



中華民國醫事放射學會

Taiwan Society of Radiological Technologists (TWSRT)

MRI
Lecture 2

ASL、Perfusion MRI 原理與介紹

台北醫學大學 一部立雙和醫院
影像醫學部 醫學物理師 李宜恬

2017.04.16

國泰

Brain Perfusion Imaging

- The information on the capillary microcirculation of tissue
- Quantitative measurement
 - **Blood volume**
 - **Blood flow**
 - **Temporal data (transit time and time to peak)**
- Two major techniques
 - **Dynamic-susceptibility-contrast (DSC) MRI**
 - **Arterial spin labeling (ASL) MRI**



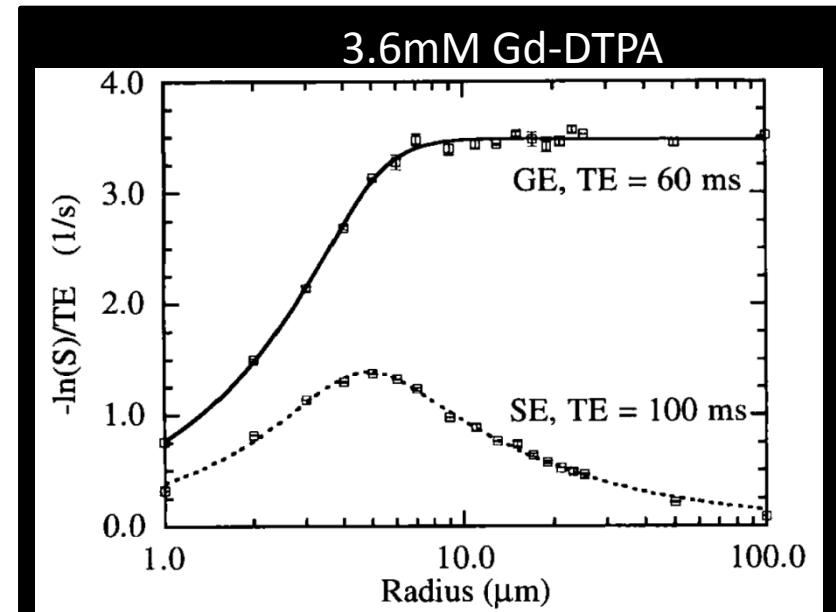
Techniques of Brain Perfusion

- **Dynamic susceptibility-contrast MRI (DSC)**
 - CBF/ CBV/ MTT/ K_2
- **Dynamic contrast-enhanced MRI (DCE)**
 - CBF/ PS/ v_p / v_e
- **Arterial spin labeling (ASL)**
 - CBF



DSC MRI

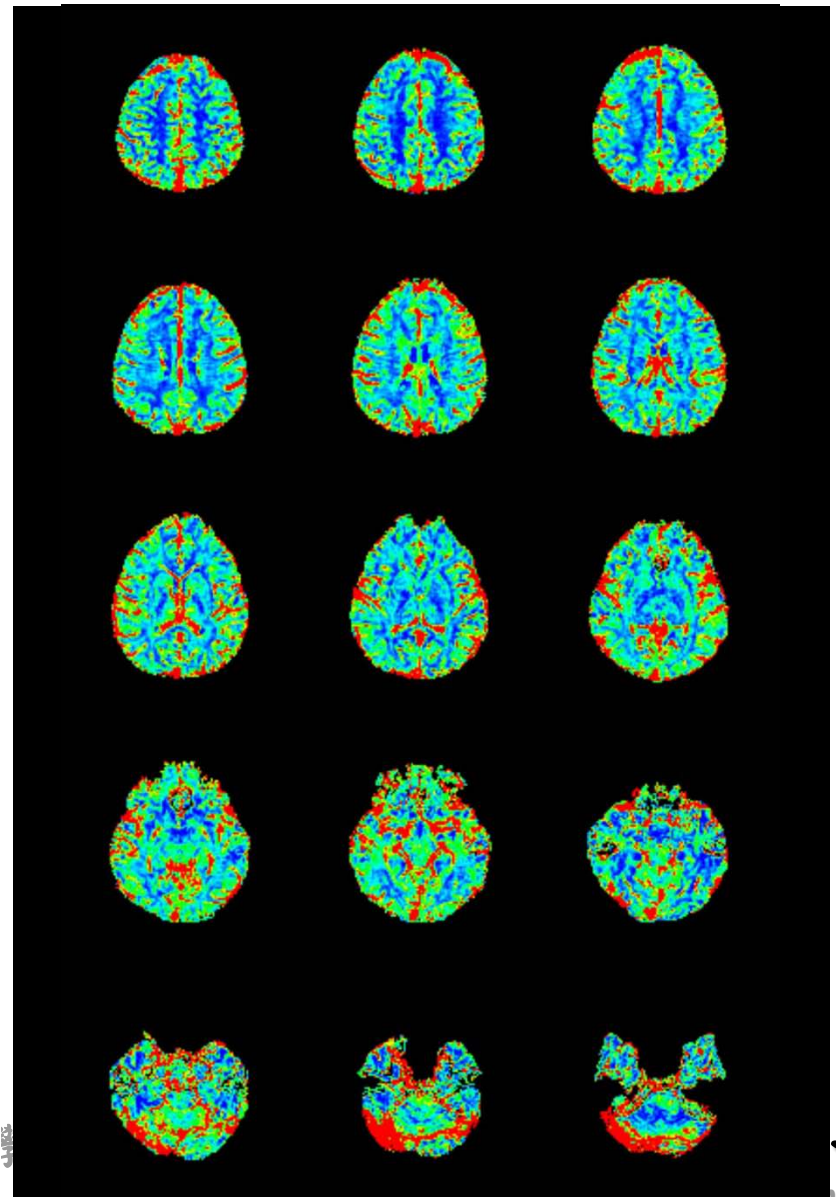
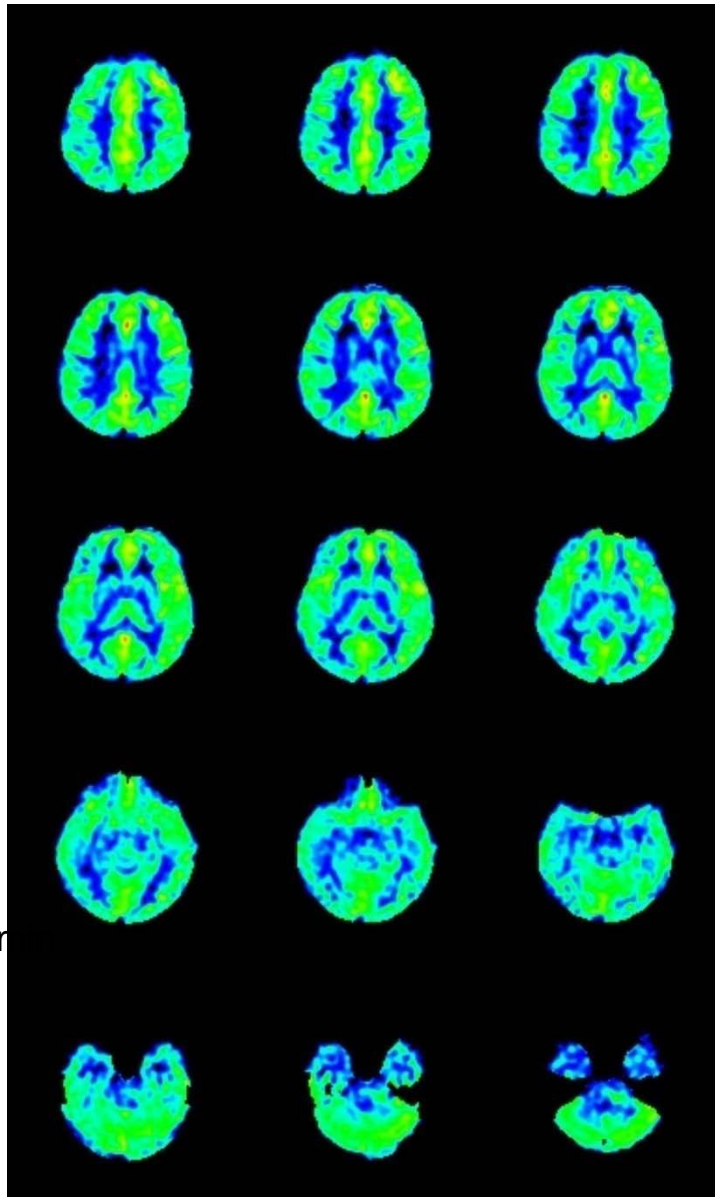
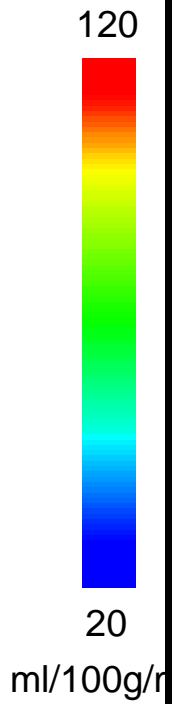
- **T₂/T₂* weighted imaging**
 - T₂*W DSC-MRI is sensitive to large vessels.
- **Bolus tracking**
 - Paramagnetic tracer
 - e.g. Gadolinium chelate
- **Fast imaging**
 - GE-/SE-EPI
 - FLASH (SPGR)
 - Fast spin echo, etc



Boxerman et al., MRM 1995

3D ASL

GE-DSC

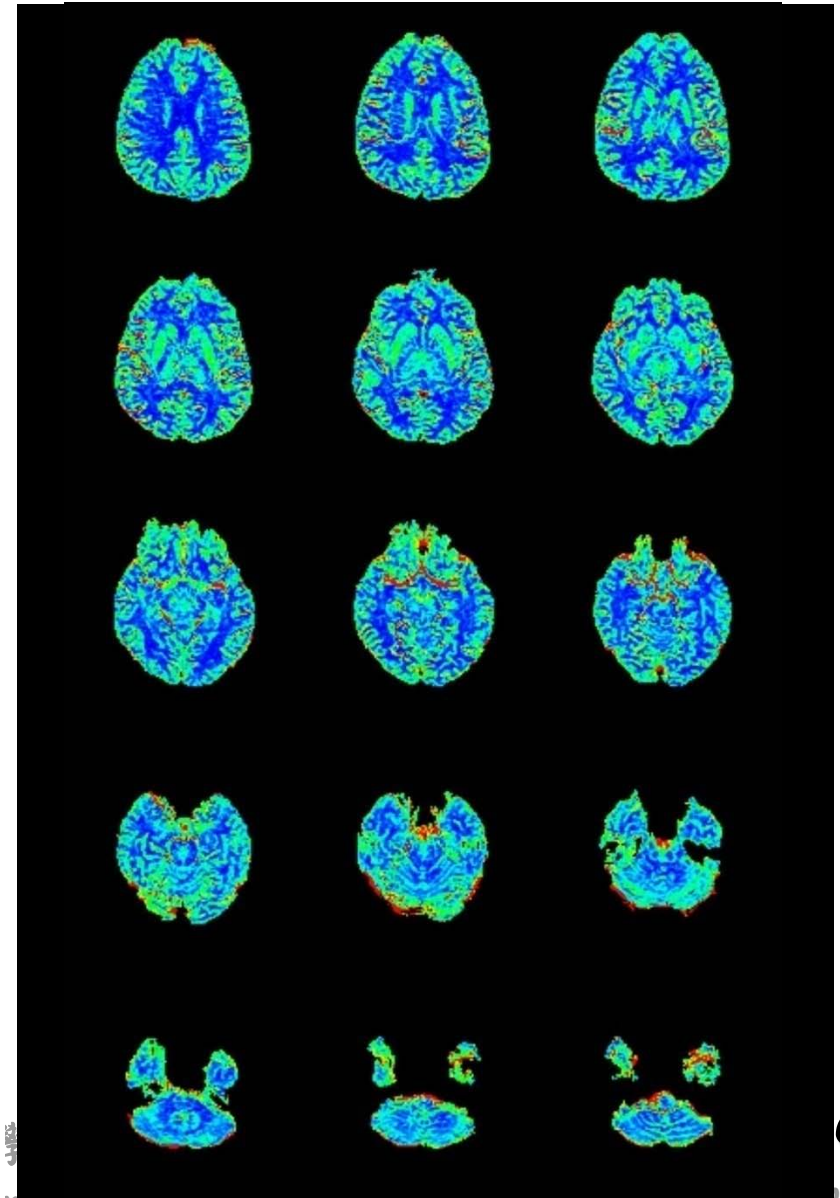
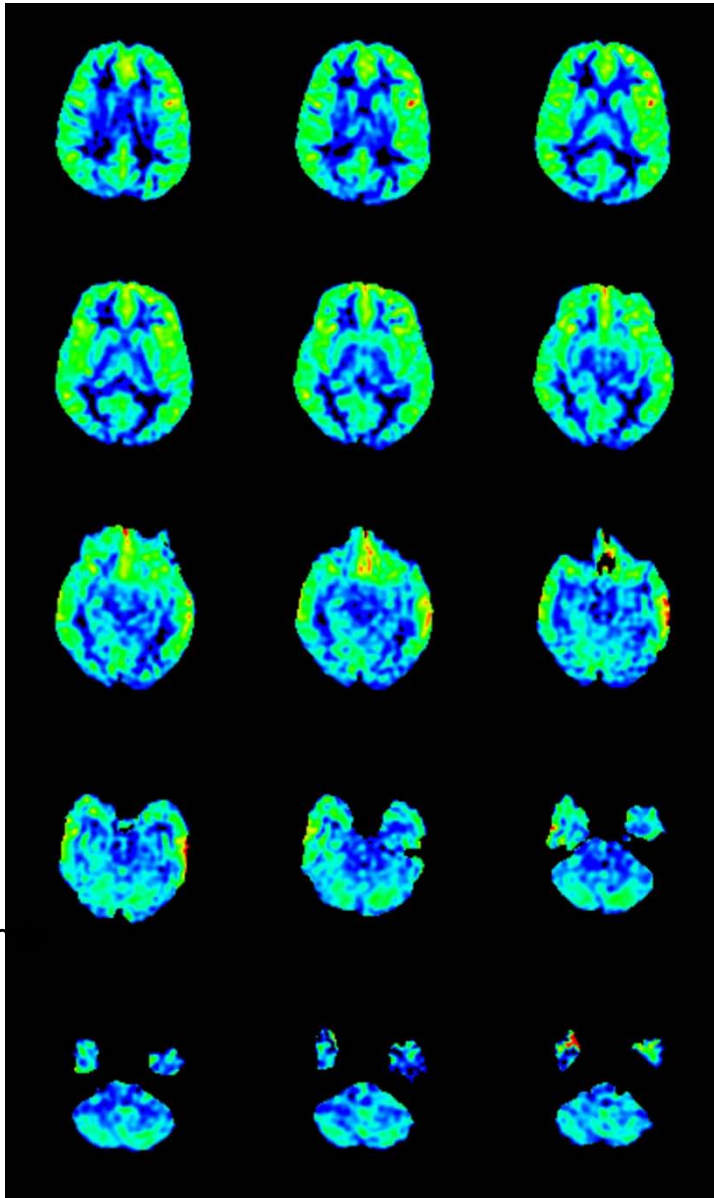
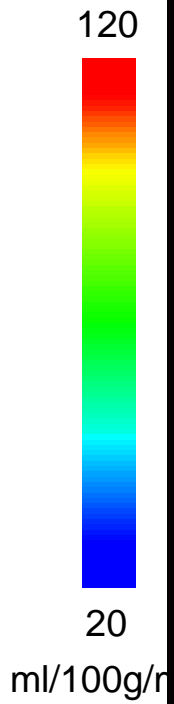


