Slide 1

中華民國醫事放射學會
Taiwan Society of Radiological Technologists (TWSRT)

MRI Lecture 1

Perfusion

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
2016.11.19

TMU-SHH 2008

Slide 2

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

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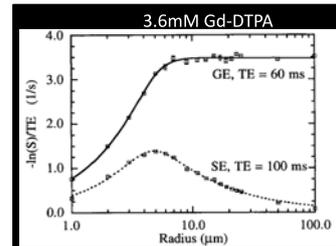Taipei Medical University - Shuang Ho Hospital Department of Radiology, Medical

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Slide 3

Techniques of Brain Perfusion

- Dynamic susceptibility-contrast MRI (DSC)
  - CBF/ CBV/ MTT/K2

- Dynamic contrast-enhanced MRI (DCE)
  - CBF/ PS/ v_p / v_e

- Arterial spin labeling (ASL)
  - CBF

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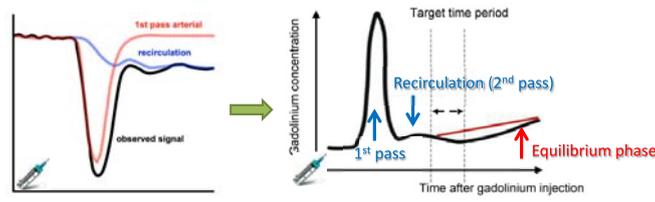Taipei Medical University - Shuang Ho Hospital Department of Radiology, Medical

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Slide 4

DSC MRI

- T_2/T_2^* weighted imaging
  - T_2^*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

3.6mM Gd-DTPA

GE, TE = 60 ms

SE, TE = 100 ms

Boxerman et al., MRM 1995

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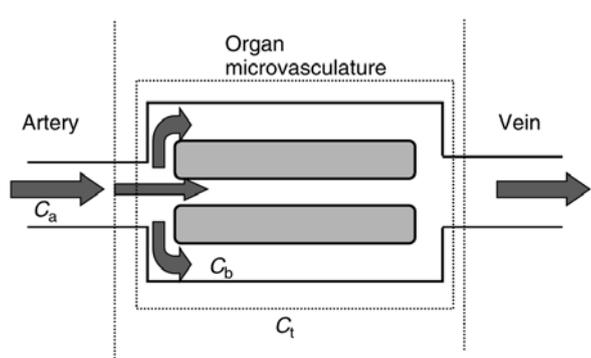Taipei Medical University - Shuang Ho Hospital Department of Radiology, Medical

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Slide 5

DSC MRI

1st pass arterial
recirculation
observed signal

Target time period
Recirculation (2nd pass)
1st pass
Equilibrium phase
Time after gadolinium injection

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

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

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Slide 6

Tracer Kinetics

Organ microvasculature
Artery
C_a
C_b
Vein
C_t

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First-pass Fitting

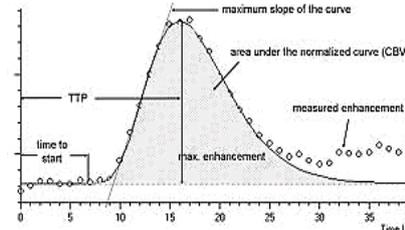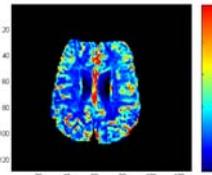$$f(t) = \frac{t^{\alpha}e^{-t/\beta}}{\beta^{(\alpha+1)}\Gamma(\alpha+1)}$$

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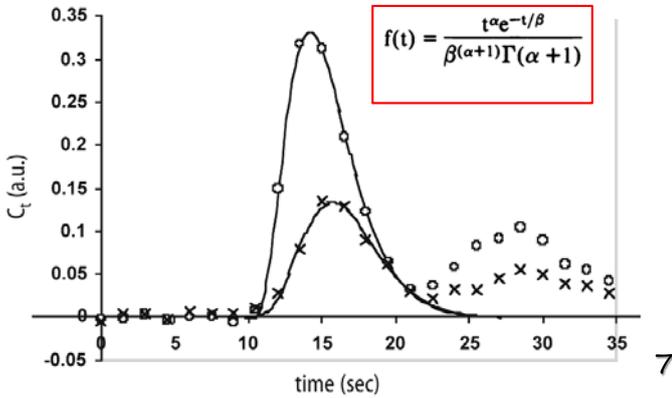
$$CBV = \frac{K_H}{\rho} \cdot \frac{\int_0^\infty c_t(t)dt}{\int_0^\infty c_a(t)dt}$$

