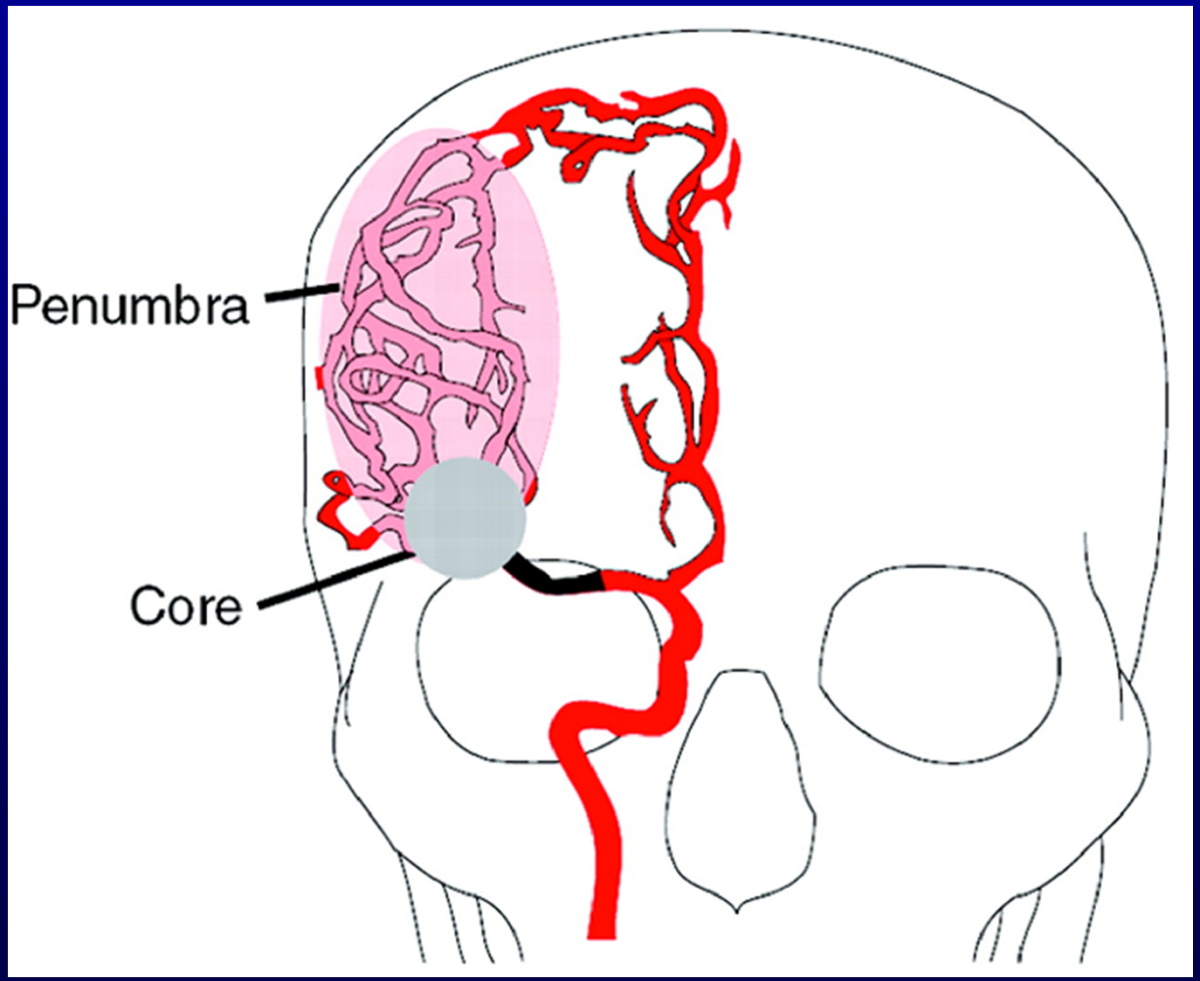


Koroshetz / Gonzalez
In :Acute Ischemic Stroke Imaging and Intervention 2006



Christoforidis *AJNR* 26:1789–1797, August 2005

The Ischemic Penumbra