R

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3D ASL

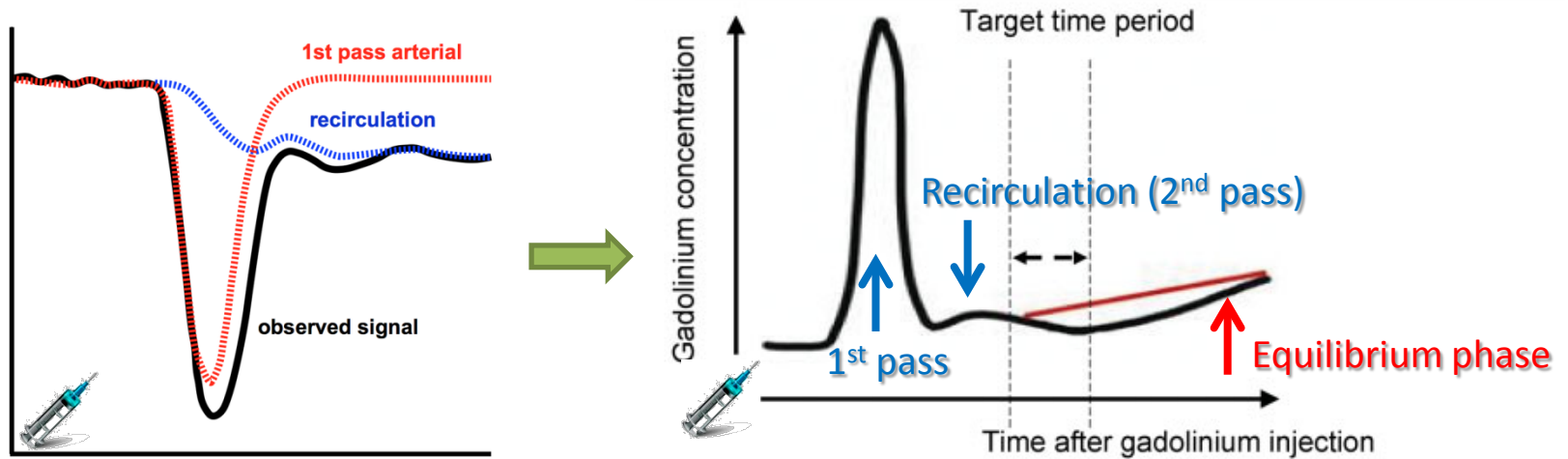
SE-DSC



R

6

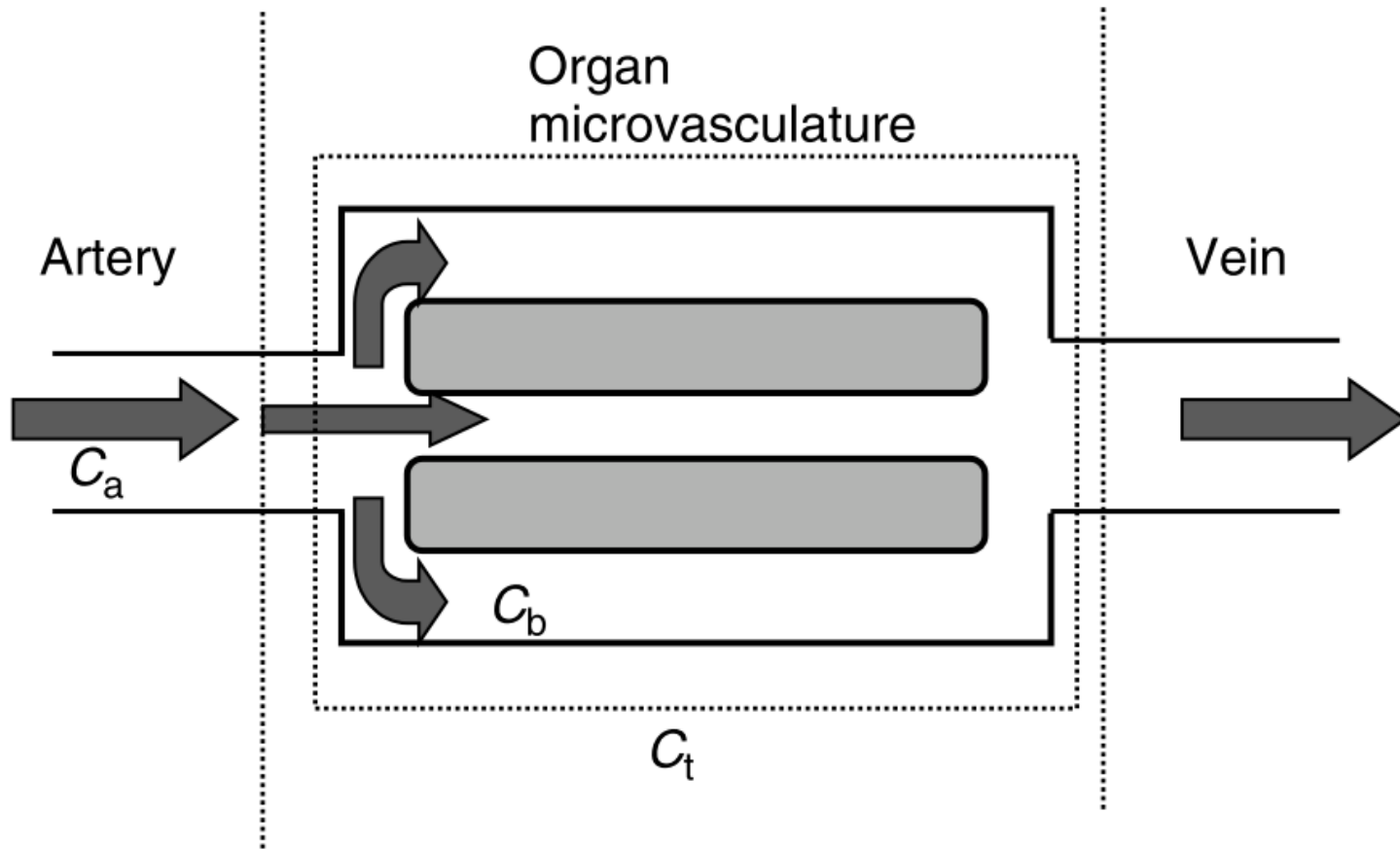
DSC MRI



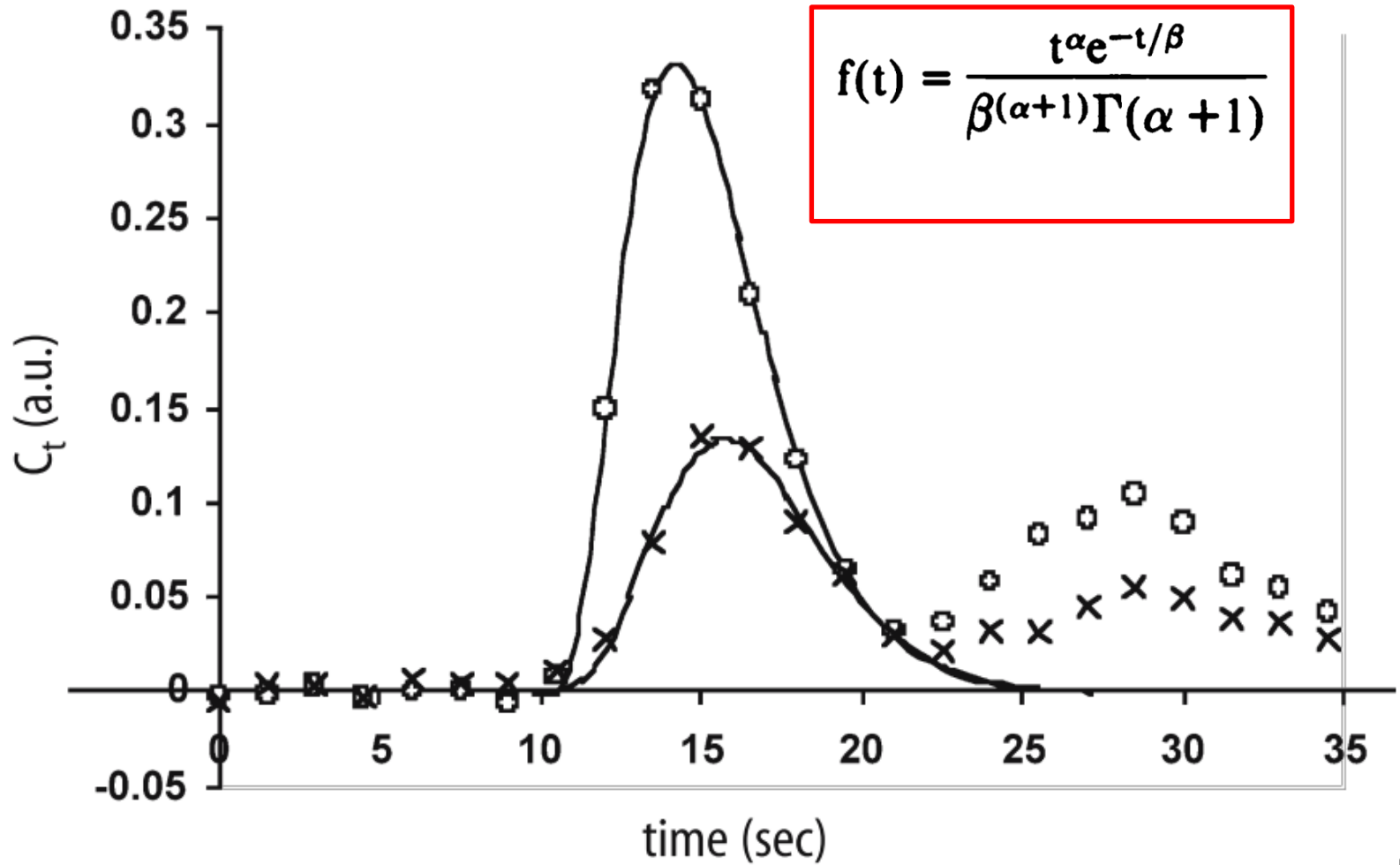
$$c_i(t) \propto \Delta R2^* = -\frac{1}{TE} \cdot \ln\left(\frac{S(t)}{S_0}\right)$$

Bang et al., Ann Neurol 2007;62:170–176

Tracer Kinetics



First-pass Fitting

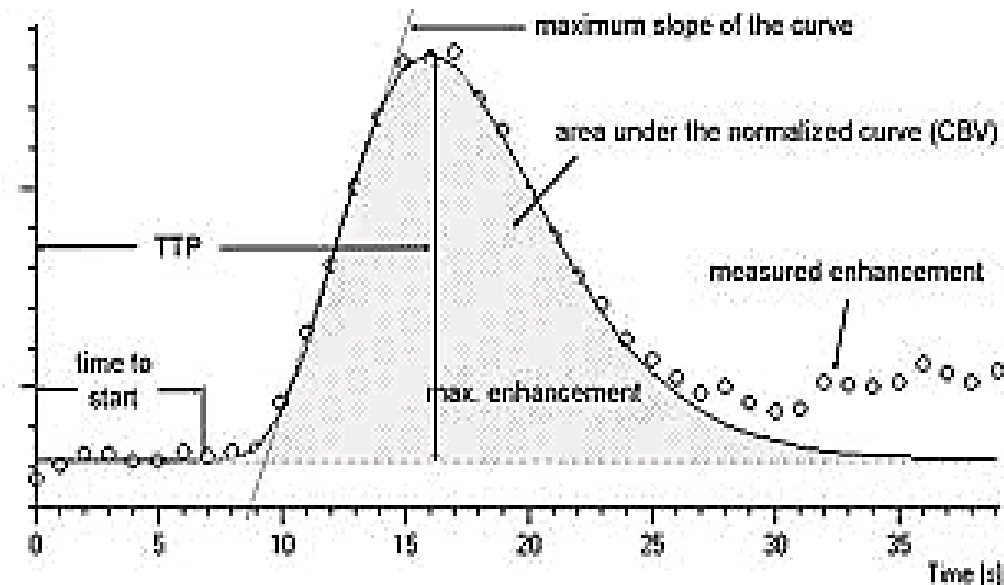
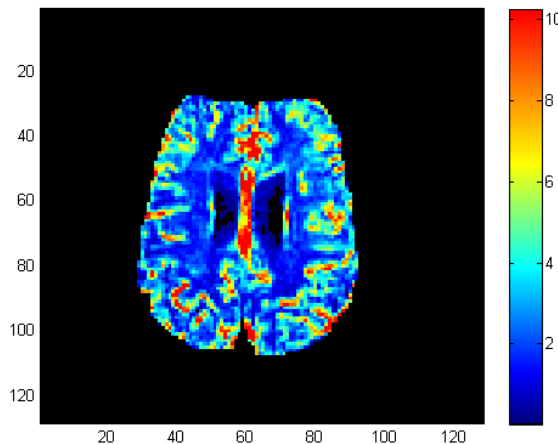


CBV

$$CBV = \frac{K_H}{\rho} \cdot \frac{\int_0^{\infty} c_i(t) dt}{\int_0^{\infty} c_a(t) dt}$$

VOF : Venous output function

- Cerebral Blood Volume
- Describes the blood volume of the cerebral capillaries and venules per cerebral tissue volume.
- Unit: % or ml/100g



Tomandl et al © RSNA, 2003 May-June

影像醫學部 醫學物理師 李宜恬

Department of Radiology, Medical Physicist, Yi-Tien Li (MSc)

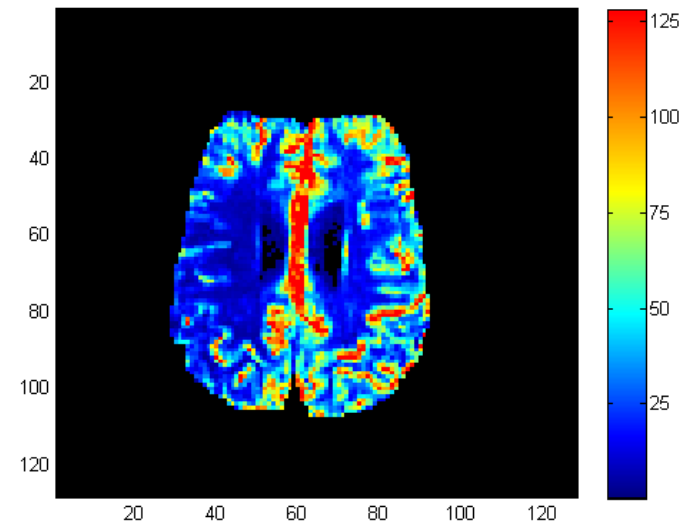




CBF

$$C_t = AIF(t) \otimes [CBF \cdot R(t)]$$

- Cerebral Blood Flow
- Represents instantaneous capillary flow in tissue.
- Unit: **ml/ 100g/ min**

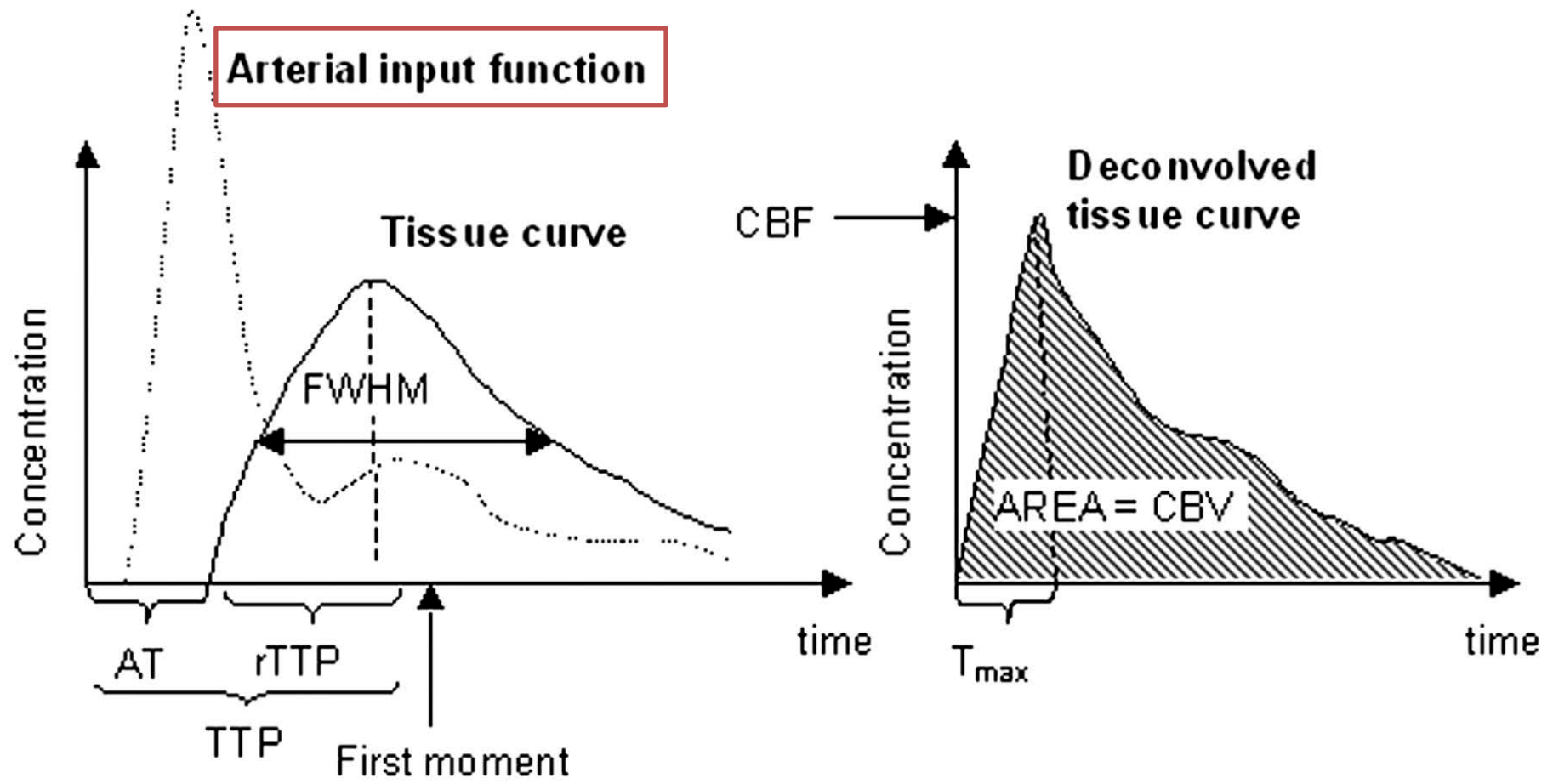


Hjort N et al. *Stroke*. 2005;36:388-397



CBF

$$C_t = AIF(t) \otimes [CBF \cdot R(t)]$$



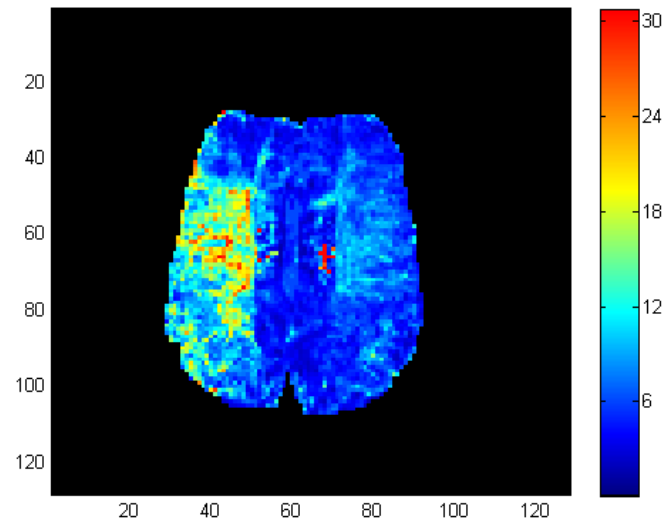
Hjort N et al. *Stroke*. 2005;36:388-397



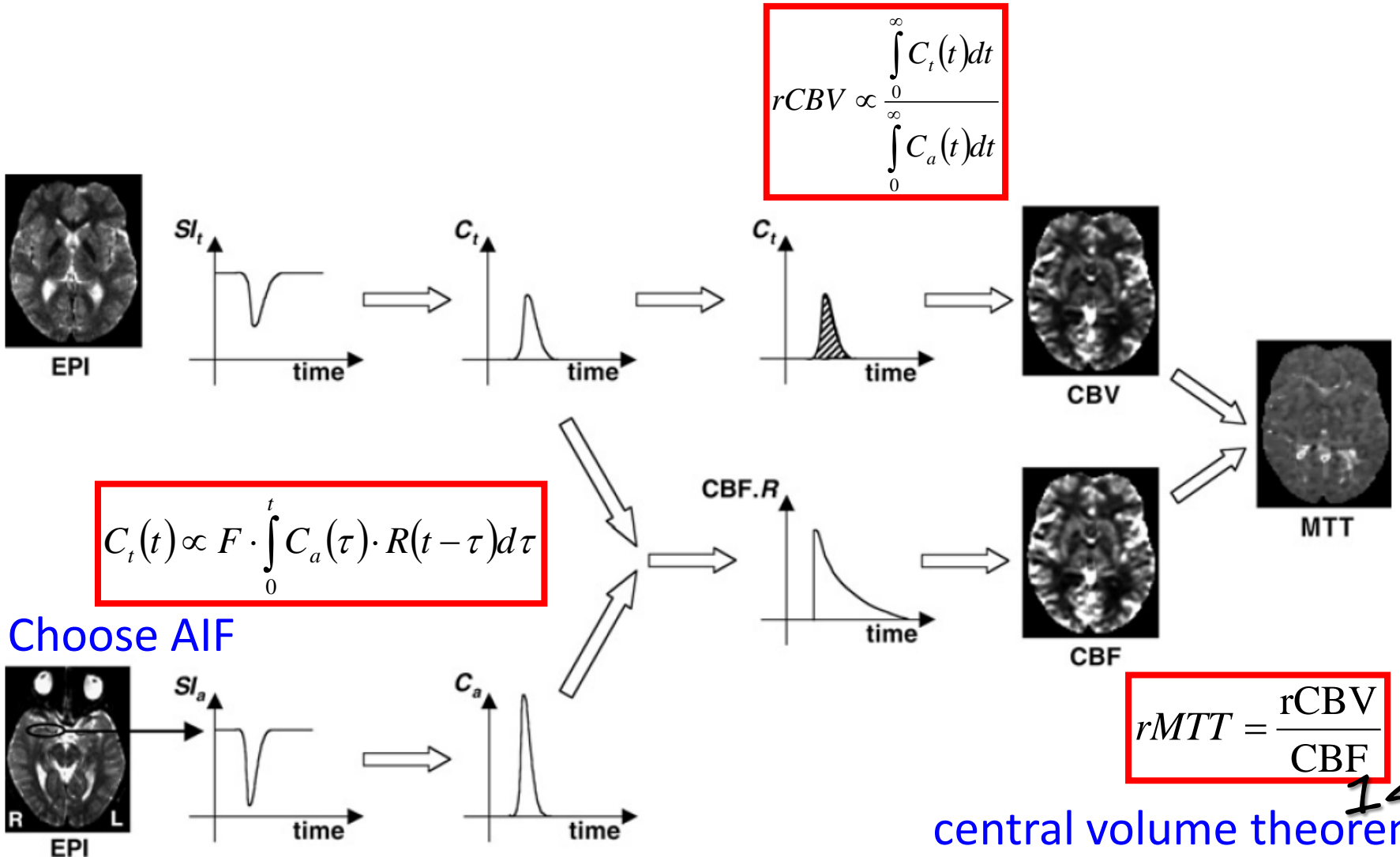
$$MTT = CBV / CBF$$

MTT

- Mean Transit Time
- Measures the length of time a certain volume of blood spends in the cerebral capillary circulation.
- Unit: **min or s**
- **$MTT = CBV / CBF$**



