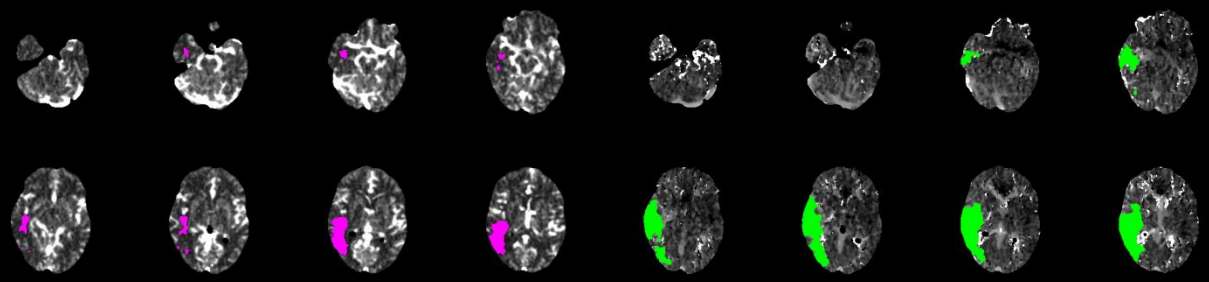
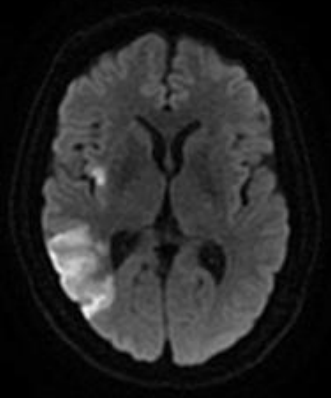
CT Perfusion Basics

Basic terms to know in stroke

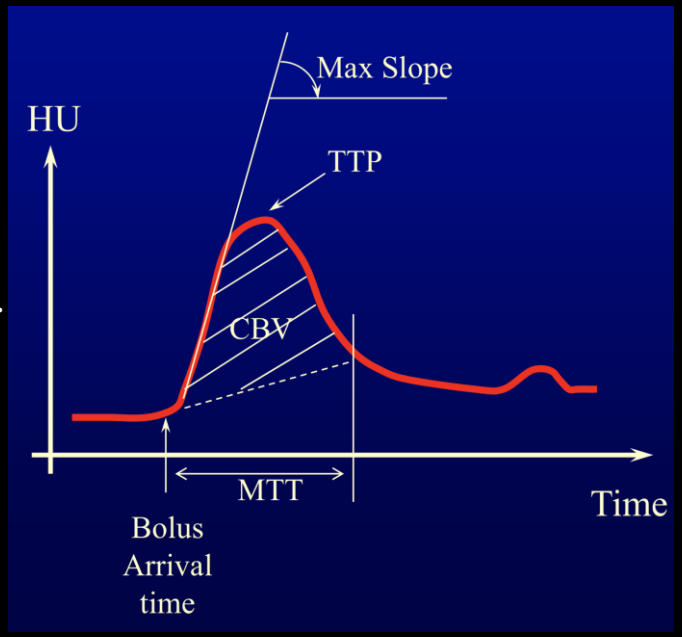
- Core
  - Infarcted brain, not salvageable
  - Depicted by reduction of cerebral blood flow (CBF) less than 30% of normal (CBF <30% volume in mL)
  - Essentially equivalent to area of diffusion restriction seen on MRI
- Penumbra
  - Hypoperfused brain at risk for progression to infarction, salvageable
  - Usually located around the ischemic core, and represents target of reperfusion therapy
  - Is represented by total area of hypoperfused brain MINUS infarcted core
  - Depicted by prolonged time it takes for contrast to reach and traverse areas of the brain. Most commonly used threshold in CTP is Tmax > 6s.