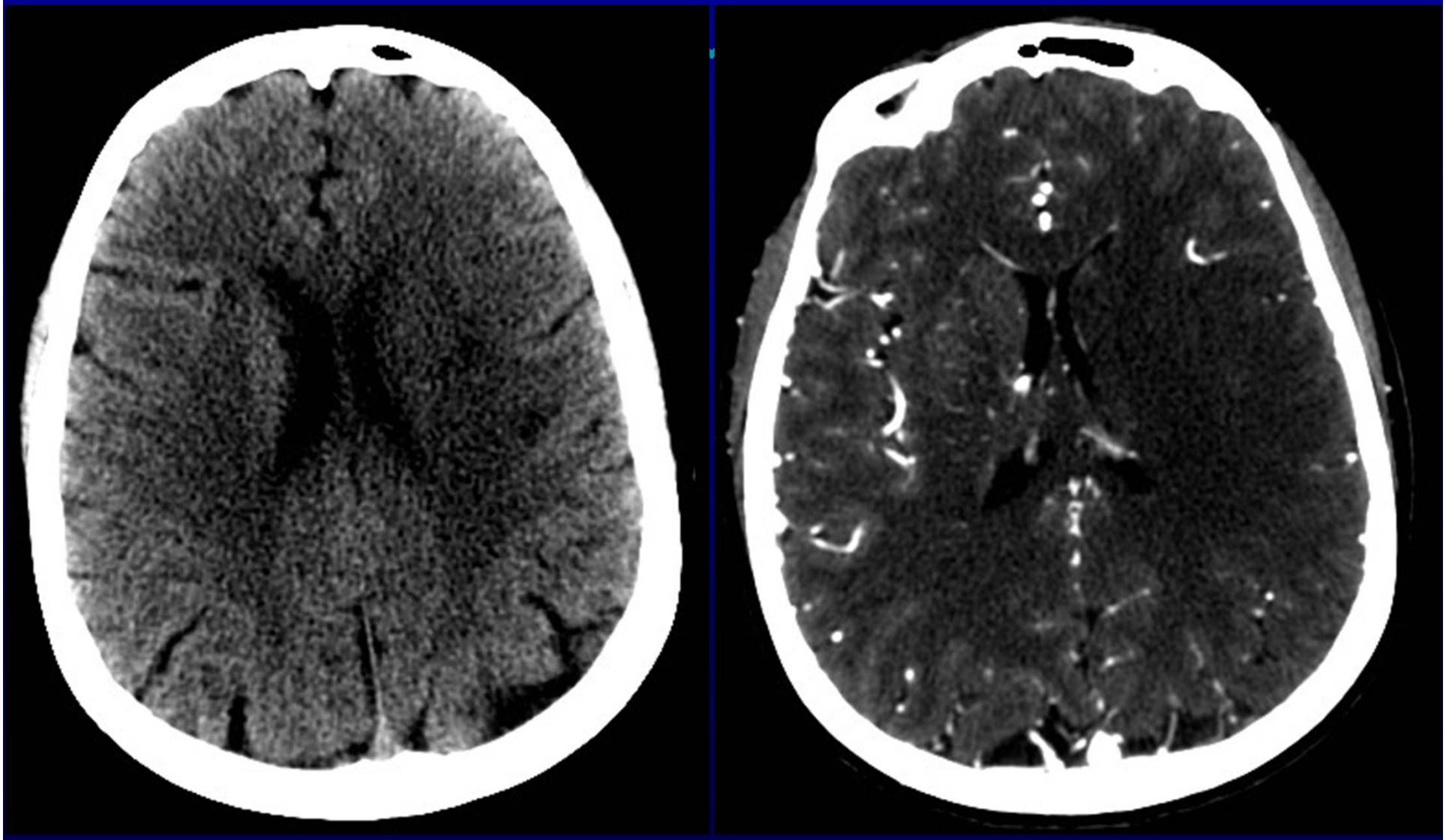
Courtesy of Dr. Gil González

Selection for IAT

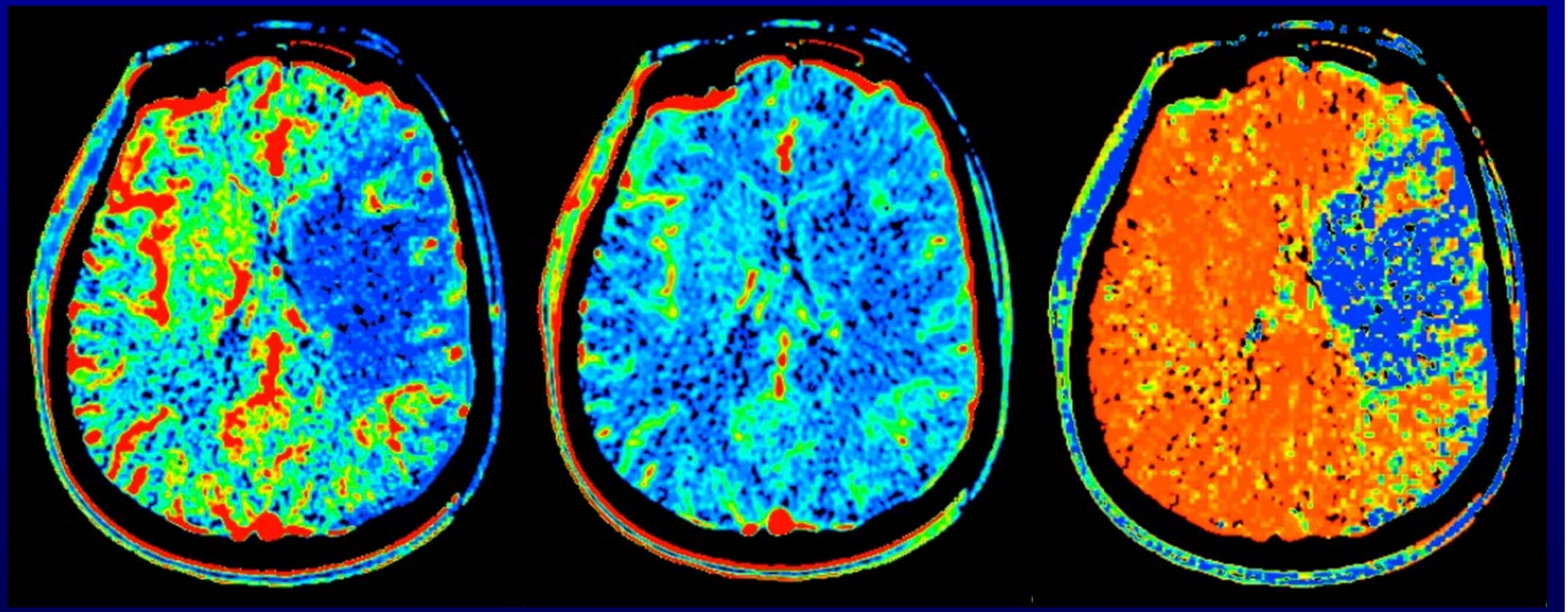
- PWI/DWI mismatch not discriminatory
- More important question: How much is dead on arrival ("core")?
- An acute infarct volume threshold of 70-100 ml has a high *specificity* for predicting a poor outcome[1,2]

[1]Sanak et al. *Neuroradiology* 2006; 48: 632-9
[2]Yoo et al. *Stroke 2009 Jun;40(6):2046-54*