Procedure of Analysis



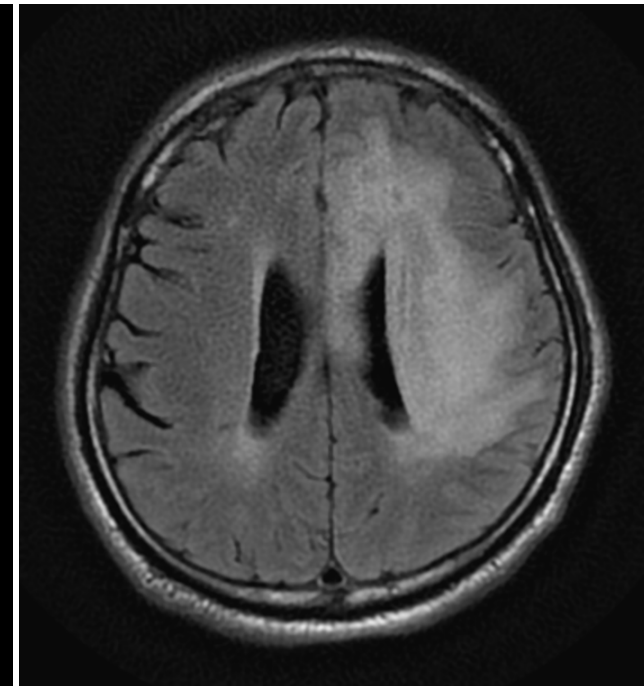
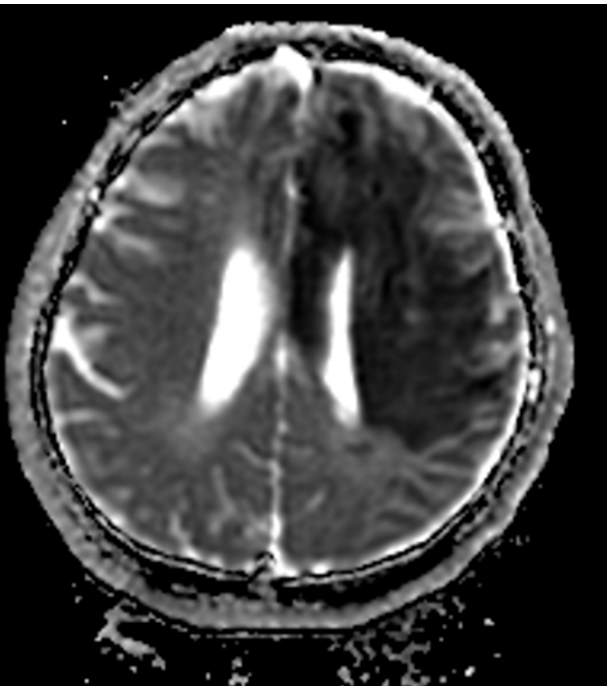
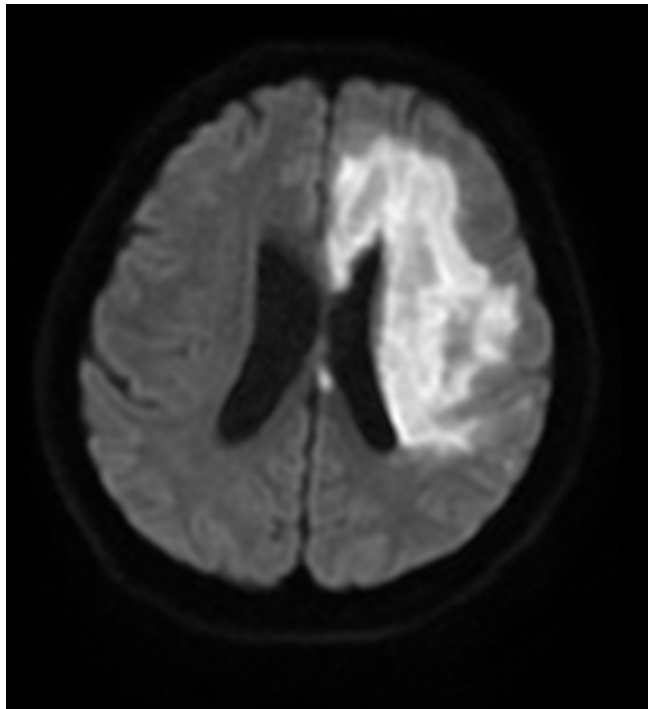


SHH Case: 吳○耀 092XX024

DWI

ADC

T2 Flair





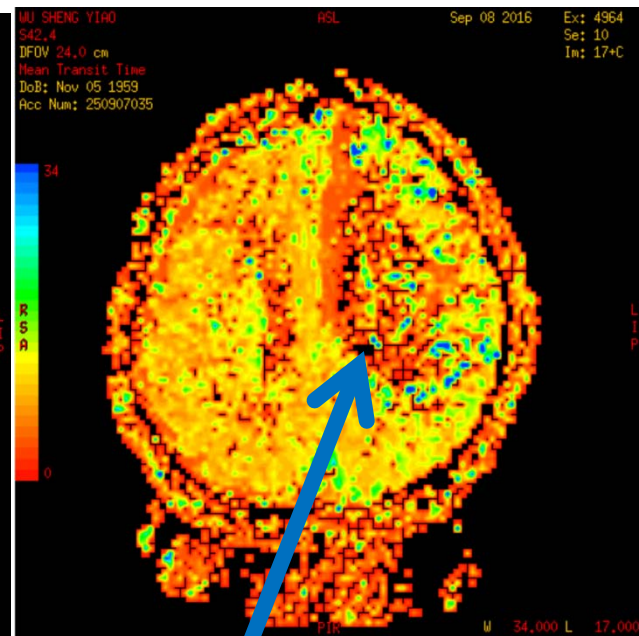
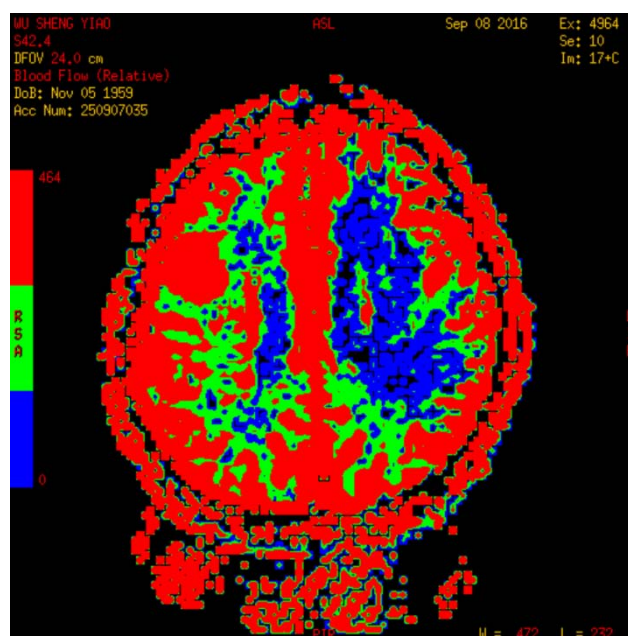
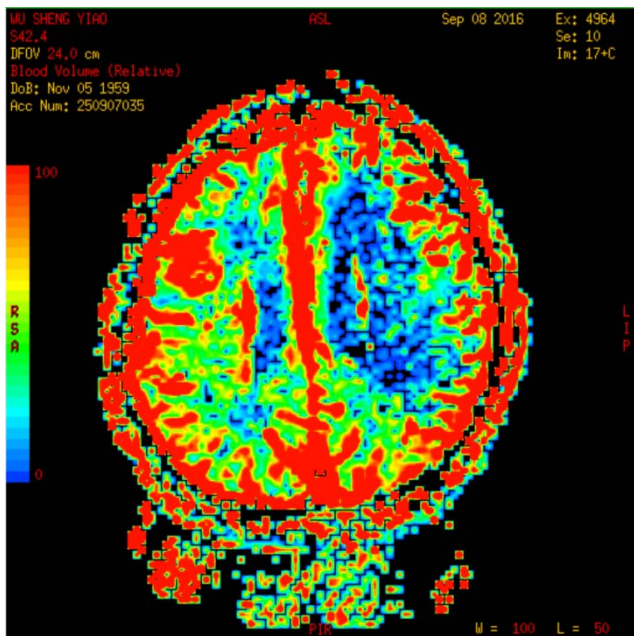
SHH Case: 吳○耀 092XX024

* GE perfusion post-processing tool:

CBV

CBF

MTT



MTT Shorten??? ¹⁶





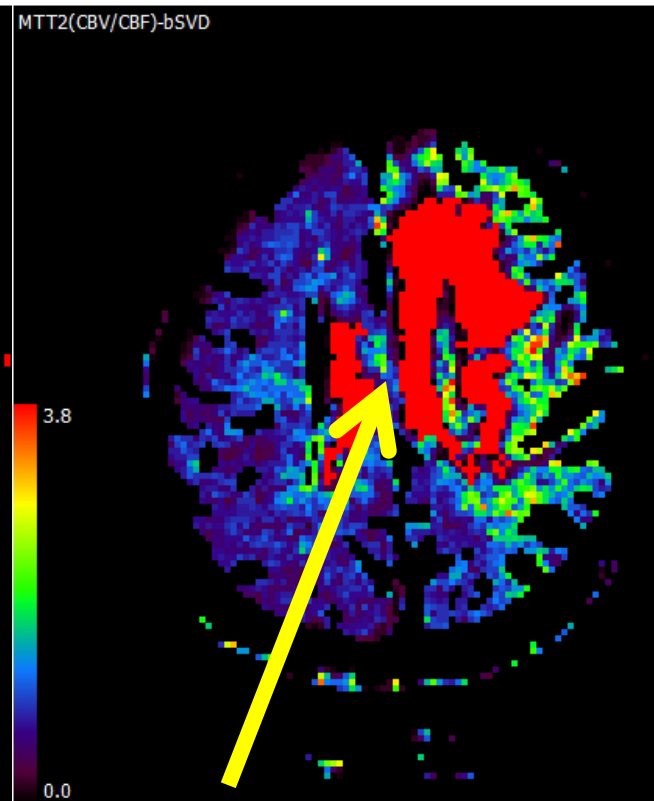
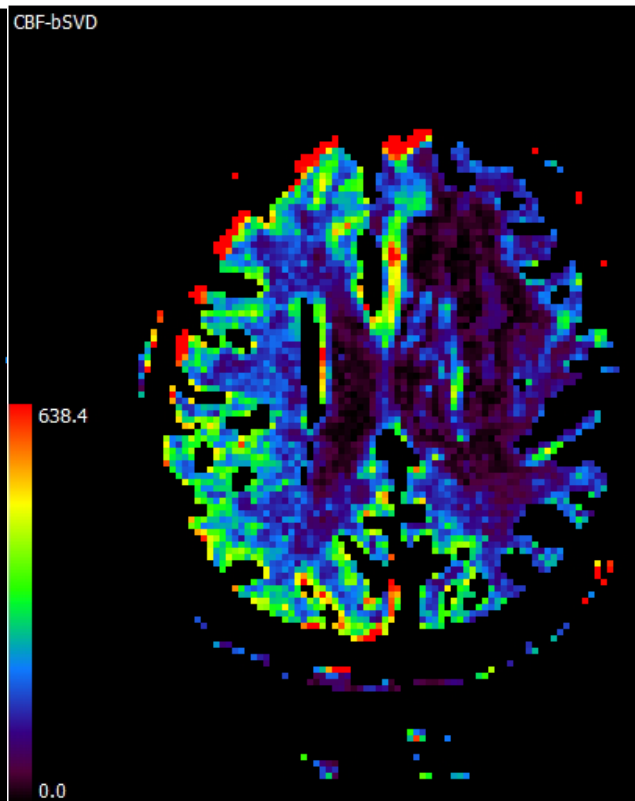
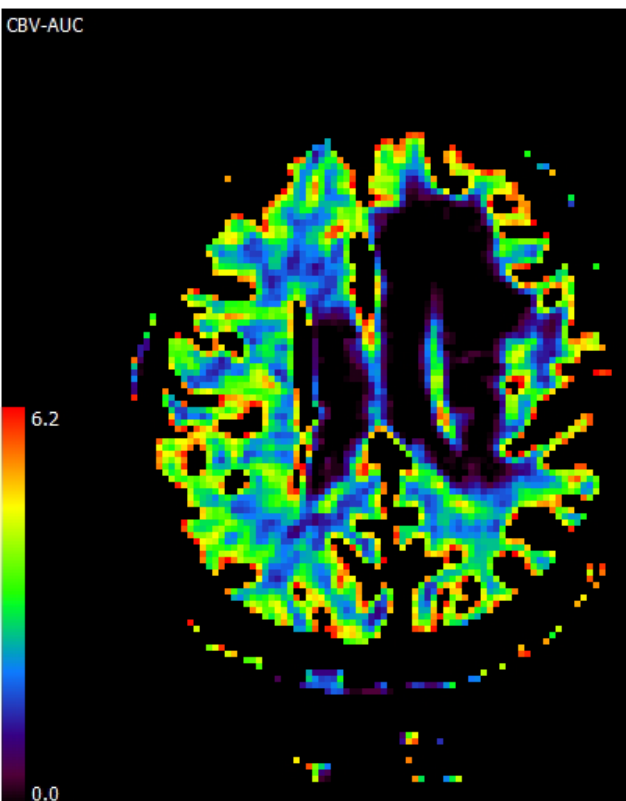
SHH Case: 吳○耀 092XX024

* PMA toolbox:

CBV

CBF

MTT



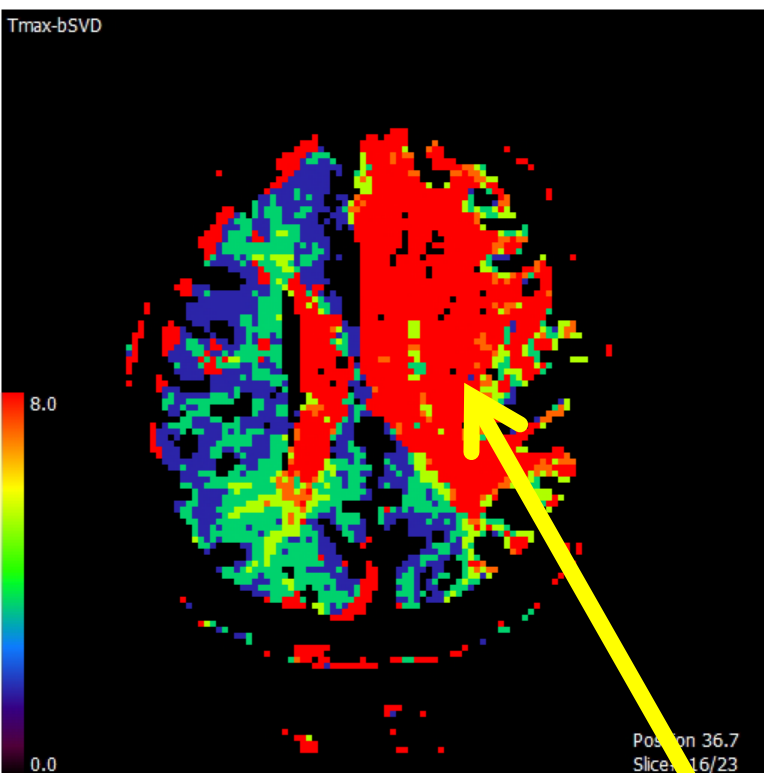
MTT Prolong!!!