Basic terms to know in stroke

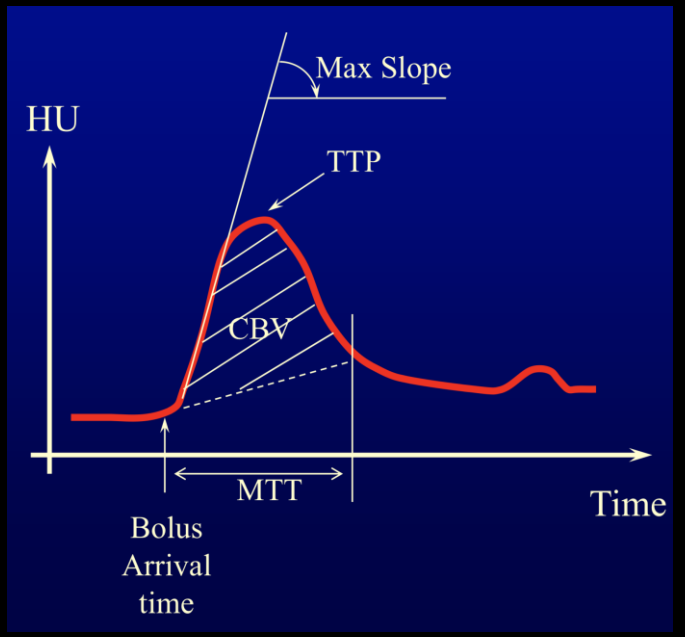
- Time to Peak (TTP)
  - Length of time in seconds to reach peak voxel enhancement
  - Indicator of delayed flow in the setting of stenosis or occlusion
  - Increased when abnormal
- Mean Transit Time (MTT)
  - Length of time in seconds for blood to move from arteries -> capillaries -> veins
  - Increase indicates vasodilatory response to reduced flow
  - MTT = CBV/CBF
- Time to maximum (Tmax)
  - Time at which maximum value of residue function occurs after deconvolution
  - Represents delayed arrival of contrast bolus



Tmax and CBF are the main parameters used to determine core and penumbra

Basic terms to know in stroke

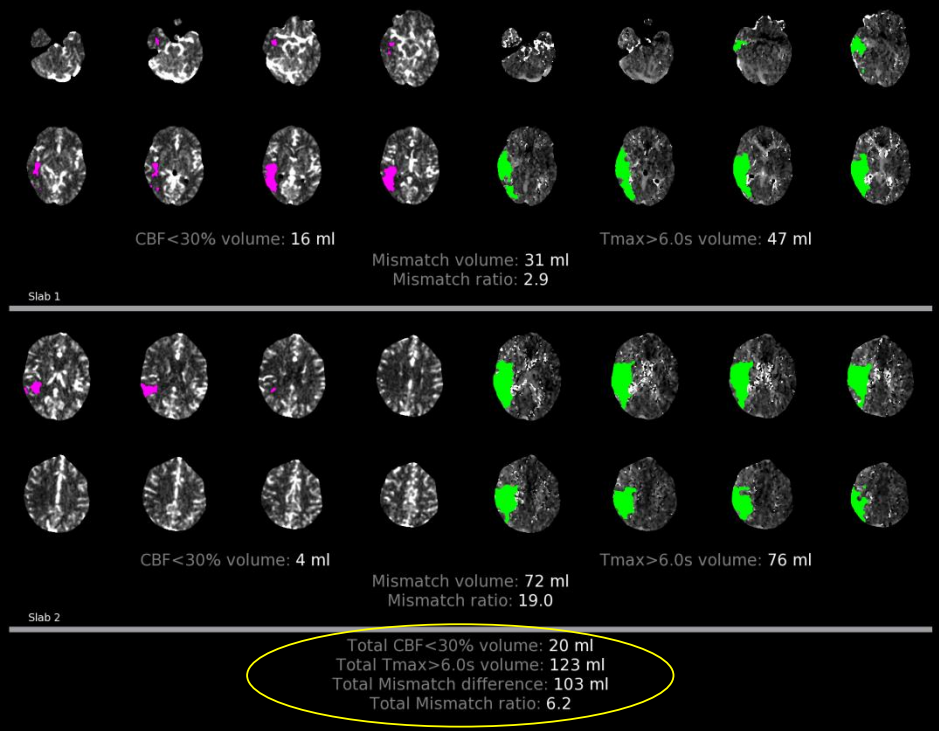
- Cerebral blood volume (CBV)
  - Volume flow rate through cerebral vasculature per unit time (ml/100g of brain tissue)
  - Penumbra may demonstrate normal or increased CBV with autoregulation
- Cerebral blood flow (CBF)
  - Amount of blood flowing through capillaries per unit time per unit tissue (ml/min/100g brain tissue)
  - Identifies areas of low blood flow (hypoperfusion)
  - Infarct core displays decreased CBF by <30%
- Mismatch Volume and Mismatch Ratio
  - Mismatch volume = Difference in volume between total hypoperfused area and core infarct, equals penumbra
  - Mismatch ratio = Ratio of total hypoperfused area and core infarct