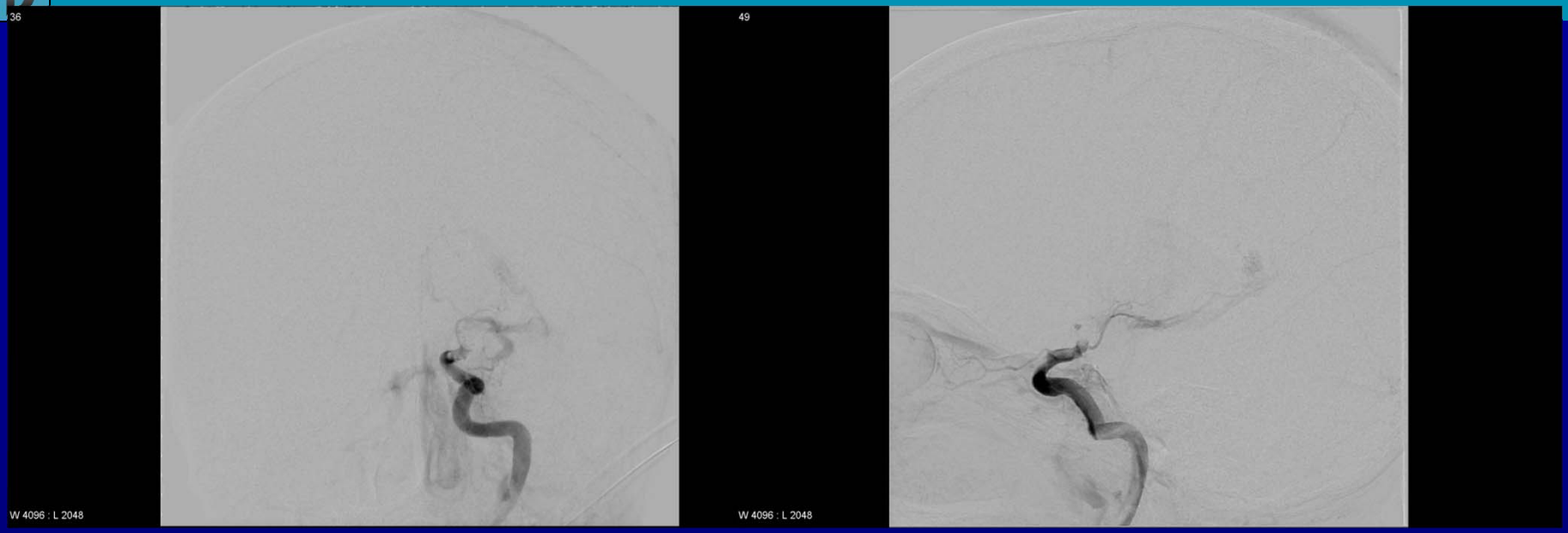
Example: Admission CT and CTA

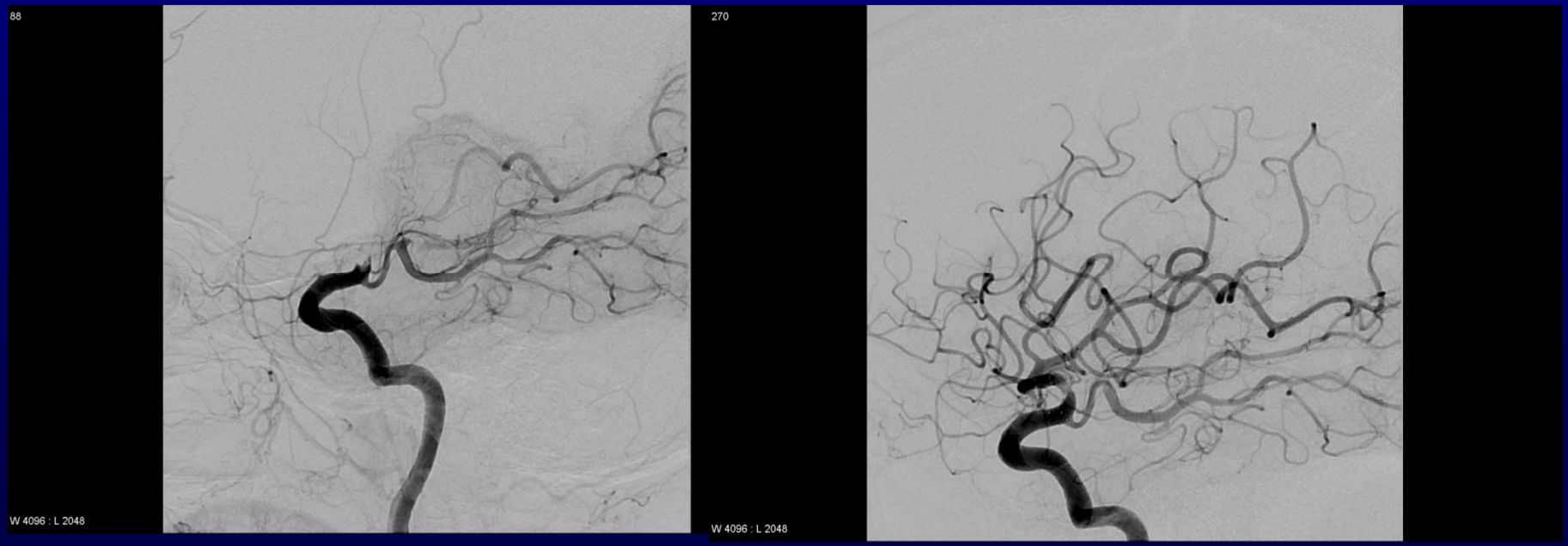


Admission CT Perfusion



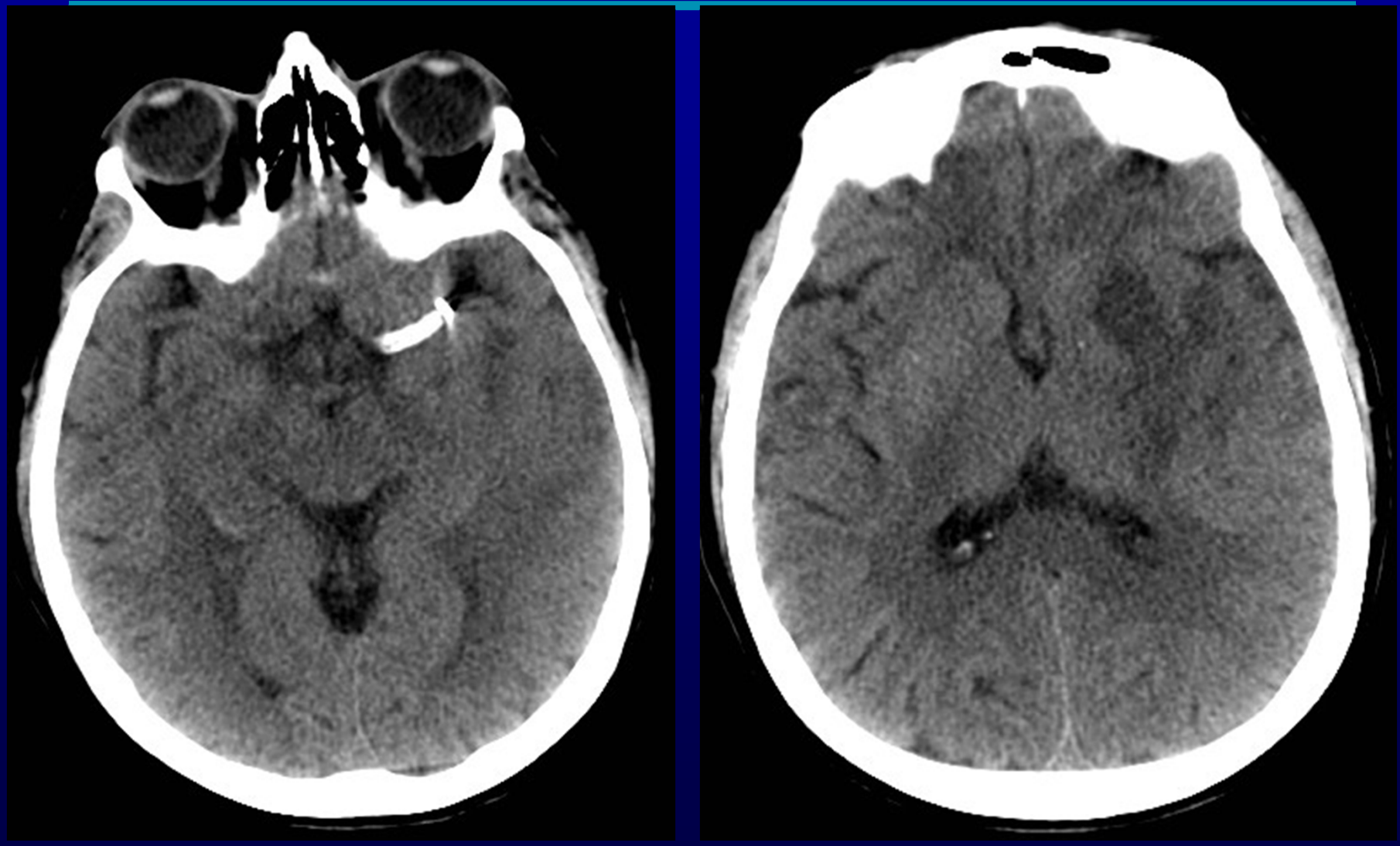
CBF CBV MTT


36
W 4096 : L 2048
49
W 4096 : L 2048

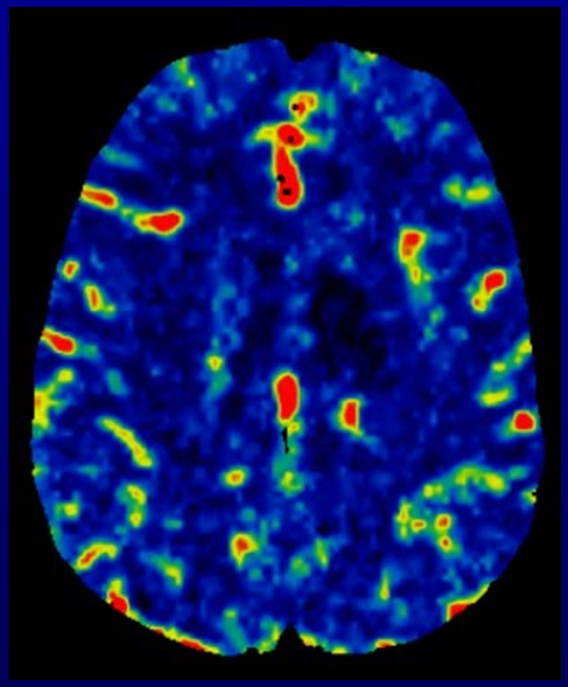

88
W 4096 : L 2048
270
W 4096 : L 2048

CTA Post Intra-arterial Tx

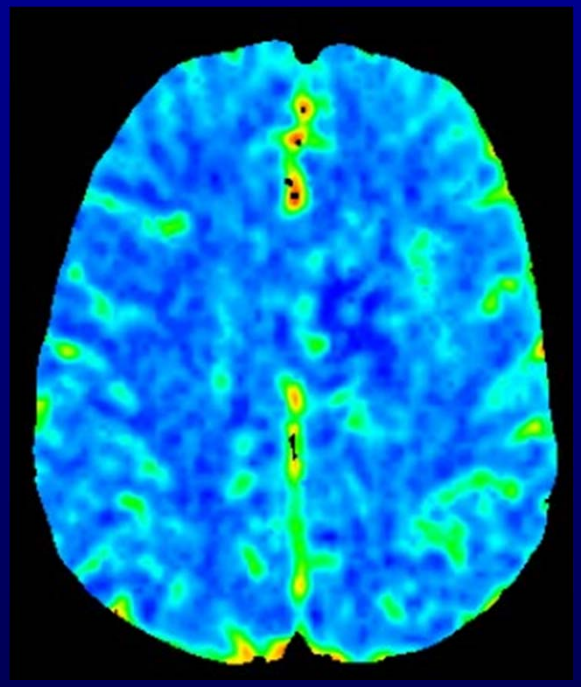