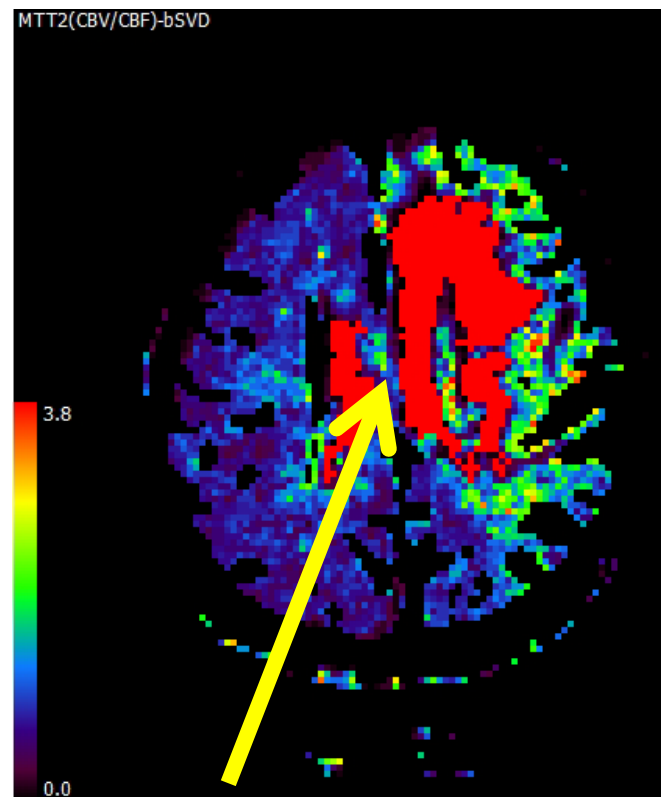
SHH Case: 吳○耀 092XX024

* PMA toolbox:

Tmax



MTT

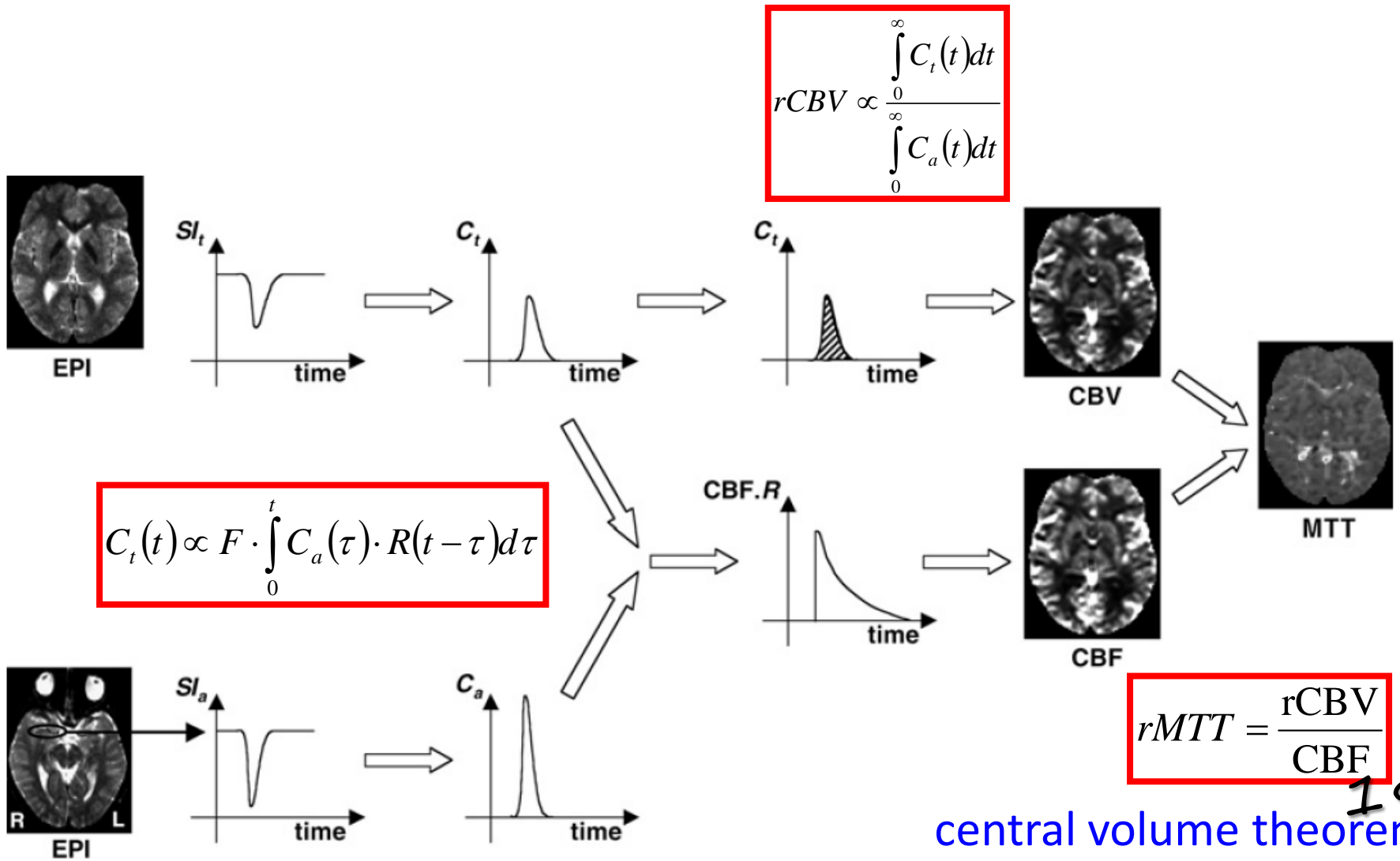


Tmax Delay!!!

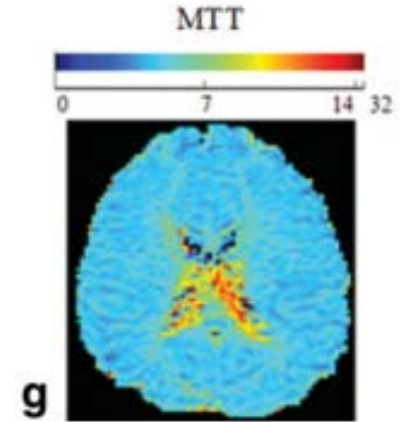
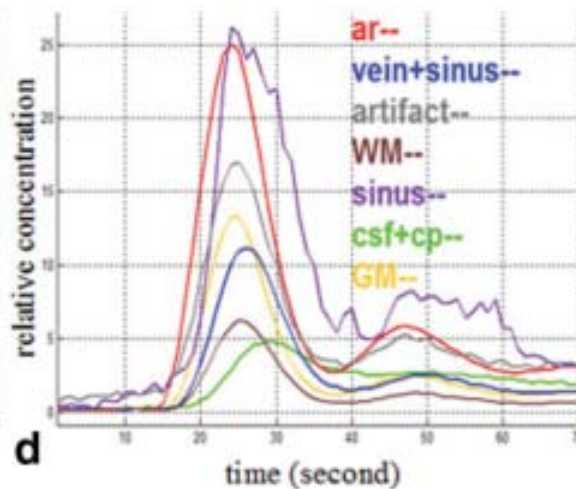
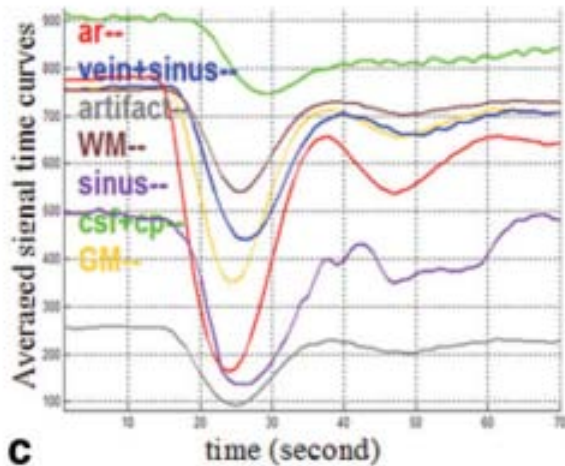
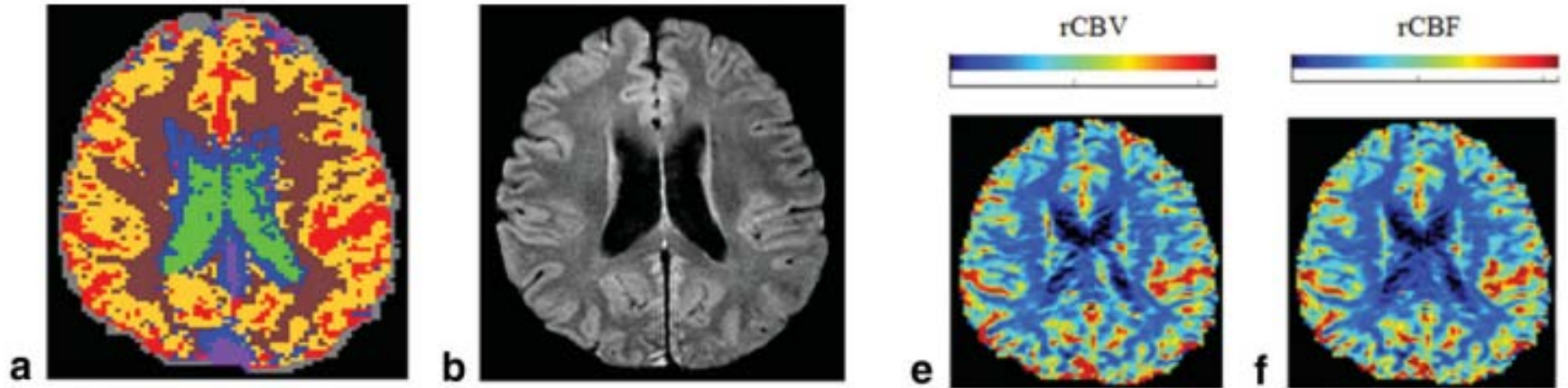
MTT Prolong!!!



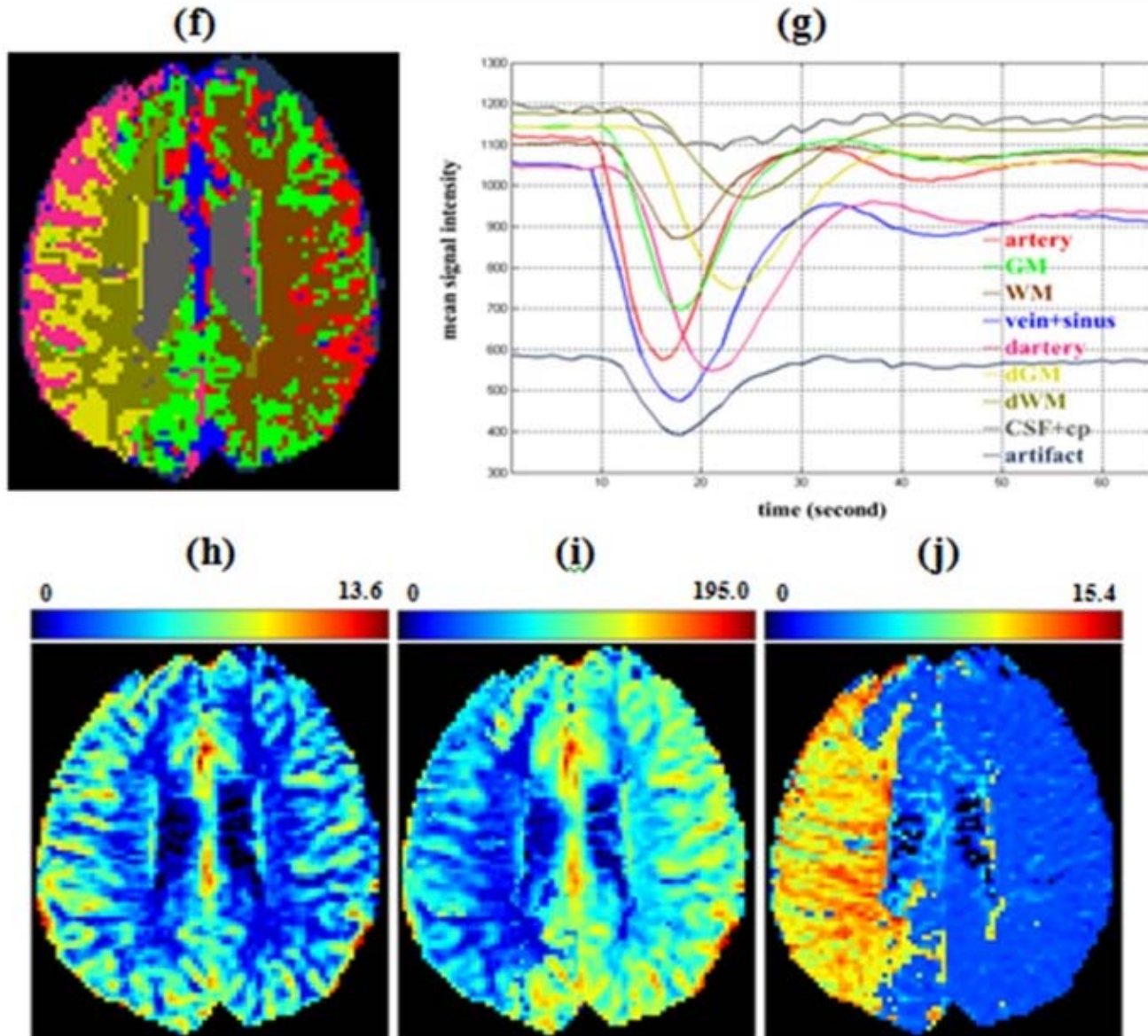
Procedure of Analysis



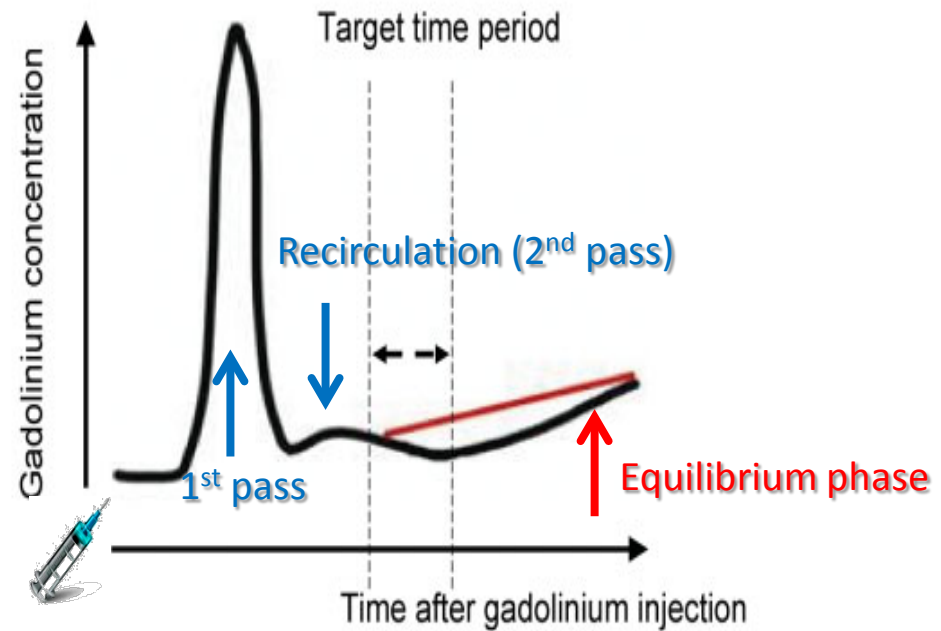
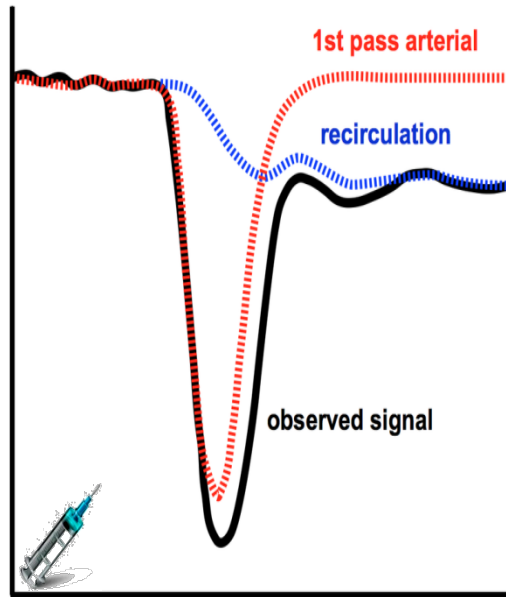
Tissue Classification



Tissue Classification



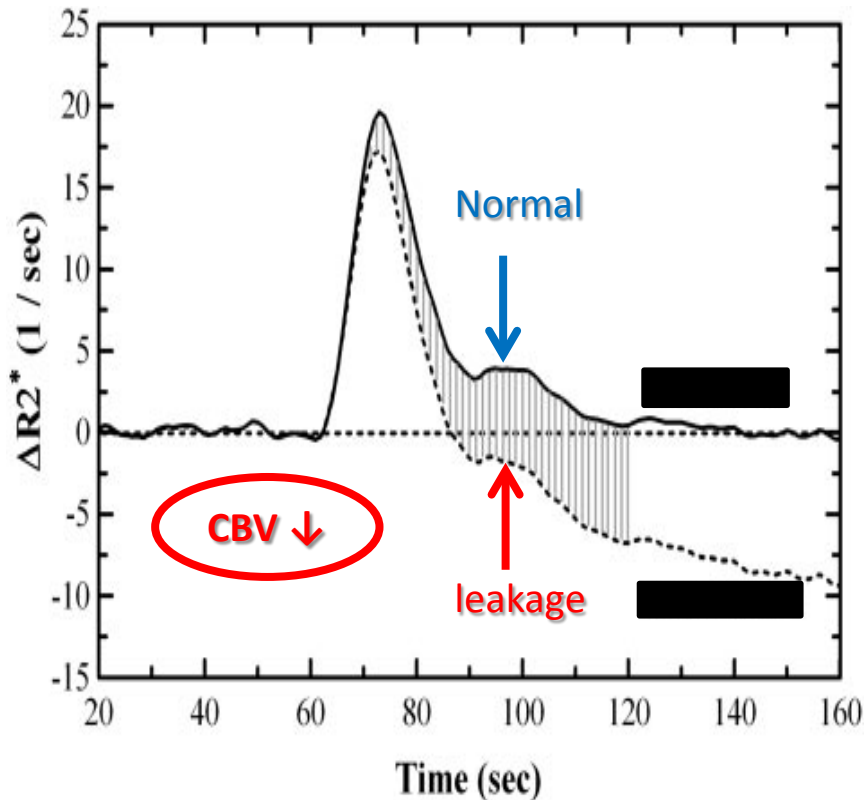
DSC-MRI for measuring Vascular permeability (K_2)



Bang et al., Ann Neurol 2007;62:170–176

- Equilibrium phase: **wash-in = wash-out** (Dynamic equilibrium)

Detect contrast agent leakage by DSC-MRI



Boxerman et al., Am J Neuroradiol 2006; 27:859–67

- BBB damage will **approach baseline faster** and may **fall below it**. (T1 effect of contrast accumulation in parenchyma)
- The effect of BBB disruption can be modeled by comparing with normal tissue.
- The measurement of **permeability**, often referred to as **K₂**, can be derived.