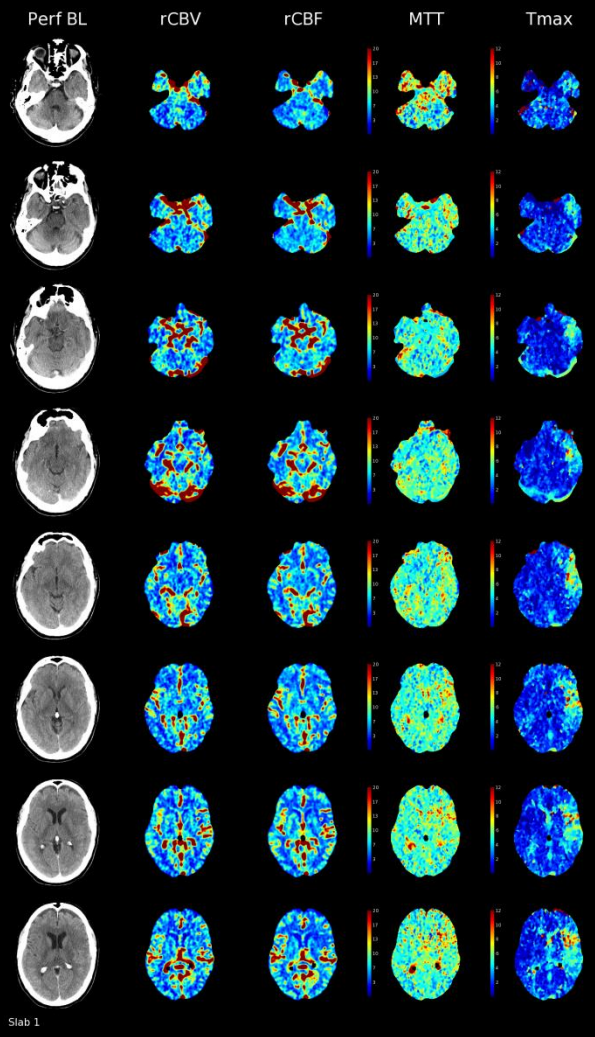


Tmax and CBF are the main parameters used to determine core and penumbra

What it looks like (RAPID software, update with Viz AI when have examples)

- Color maps corresponding to the 2 slabs obtained (below)
- Need to use the TOTAL values provided which sums the two slabs for better coverage
- Color maps also provided (right, different example), can help with assessing global picture





Questions to answer by CT

- Hemorrhagic versus ischemic stroke?
  - Noncontrast head CT
- Evidence of large vessel occlusion?
  - CT angiography
- What tissue is infarcted (core) and what is salvageable (penumbra)?
  - CT perfusion

Performance of CT Perfusion

- Monitor first pass of contrast bolus through cerebral circulation
  - Usually performed at 2 separate slabs to maximize coverage with first slab parallel to and just above the orbital roof, and the second more superiorly to avoid any overlap in slabs
  - Power injection at between 4-7 mL/sec
- CT angiography is then performed with additional bolus of contrast
- CT perfusion software analyzes data and generates color maps and outputs values
  - Usually a threshold HU below which the software does not include as an area of hypoperfusion to avoid counting prior infarcts/encephalomalacia in calculations

Sample dictation template

EXAM: [Procedures].
DATE: [Order Date].

INDICATION: [Reason For Study]
COMPARISON: [Field 2]
TECHNIQUE: CT perfusion was performed utilizing a total of [contrast volume] mL Omnipaque 350 intravenous contrast injection rate 5 mL/s. A total of 8 cm of brain coverage was used for the CTP study. The images were processed using [software] software.