Post Intra-arterial Tx



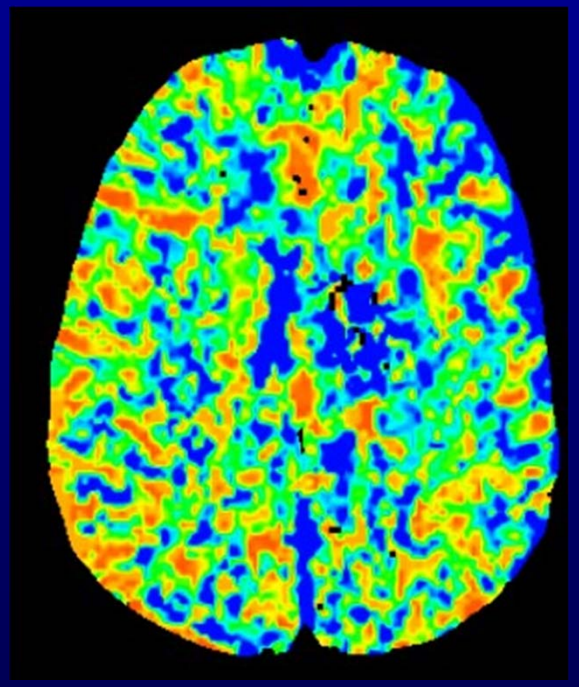
CTP Post Intra-arterial Tx



CBF



CBV



MTT

Conclusion

- CTP is exciting
  - "Time is muscle"
  - "Time is brain"
  - "Mismatch is brain"
- CTP is challenging
  - Many technologies
  - Low CNR and SNR
  - Potentially high dose
- The complexity can be managed
  - Use low kVP
  - Use low mAs
  - Use sufficient temporal resolution
  - Don't truncate the time opcification curve
  - Don't over-interpret CTP maps

Bottom Line

- Perfusion cannot replace DWI
- Perfusion shows the state of plumbing and not tissue viability
- When DWI is not available/feasible, in counjunction with other parameters, CTP can be used to guide decision making