Methods for Measuring Leakage by DSC-MRI

- Preloading Dose (Opts) + Weisskoff model
- Dual echo (spin and gradient echo, SAGE) + Vonken model

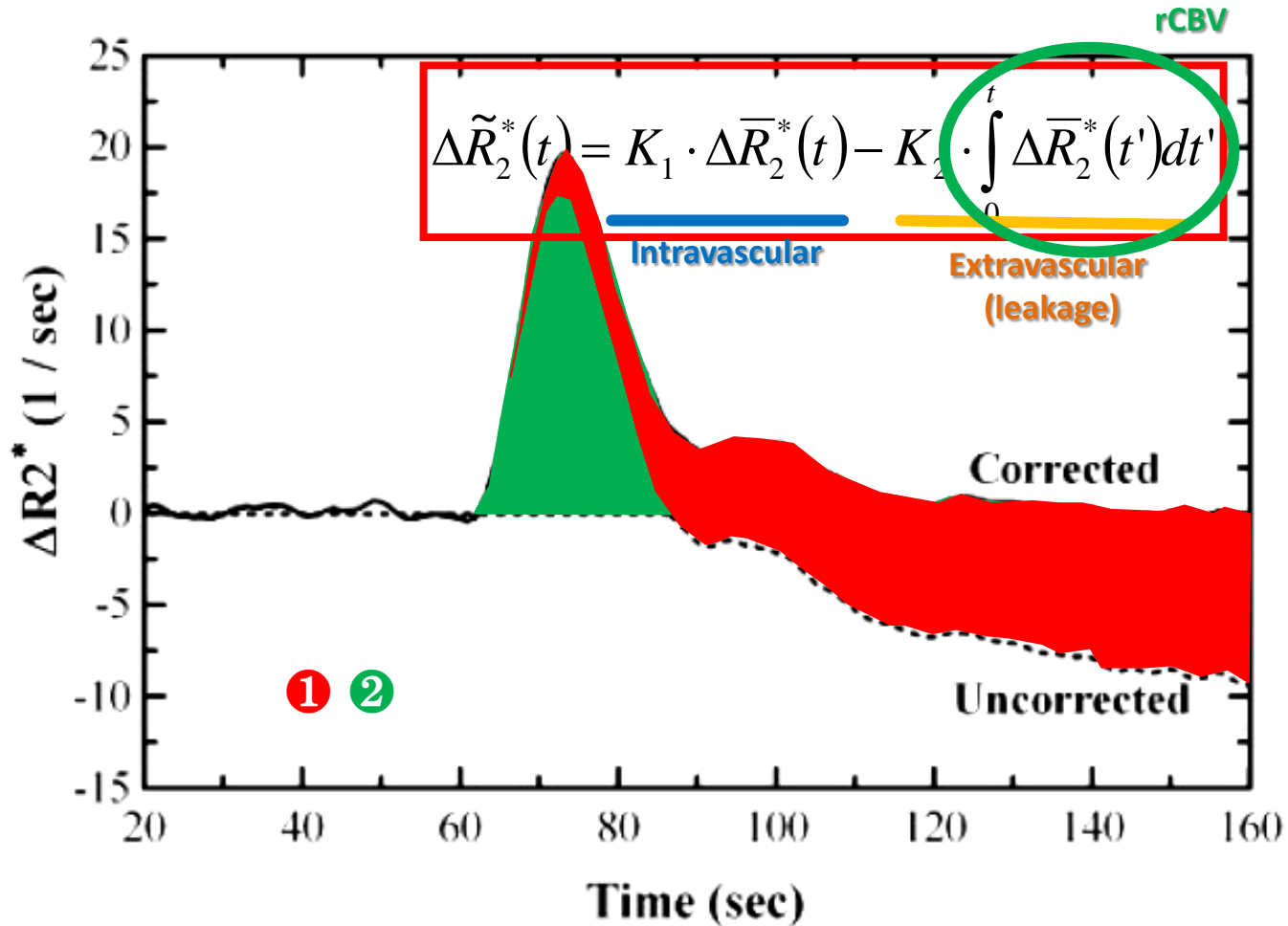


Preloading Dose

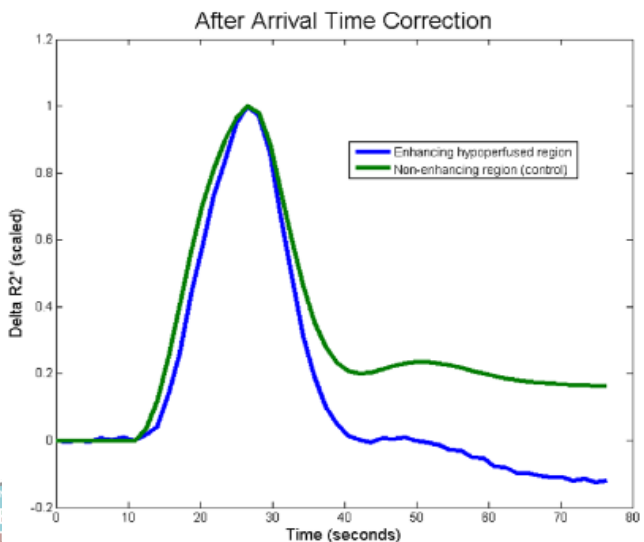
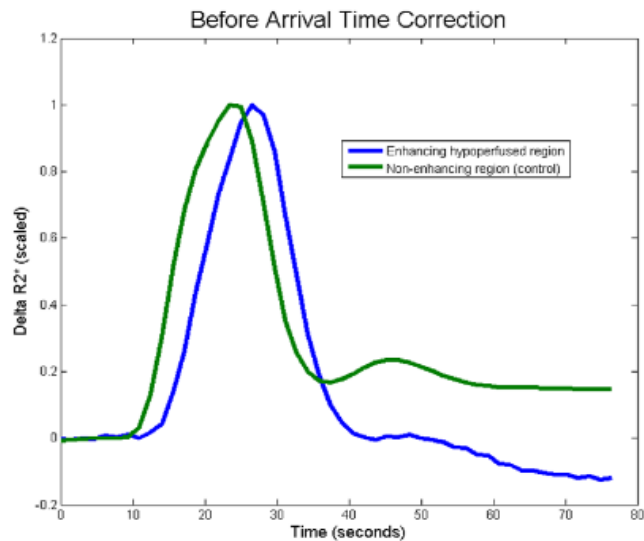
- Procedure
 - Dose: 0.05 -0.1 mmol/kg
 - Infusion
 - Wait for about 5 - 6 minutes.
- T1 effect decreases while dose increases.
 - Sufficient dose may **correct rCBV** perfectly.
 - Too high dose may collide the assumptions of Weiskoff model.



Weisskoff Model



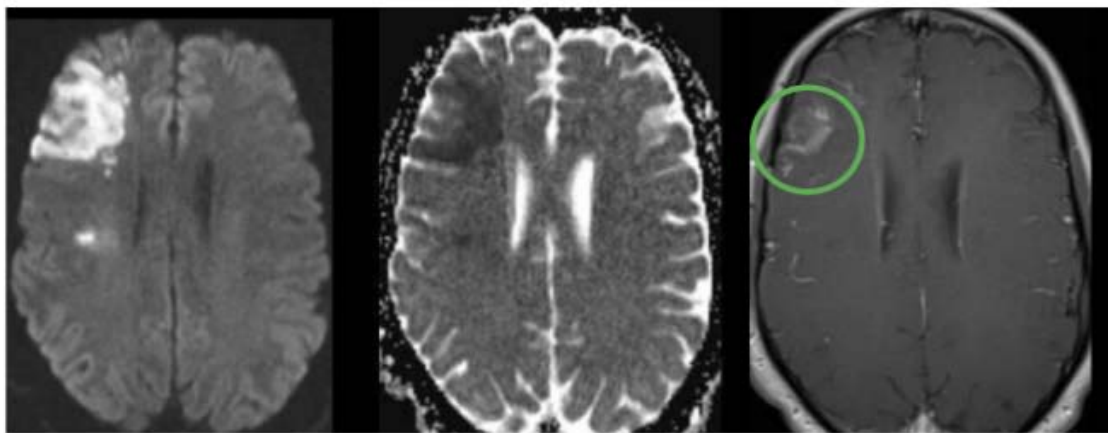
Arrival time correction (ATC)



DWI

ADC

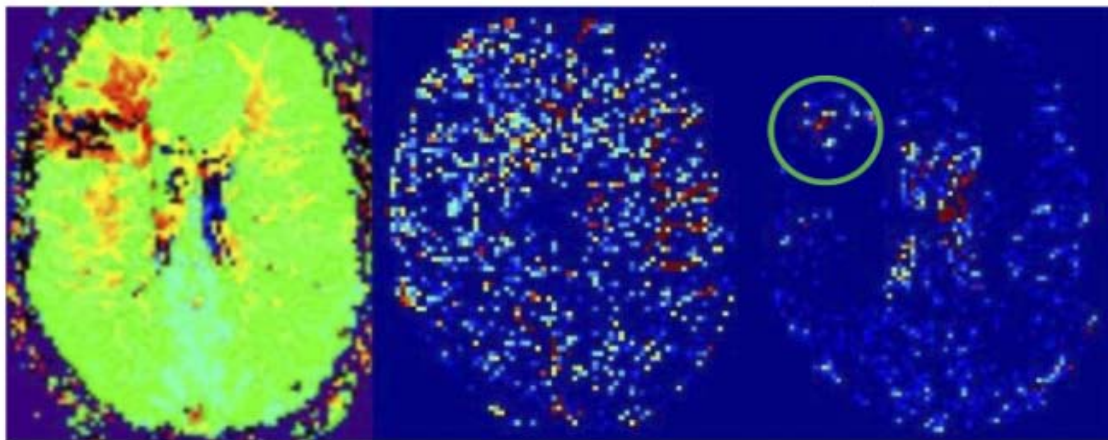
T1 post contrast



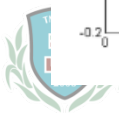
PWI - TTP

Permeability (Uncorrected)

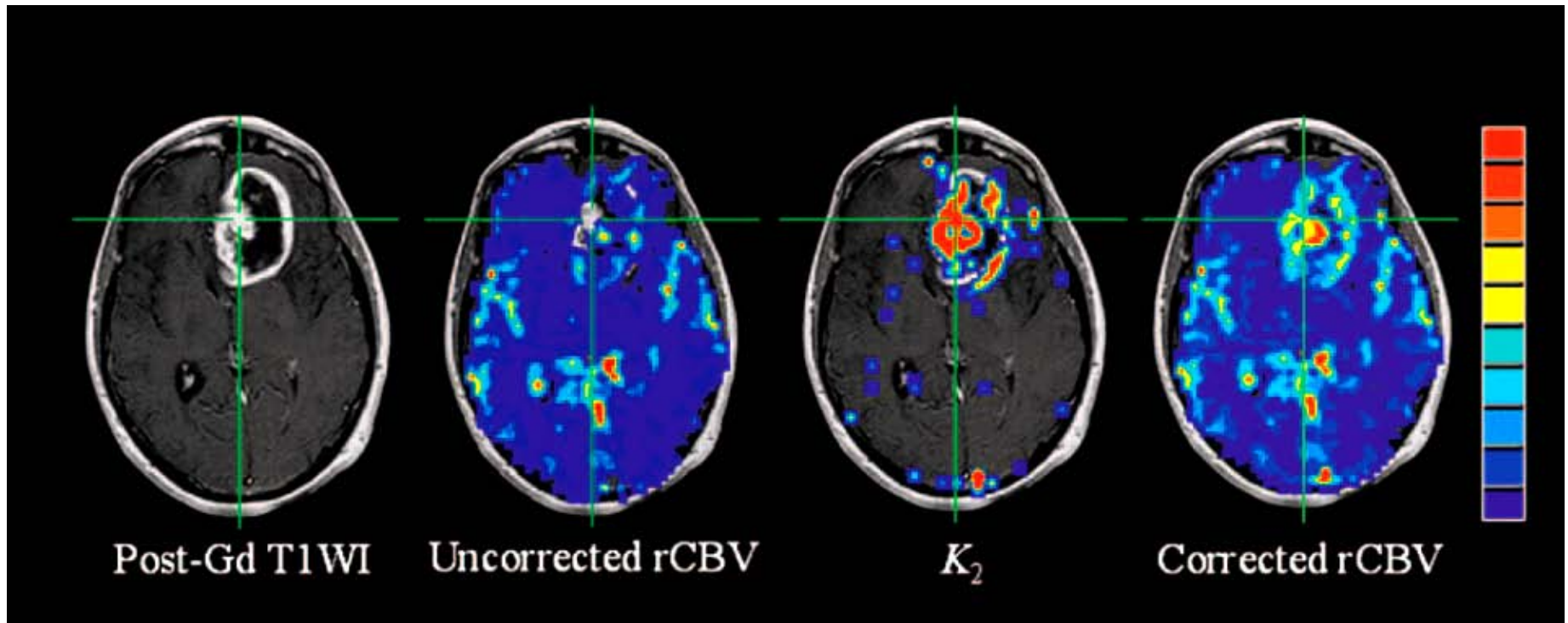
Permeability (with ATC)



Leigh et al, PLoS one 7, 12 (2012): e52656.



Weisskoff Model Correction



Lung meta with chemotherapy

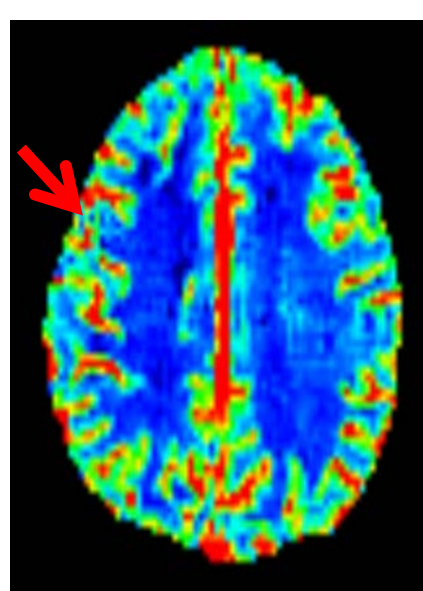
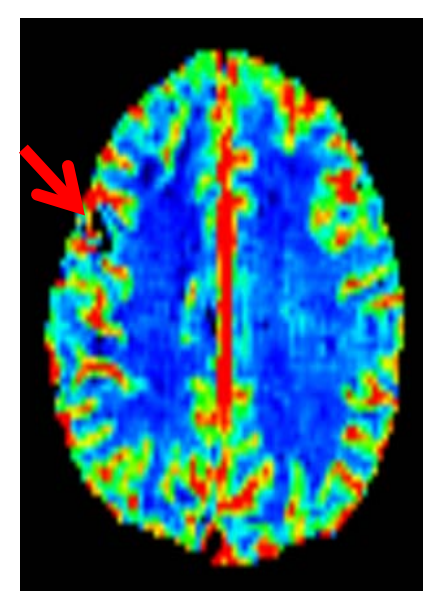
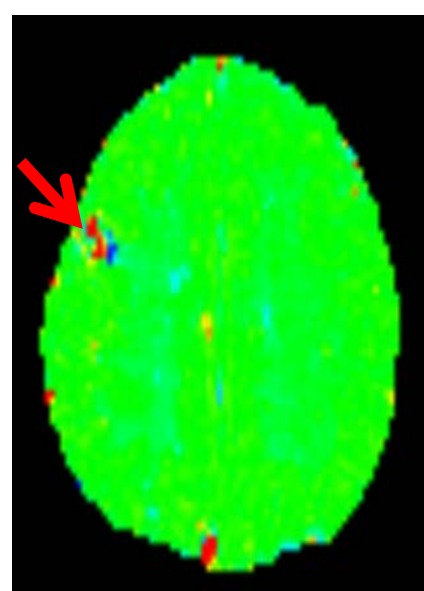
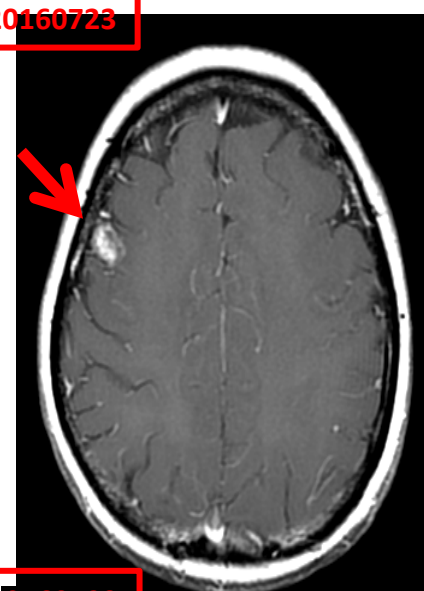
T1 C+

K₂ (permeability)

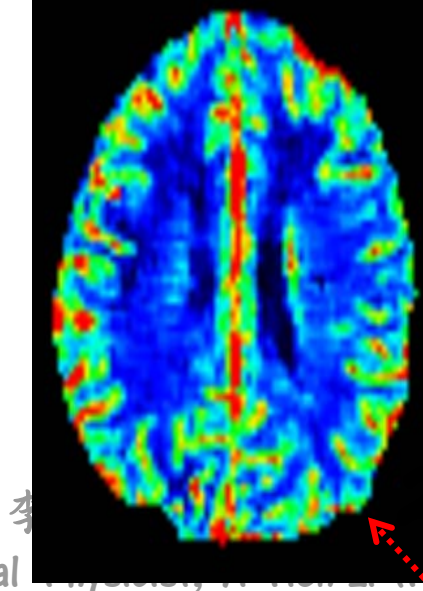
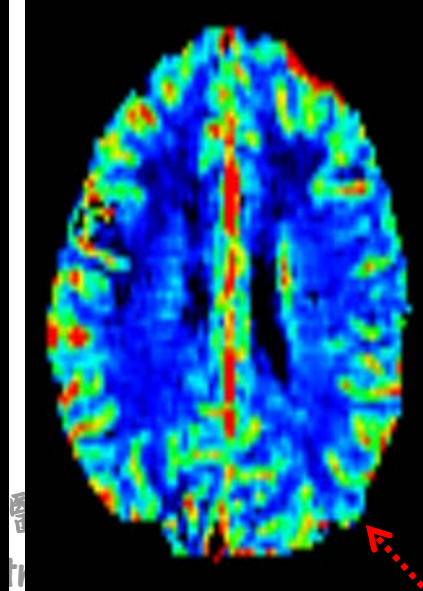
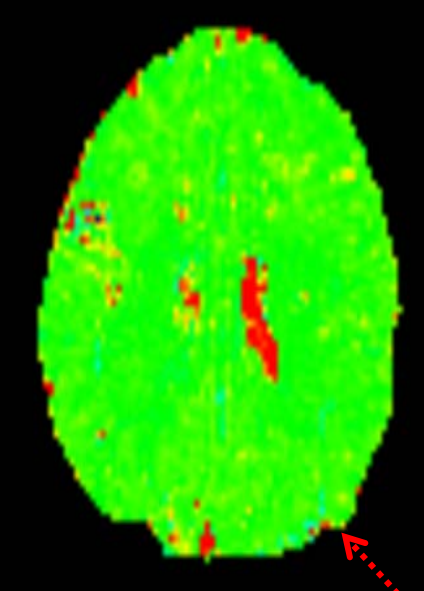
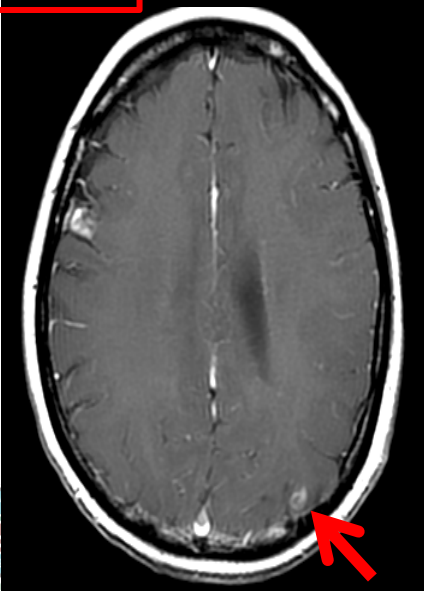
rCBV_{uncorrected}

rCBV_{corrected}

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(Sc)