FINDINGS:

TOTAL HYPOPERFUSION: Using the threshold of Tmax greater than 6 seconds, there is an area of hypoperfusion in the [side] MCA territory with a total volume of hypoperfusion of [Tmax > 6s volume] mL.

CORE INFARCT: Using the threshold of CBF less than 30%, there is an area of ischemic core in the [side] MCA territory with a total volume of ischemic core of [CBF <30% volume] mL.

PENUMBRA: The penumbra volume (mismatch volume) is [mismatch volume]. The mismatch ratio is [mismatch ratio].

IMPRESSION:

Hypoperfusion in the [side] MCA territory with a central ischemic core of [CBF <30% volume] mL, total volume of hypoperfusion of [Tmax > 6s volume] mL, and penumbra of [mismatch volume] mL.

Target values for reperfusion

- May be in constant evolution and not strictly defined
  - Ischemic core volume < 60-70 mL
    - May vary depending on location of infarct and patient age with desired aggressiveness
  - Mismatch ratio > 1.8
  - Mismatch volume ≥ 15 mL

Pitfalls

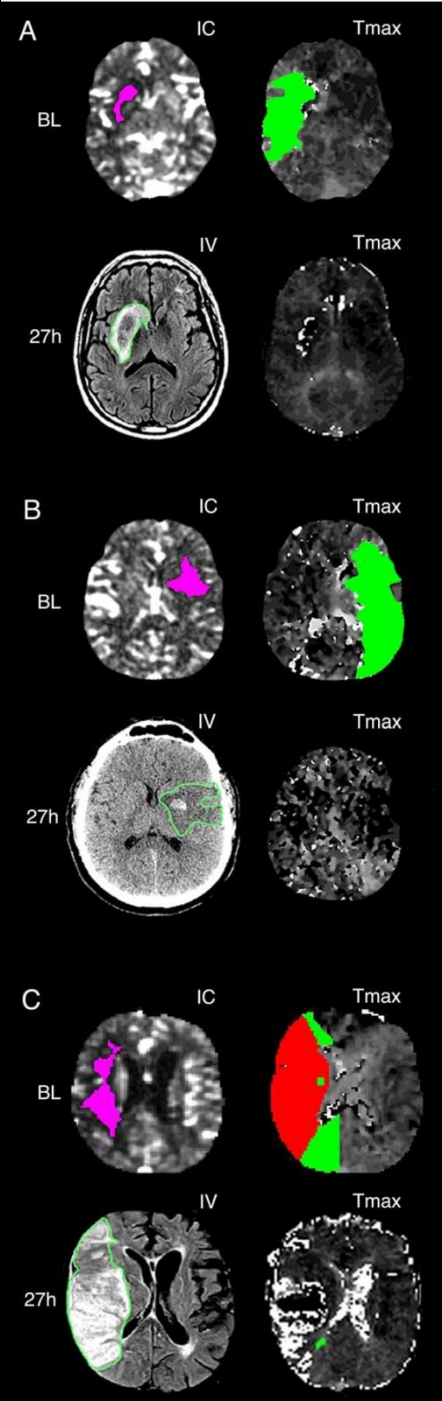
- Underprediction of final infarction by core

Examples where 27-hour infarct volume is larger than predicted infarct volume.

(A) The baseline core is 14ml (pink); following complete reperfusion, the 27-hour infarct volume is 45ml (green outline) and demonstrates hemorrhagic transformation.

(B) The baseline core is 10ml (pink); following complete reperfusion, the 27-hour infarct volume (green outline) is 47ml and has hemorrhagic transformation.

(C) Example of the malignant profile. The baseline core is 24ml (pink) and the Tmax>10-second volume (shown in red) is 177ml. Following 98% reperfusion, the 27- hour infarct volume (green outline) is 269ml. IC ischemic core; IV infarct volume



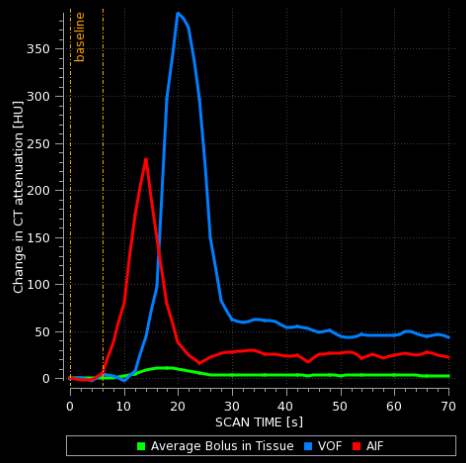
Albers, Gregory W., et al. "Ischemic core and hypoperfusion volumes predict infarct size in SWIFT PRIME." *Annals of neurology* 79.1 (2016): 76-89.

Pitfalls

- Core infarct may not show up if there is later recruitment of collateral vessels from ACA and PCA (“futile leptomeningeal perfusion”)
- If imaging patients very early (within an hour) after stroke, the volume of core infarct may be substantially overcalled at a CBF <30% threshold. Within an hour of stroke, a CBF <20% threshold may be more appropriate (not used in current practice)
- Understand that areas of brain with HU under a certain threshold (approaching CSF density) will not be counted as core infarct, assumed to represent encephalomalacia
- Software may only include lesions greater than 3 mL on mismatch maps so lacunar infarcts may not show up. They may be visible on the global color maps if provided.

Pitfalls

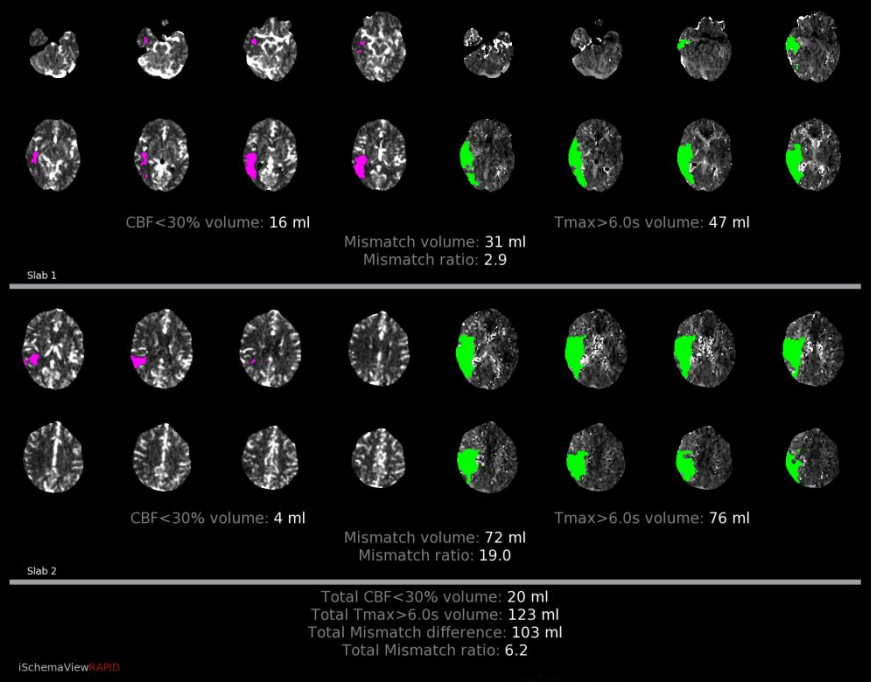
- AIF (arterial input function) and VOF (venous output function)
  - AIF often placed on A2 segment of anterior cerebral artery due to its course and easy visualization on multiple axial images. The MCA is often used as well.
  - VOF often placed on superior sagittal sinus
  - Inappropriate placement of either can give appearance of global perfusion abnormality or other abnormality
  - If images or numbers don't look right, verify placement of AIF and VOF and look at time curves
    - Make sure there is good bolus and curves have sharp upstroke
    - If there are a lot of jagged lines in the curves, it is suggestive of movement
  - Make sure that there is no truncation of the curves (stopped scanning too early)