Lung meta with chemotherapy

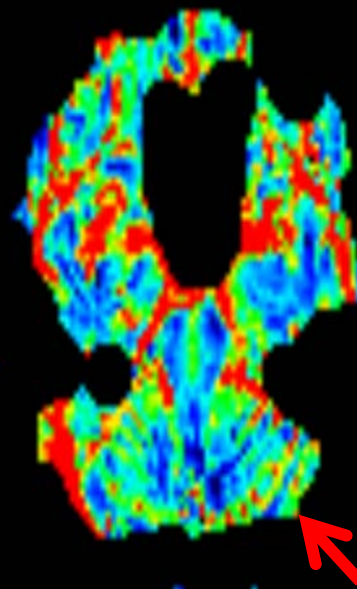
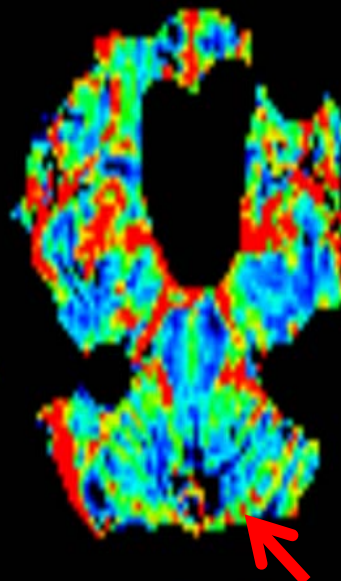
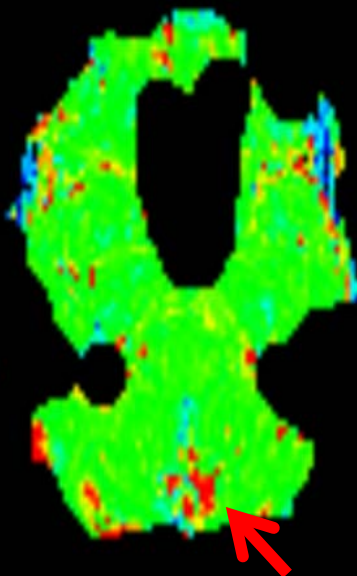
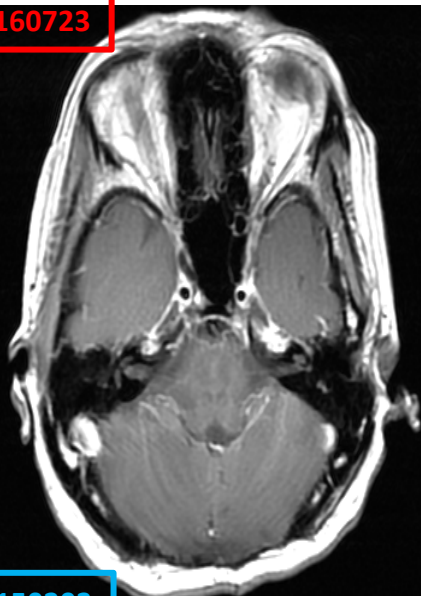
T1 C+

K₂ (permeability)

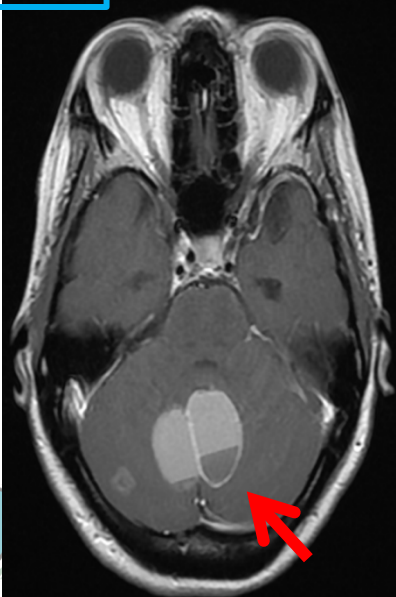
rCBV_{uncorrected}

rCBV_{corrected}

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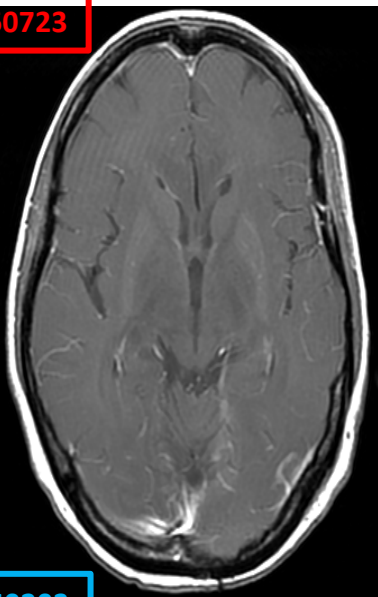
Yi-Shuang Ho Hospital Department of Radiology, Medical Physicist, Yi-Tien Li (MSc)



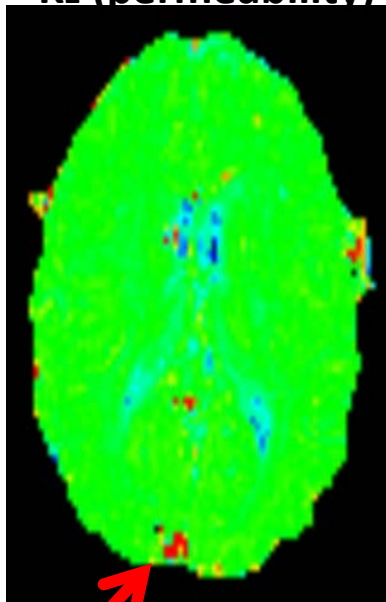
Lung meta with chemotherapy

T1 C+

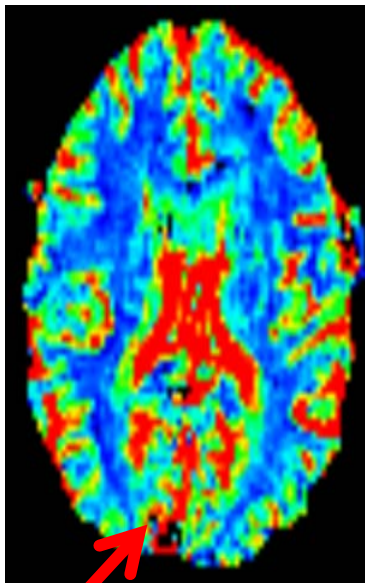
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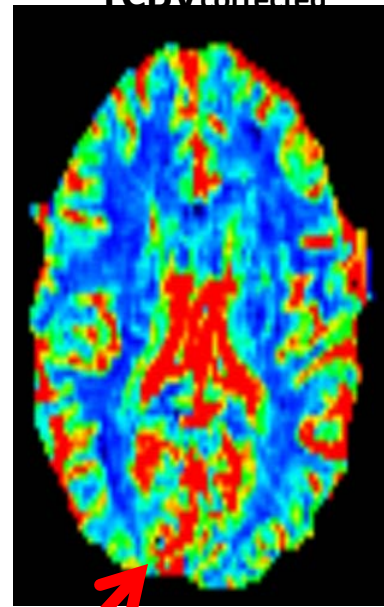
K₂ (permeability)



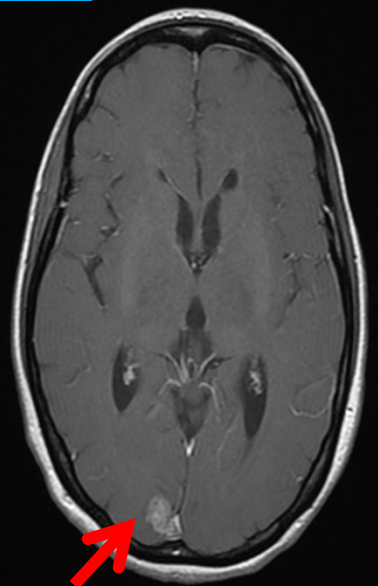
rCBV_{uncorrected}



rCBV_{corrected}



20150203



ICA stenosis & normal perfusion with infarct

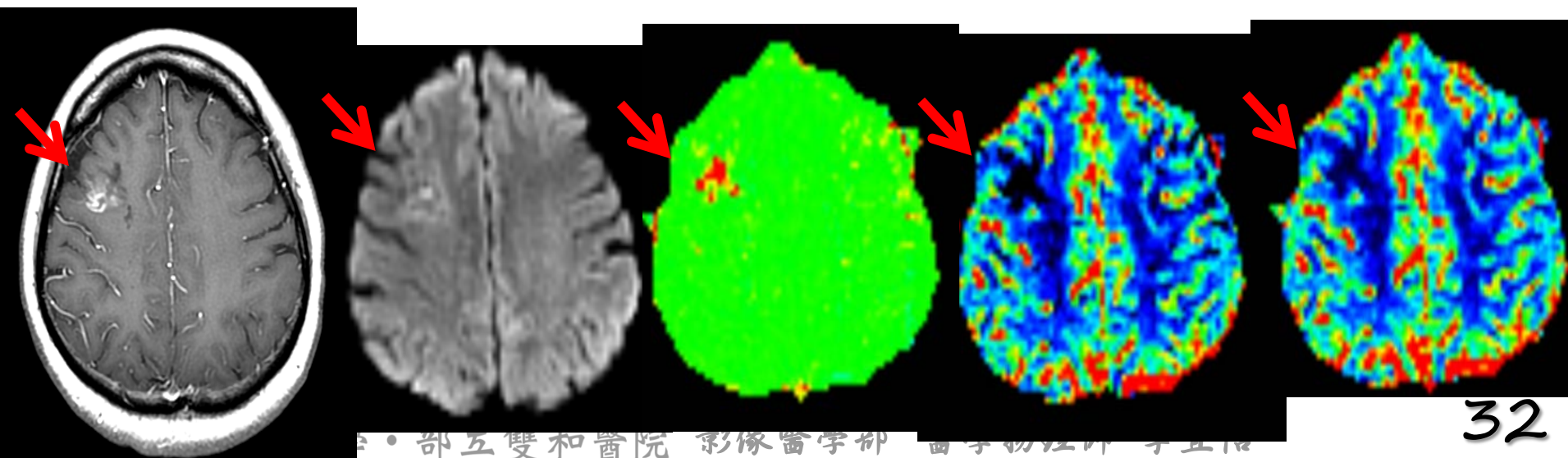
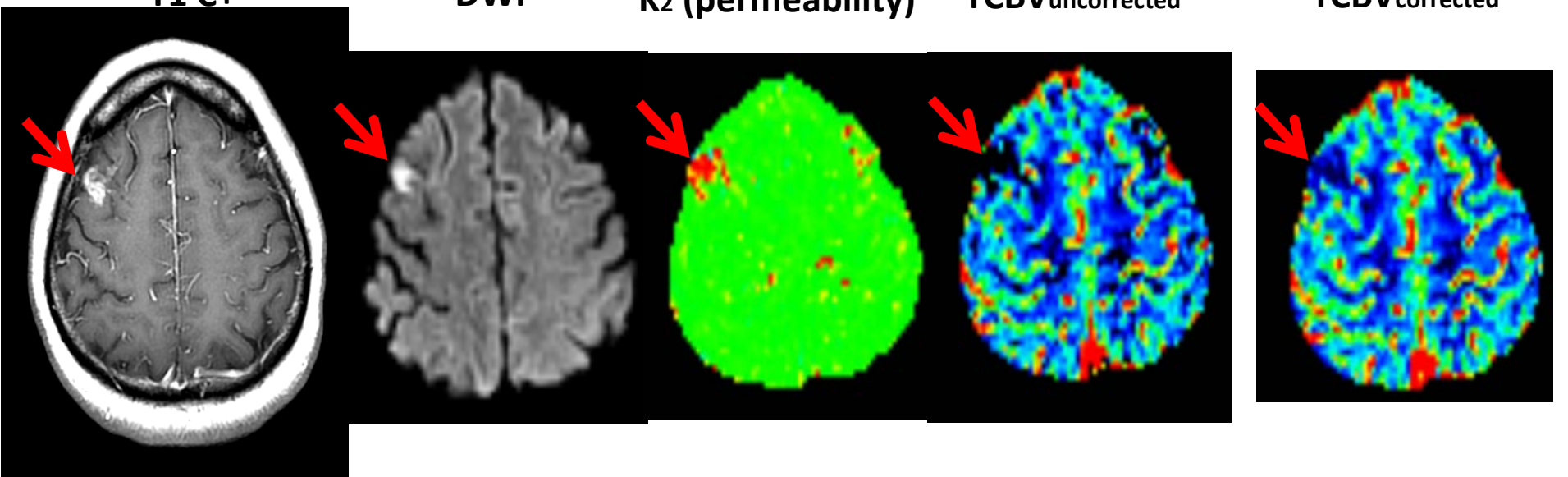
T1 C+

DWI

K₂ (permeability)

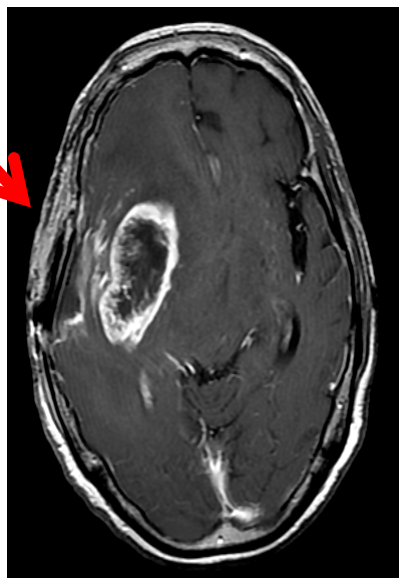
rCBV_{uncorrected}

rCBV_{corrected}

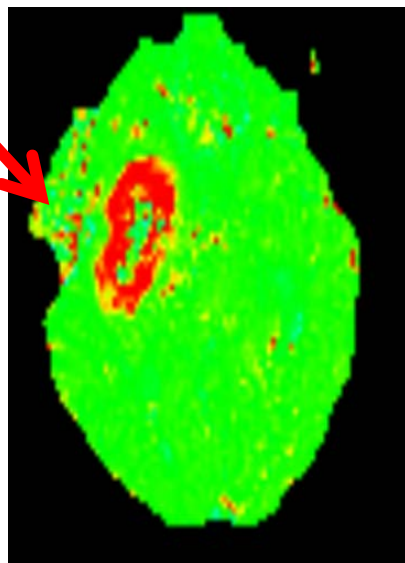


Radiation necrosis or recurrent tumor?

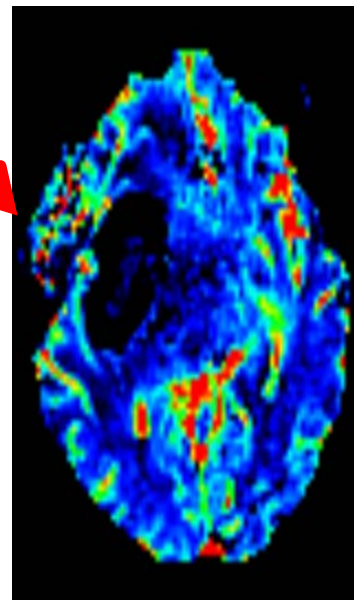
T1 C+



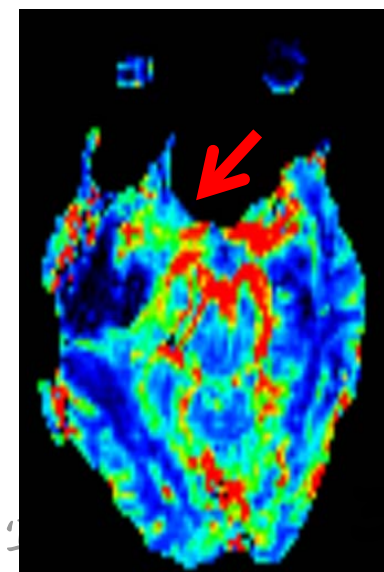
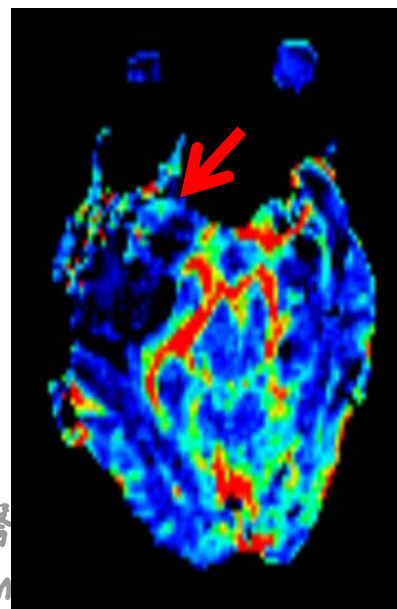
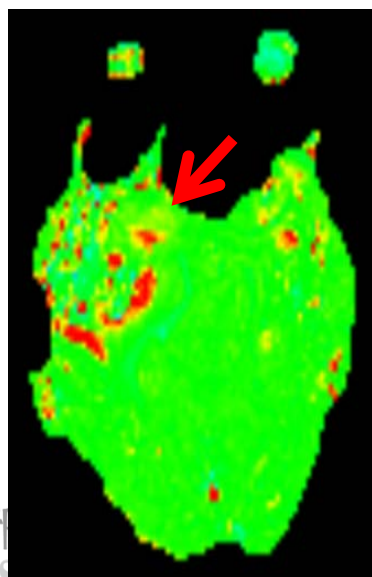
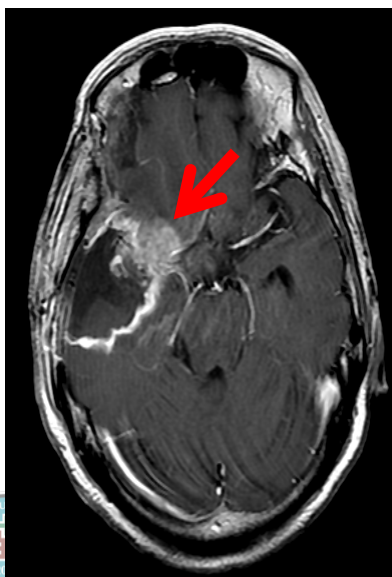
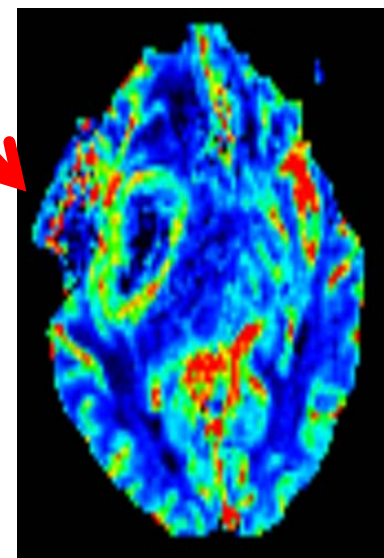
K₂ (permeability)



rCBV_{uncorrected}



rCBV_{corrected}



ASL MRI

- Arterial spin labeling uses **arterial blood water** as an endogenous contrast agent.
- Blood is "**tagged**" or **magnetically inverted** which changes its magnetic properties and its effect on MR signal.
- Create paramagnetic tracer to suppress MR signal wherever arterial blood is delivered.
- Can be used to **quantify CBF** (cerebral blood flow) in arterioles and capillaries.