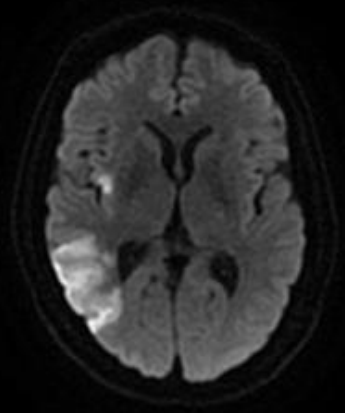


Good AIF and VOF placement and curves

Case 1

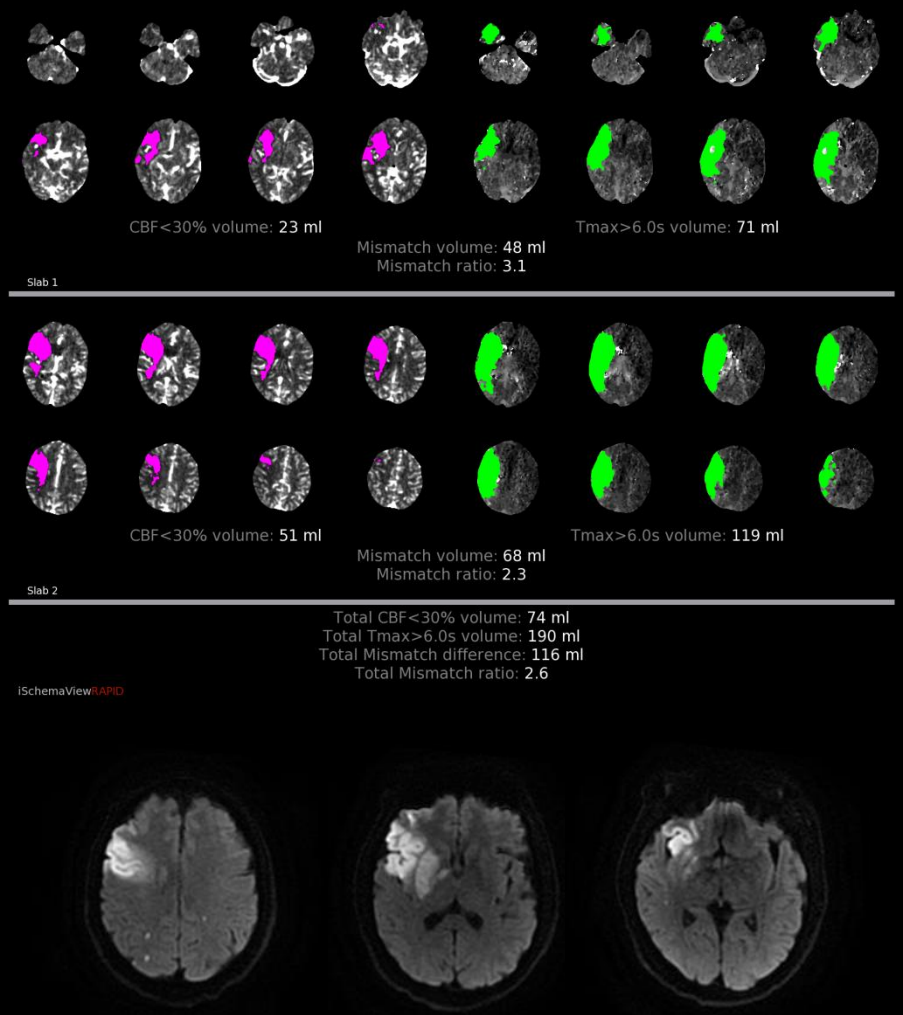
- CT perfusion shows area of hypoperfusion in right MCA territory with total volume of 123 ml, core of 20 mL, and penumbra of 103 mL
- Patient underwent successful RICA angioplasty and R MCA thrombectomy
- Followup DWI MRI closely matches initial area of core infarct seen on CT perfusion, with sparing of some of penumbra area