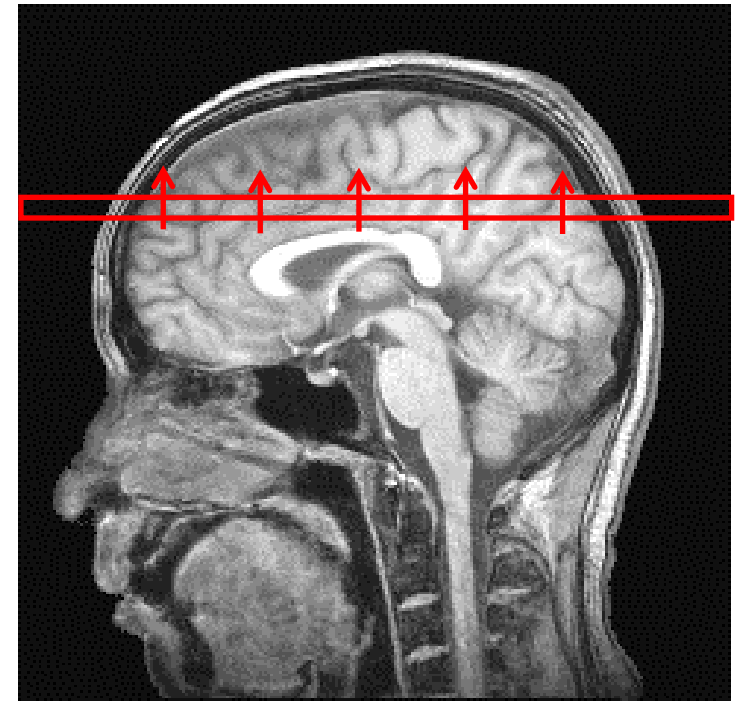
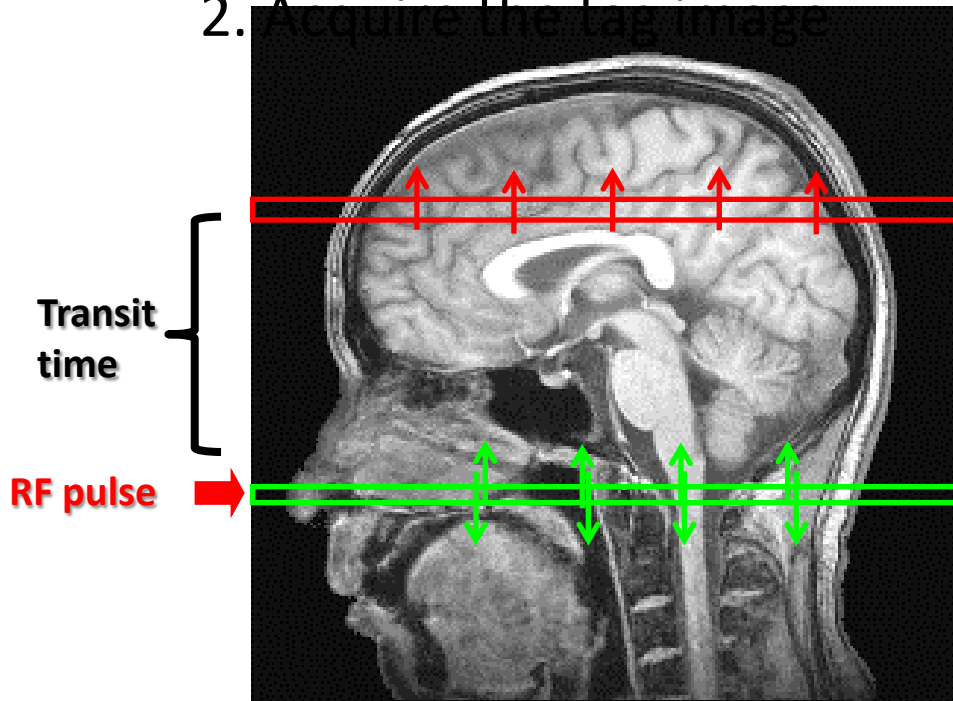
ASL CBF MAP

- **Pulsed Arterial Spin Labeling (PASL)**
 - A volume of blood is labeled upstream of the region of interest by a short RF pulse
- **Continuous Arterial Spin Labeling (CASL)**
 - Increase the delivered RF energy
 - Two sets of transmitter and receiver coils



(Pseudo) Continuous ASL

1. Tag inflowing arterial blood by magnetic inversion
2. Acquire the tag image



Tagging

Control

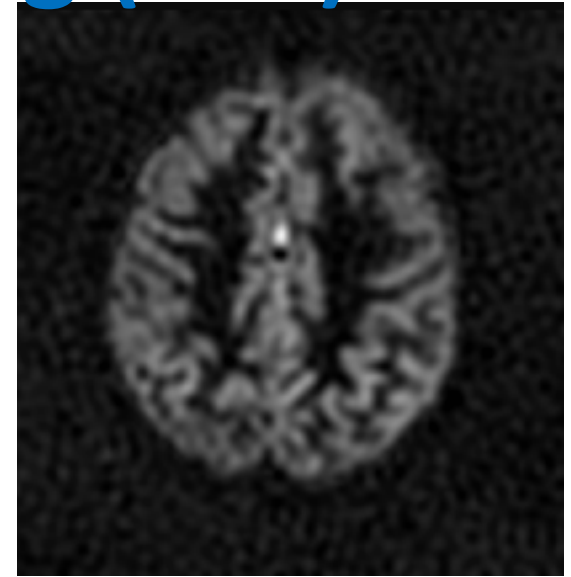
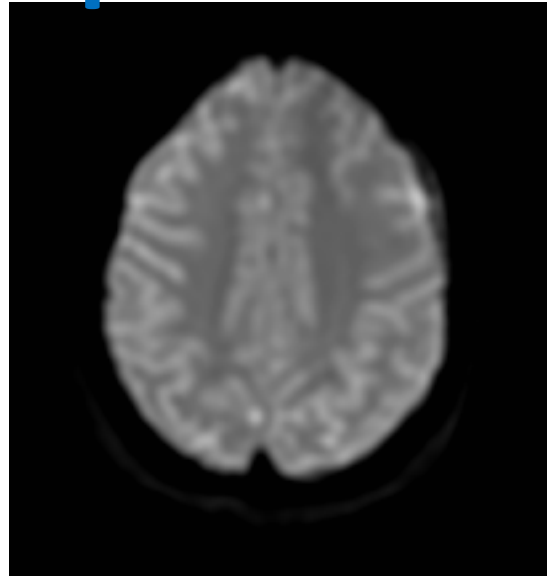
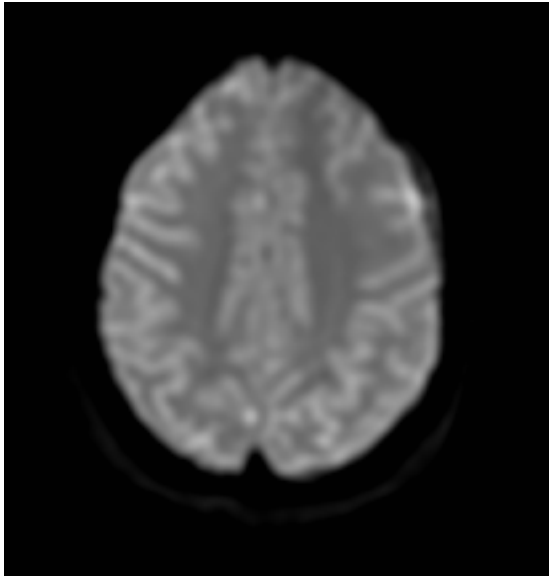
Imaging slice

Tagging plane

Courtesy from CGMH Prof. Liu Ho-Ling

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Arterial Spin Labeling (ASL)



$$\text{Control} - \text{Labeling} = \Delta M$$

- ΔM is usually about 1% of the control signal, so many averages are usually required.
- (Tagging duration 2s + PLD 2.5s + image acquisition 0.6s) X 2 X 32 = 6 mins

Potential Confounds in CBF Quantification with ASL Imaging

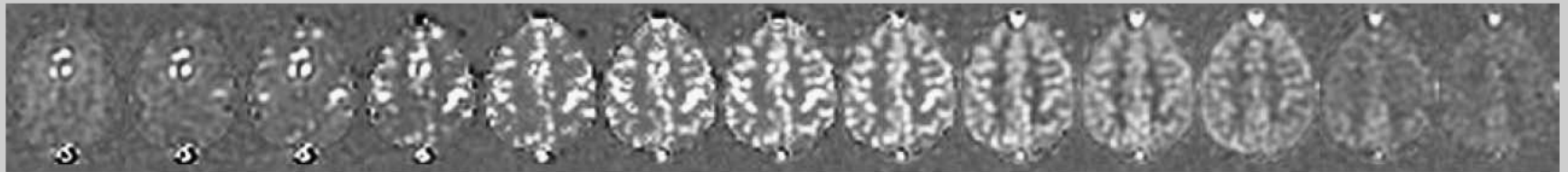
- Intra-arterial signal effects
- Transit/ Trailing time effects
- Relaxation effects



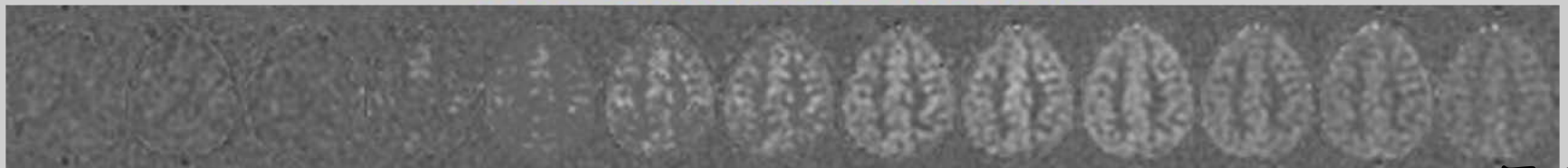
Intra arterial signal effects

- Perfusion signal could be contaminated by the signal coming from the labeled intra-arterial blood, which has not reached the capillary/ tissue site for exchange.

Without Gradient Crushers



With Gradient Crushers

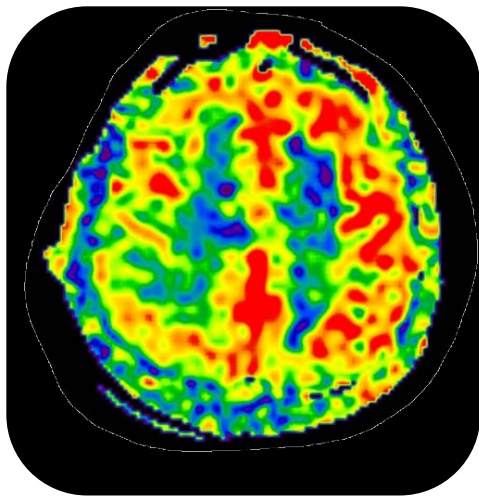


TI = 0.26 0.29 0.35 0.55 0.75 0.95 1.15 1.35 1.55 1.85 2.15 2.45 2.75 s



Intra arterial signal effects

- Perfusion signal could be contaminated by the signal coming from the labeled intra-arterial blood, which has not reached the capillary/ tissue site for exchange.



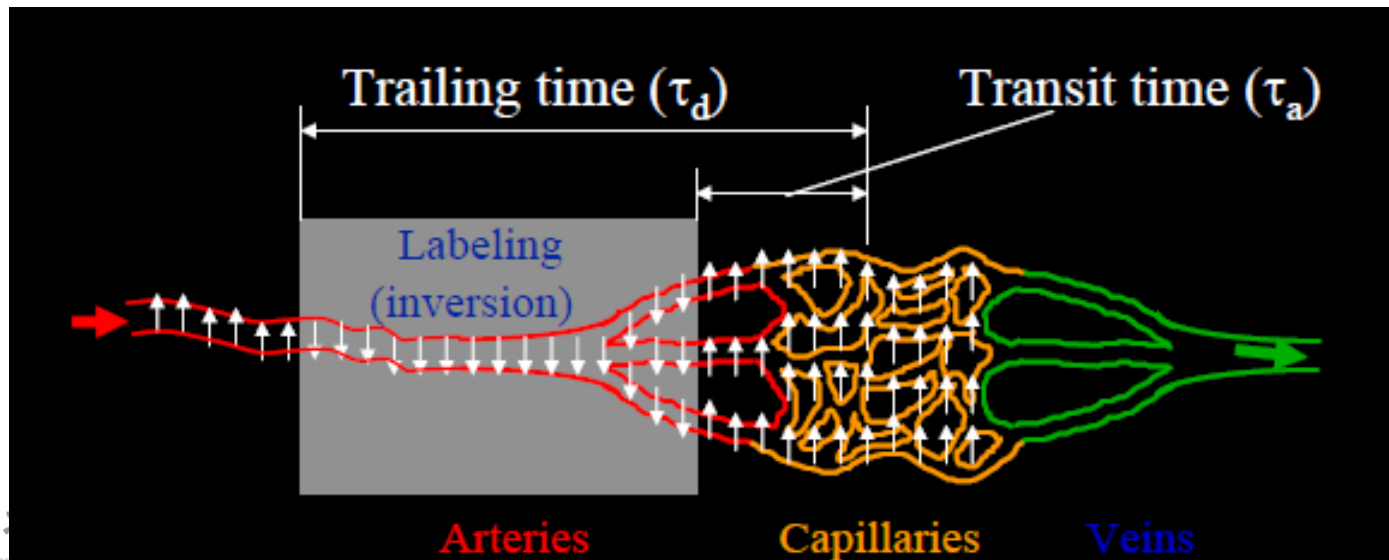
Intra-arterial blood (Slow flow)?
L't hyperperfusion?

R't hypoperfusion?

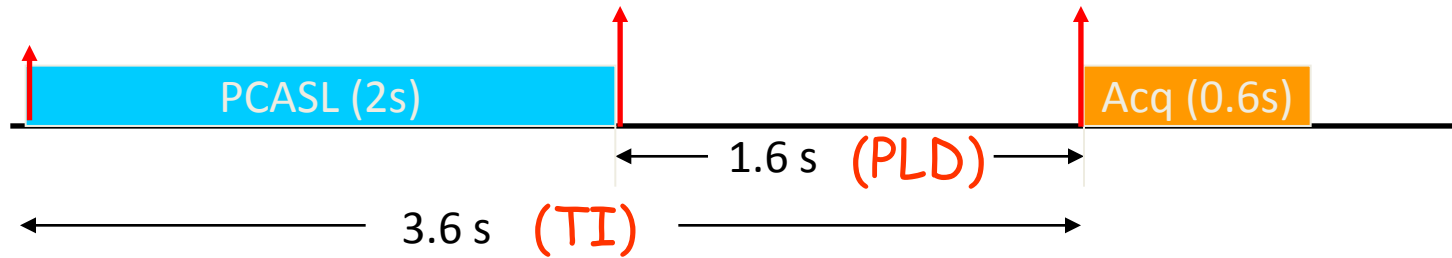
Tagging artifact (Stent cases)

Transit/ Trailing Time Effects

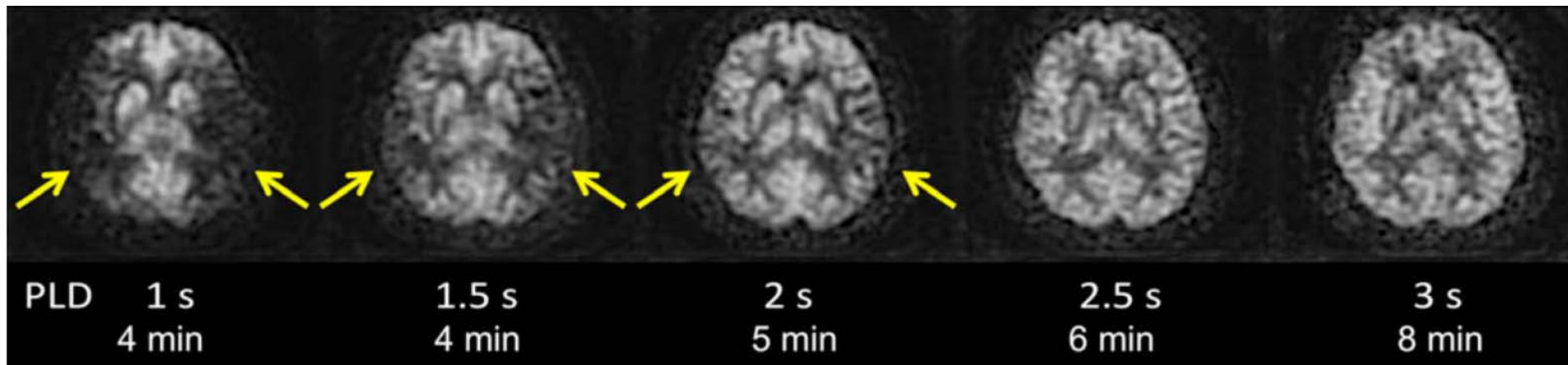
- Transit/trailing time – the time for the leading/ trailing edge of the labeled blood to reach the capillary/tissue exchange site.
- Caused by
 1. Gap between the inversion slab and image slices
 2. Blood Traveling time from arterials to capillaries.



Post Labeling Delay



Courtesy CGMH Prof. Liu Ho-Ling



- Improved CBF quantitation on long PLD using PCASL at 3 T in a patient with bil Moyamoya disease

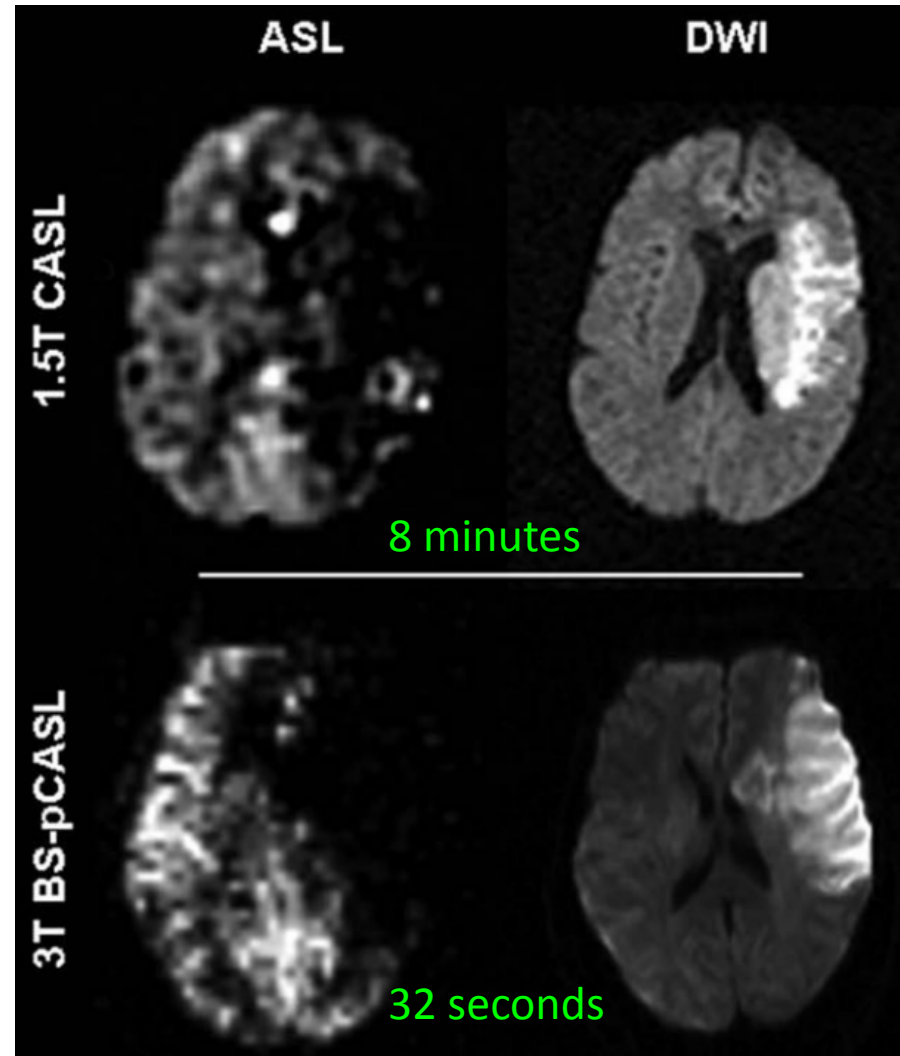
Solution to Transit Delay

- High main magnetic field
 - Extended ASL (eASL)
 - Multiple PLD
 - Velocity selective ASL (VASL)
- } Longer PLD



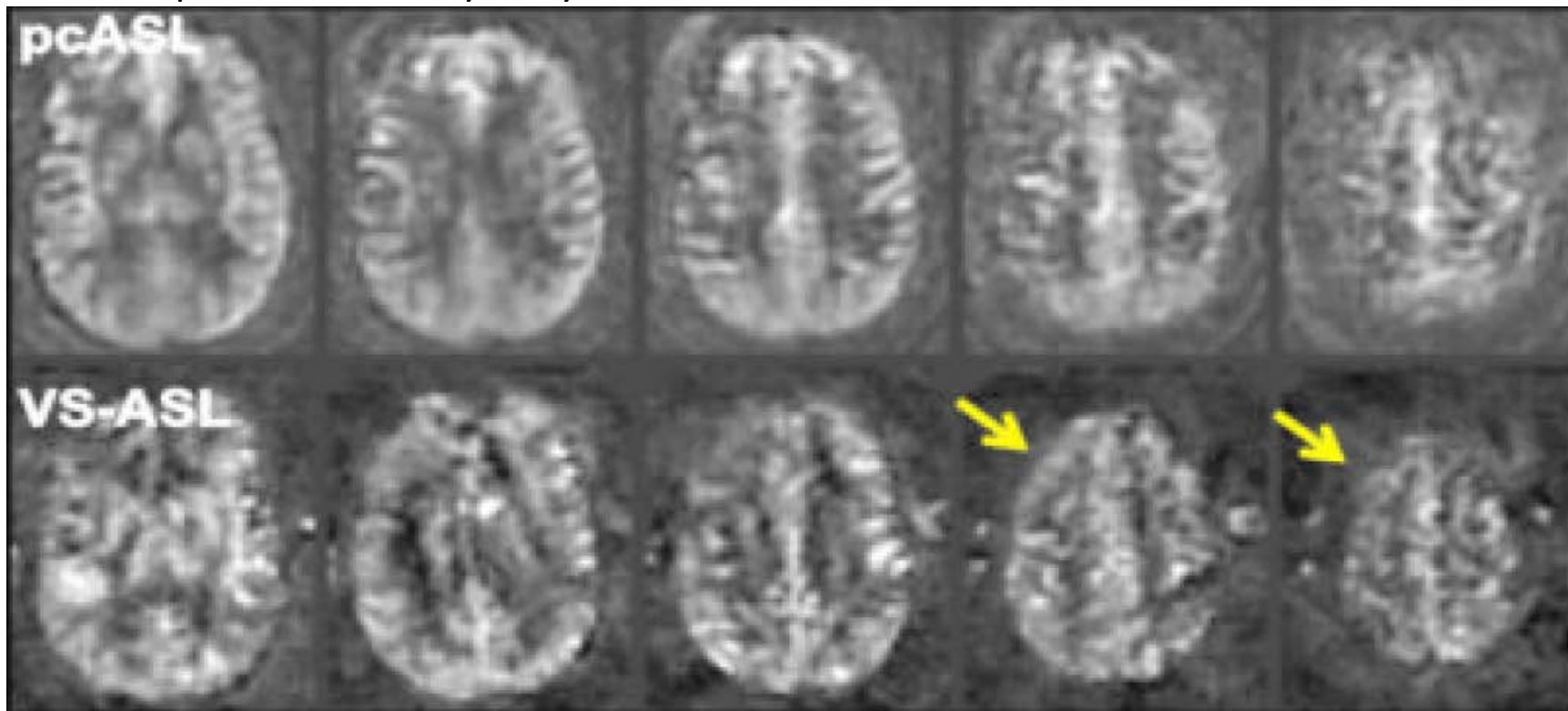
1.5T VS 3T

- Higher magnetic field
 - Inherent high SNR:
Less repeated acquisition => shorter imaging time
 - Longer blood T_1 :
Allow longer post labeling delay

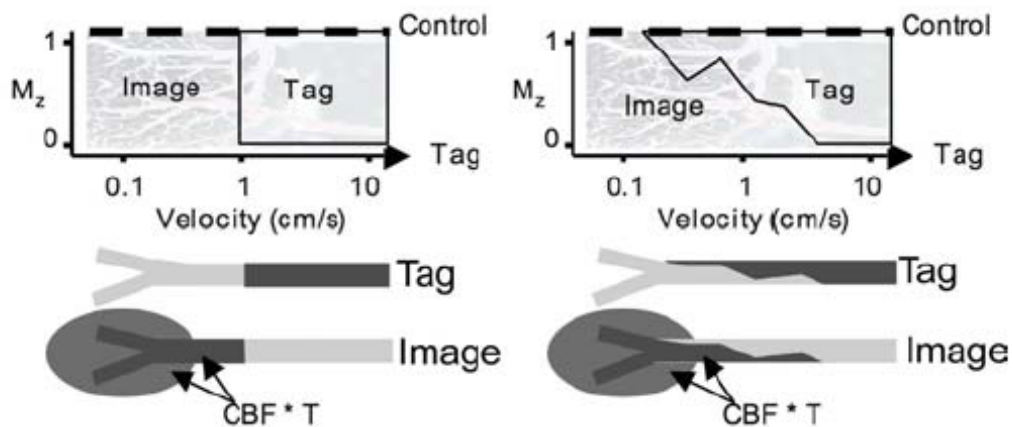


VASL

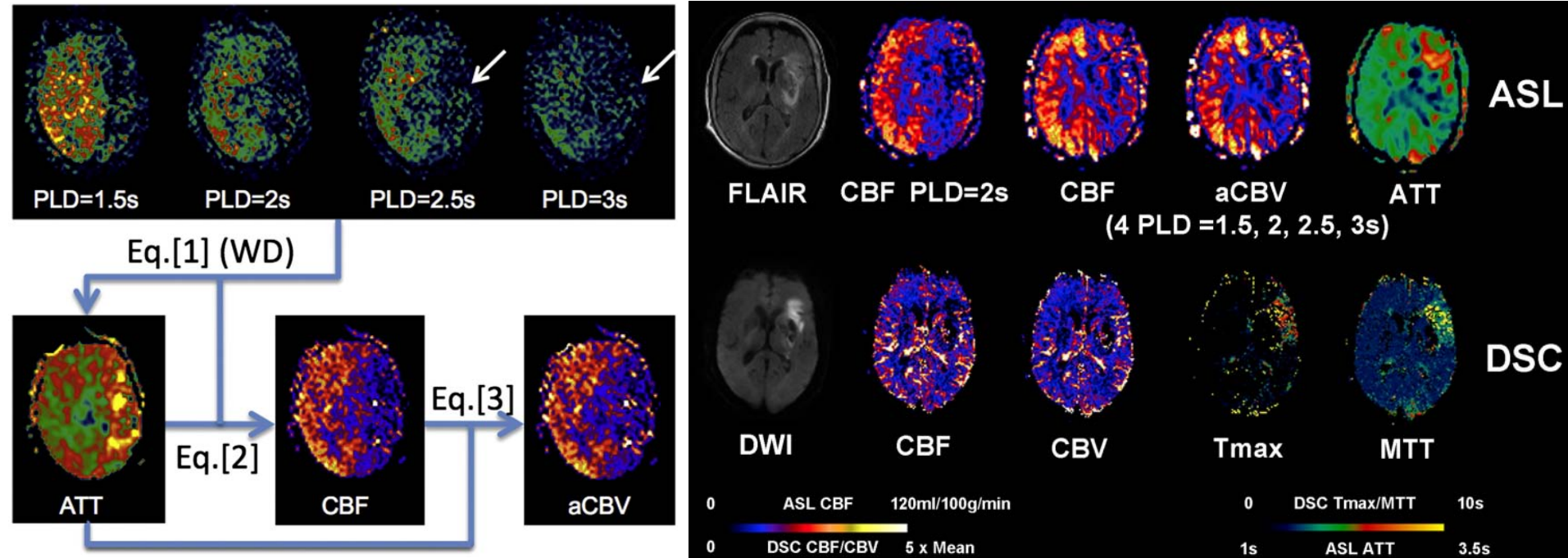
A patient with Moyamoya disease and bilateral MCA occlusion



Neuroimaging Clin N Am. 2011 May ; 21(2): 285-301

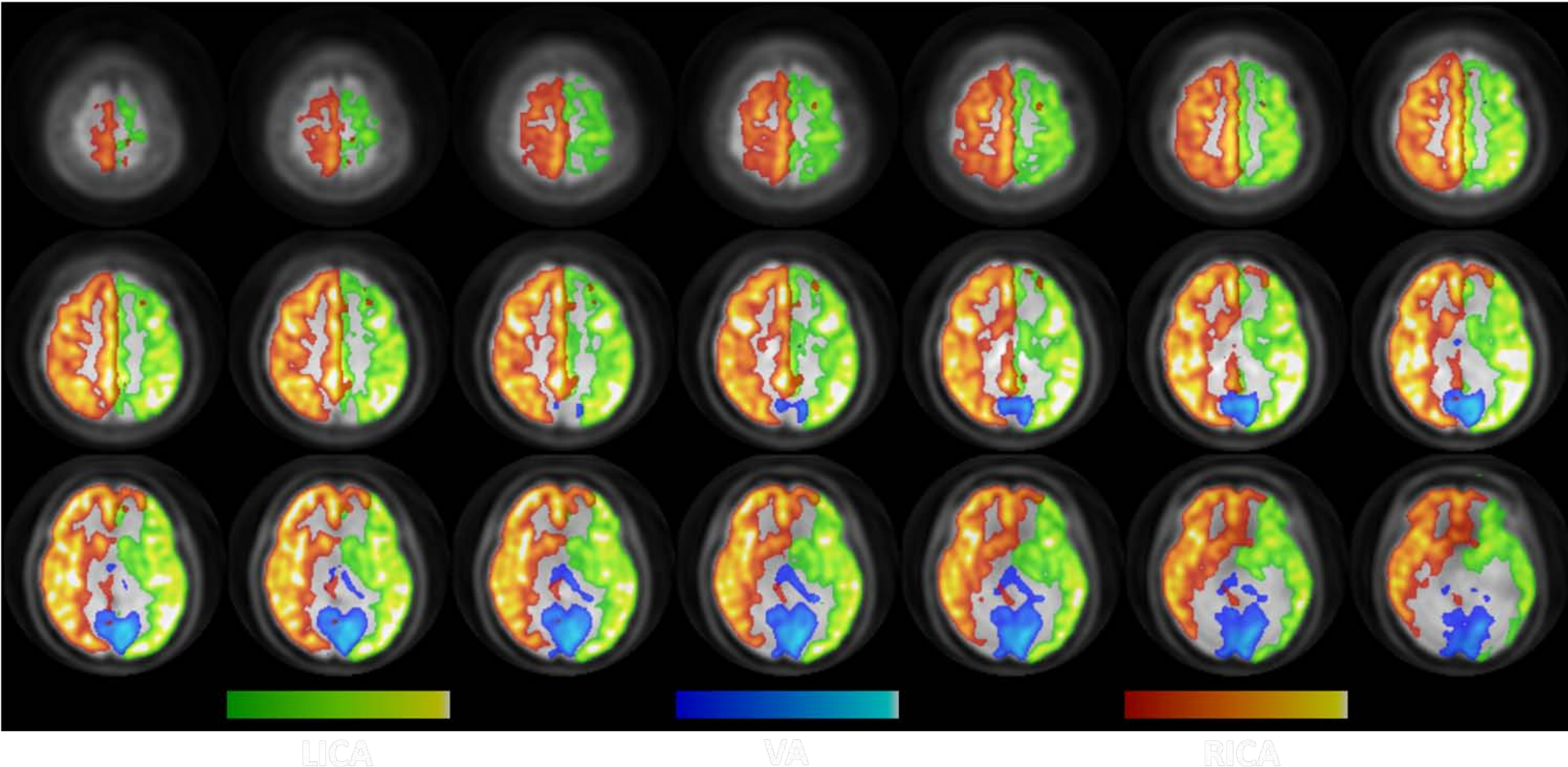


Multiple PLD

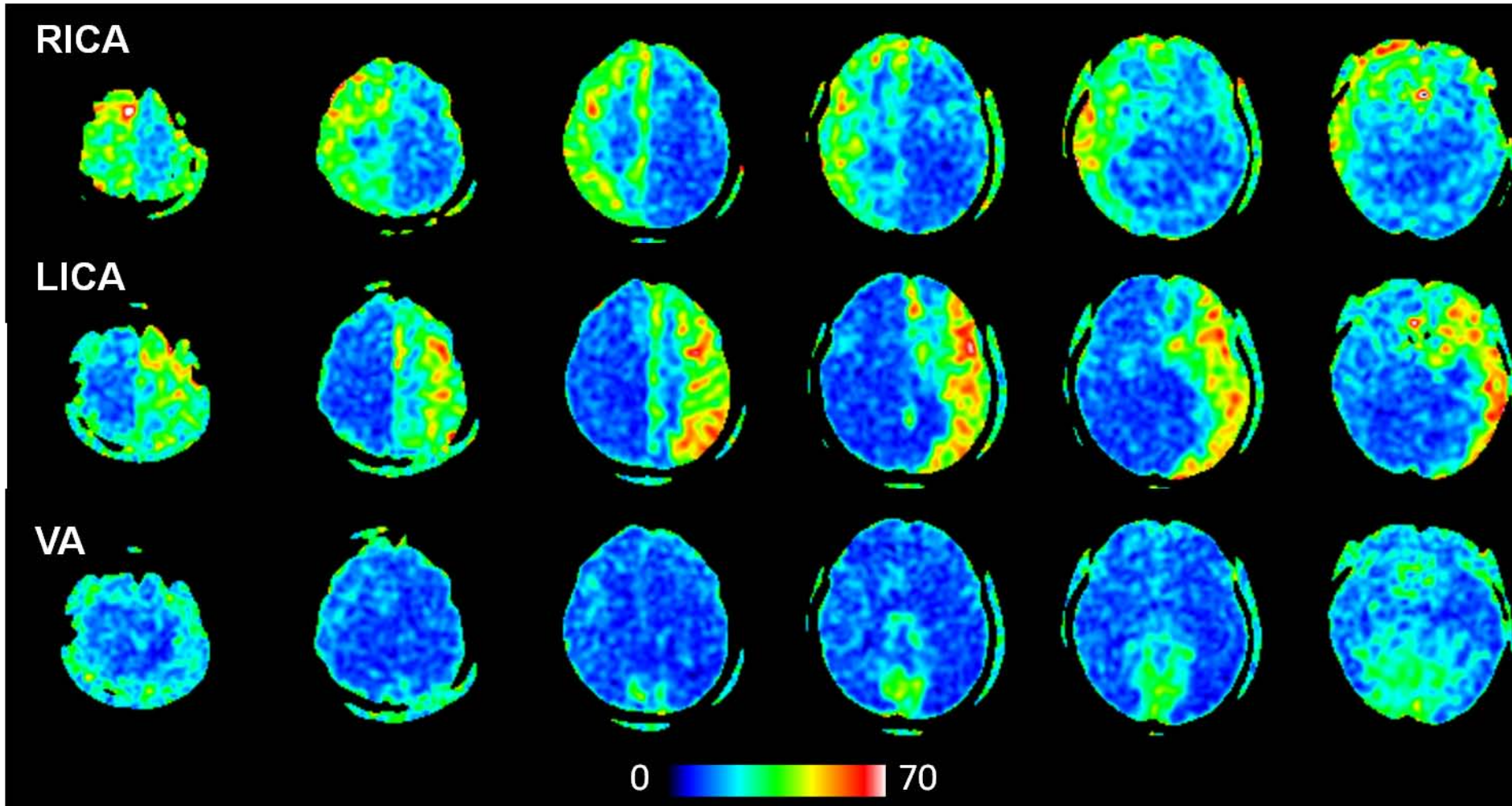


- PCASL at 4 PLDs (PLD = 1.5, 2, 2.5, 3 s) were acquired within 4.5 min in 24 patients with acute MCA infarct
- Highly significant correlations between pCASL and DSC CBF ($r=0.70$, $p=0.0001$)
- ASL ATT correlate with DSC Tmax ($r = 0.66$, $p = 0.0005$) and MTT ($r = 0.59$, $p = 0.0023$) in leptomenigeal MCA territories

tASL—Vessel Territory



tASL – CBF



Conclusions

- ASL allows perfusion imaging **without contrast injection**
- ASL allows repeated measurements
- Limitations of ASL include:
 - SNR
 - Coverage
 - Delay time variations