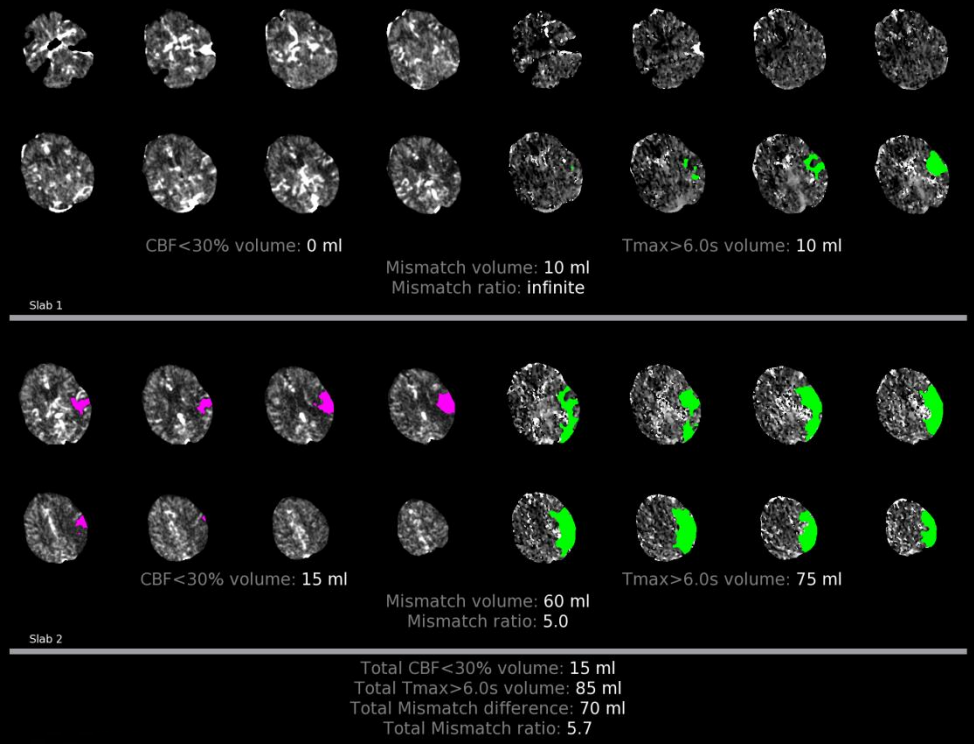
Case 2

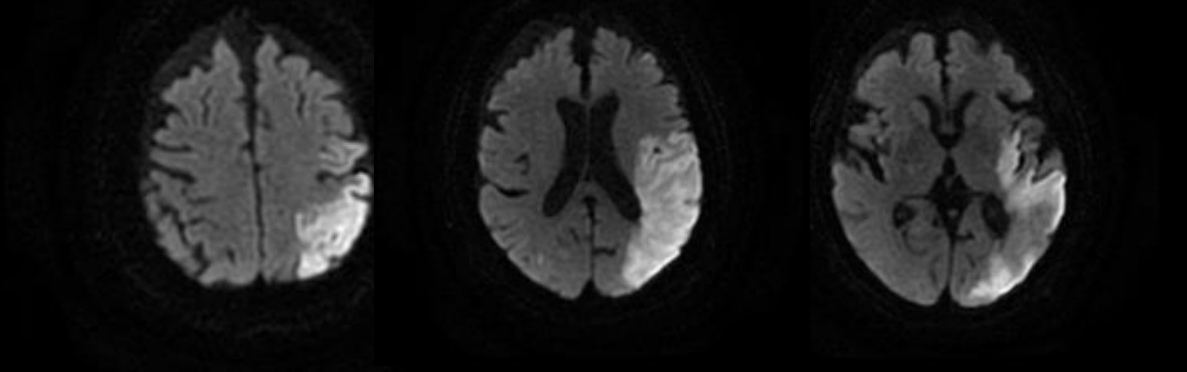
- CT perfusion shows area of hypoperfusion in right MCA territory with total volume of 190 mL, core volume of 74 mL, and penumbra of 116 mL
- Patient underwent successful RICA and R MCA thrombectomy
- Followup DWI MRI closely matches initial area of core infarct seen on CT perfusion, with sparing of much of penumbra area



Case 3

- CT perfusion shows area of hypoperfusion in left MCA territory with total volume of 85 mL, core infarct of 15 mL, and penumbra of 70 mL
- Attempted left MCA thrombectomy was unsuccessful
- Followup DWI MRI shows infarct closely resembles initial CT perfusion area of penumbra which has progressed to infarct





Summary

- Total hypoperfused brain volume
  - Volume of brain with Tmax > 6 sec
  - Equivalent to infarct core PLUS surrounding penumbra
- Infarct core volume
  - Volume of brain demonstrating CBF < 30%
  - Non-viable/non-salveagable brain
- Penumbra volume
  - Total hypoperfusion volume MINUS core volume
  - Equals mismatch volume
  - Potentially salveagable brain