- Cerebral Blood Volume

VOF : Venous output function

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

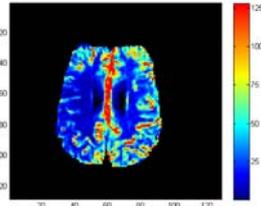Tomandl et al © RSNA, 2003 May-Jun

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

CBF

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

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

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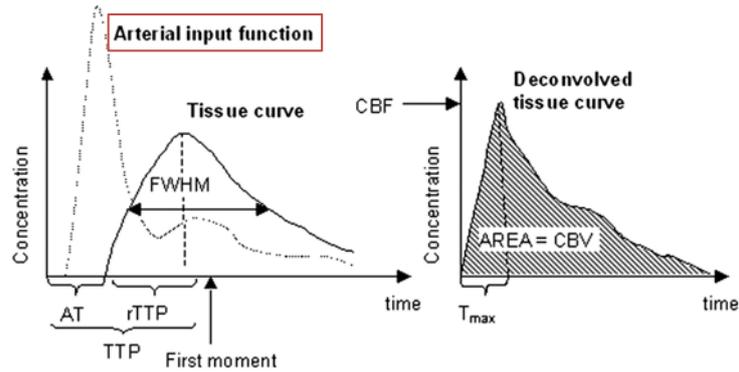
$$C_t = AIF(t) \otimes [CBF \cdot R(t)]$$

CBF

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

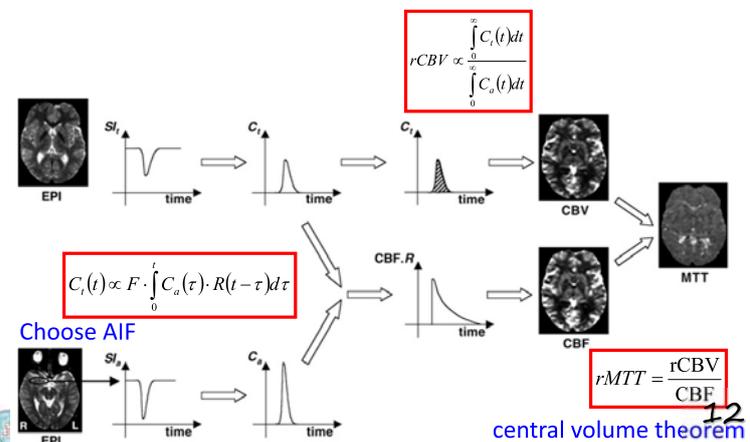10

$$MTT = CBV/CBF$$

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

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Procedure of Analysis

$$rCBV \propto \frac{\int_0^\infty C_t(t)dt}{\int_0^\infty C_a(t)dt}$$

$$C_t(t) \propto F \cdot \int_0^t C_a(\tau) \cdot R(t-\tau)d\tau$$

Choose AIF

$$rMTT = \frac{rCBV}{CBF}$$

central volume theorem

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SHH Case: 吳〇耀 092XX024

DWI   **ADC**   **T2 Flair**

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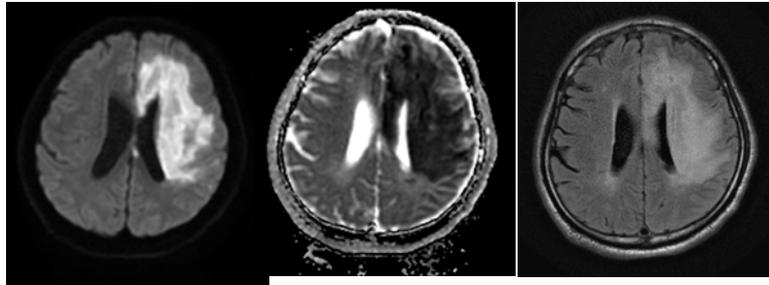
SHH Case: 吳〇耀 092XX024

＊GE perfusion post-processing tool:

CBV   **CBF**   **MTT**

MTT Shorten???

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14
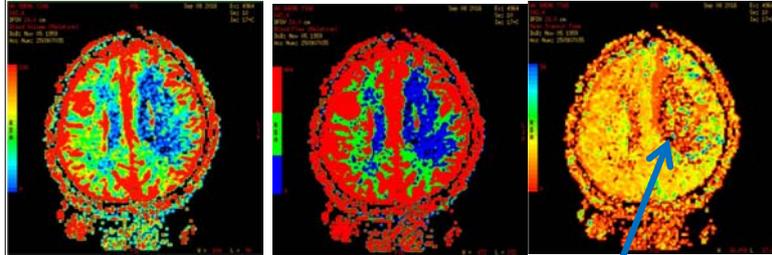
SHH Case: 吳〇耀 092XX024

＊PMA toolbox:

CBV   **CBF**   **MTT**

MTT Prolong!!!

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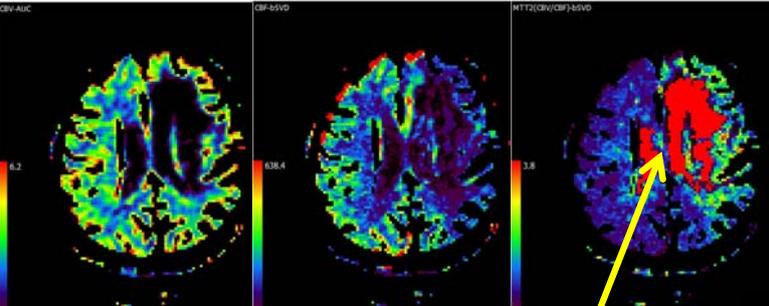
SHH Case: 吳〇耀 092XX024

＊PMA toolbox:

Tmax   **MTT**

Tmax Delay!!!   **MTT Prolong!!!**

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Procedure of Analysis

$$rCBV \propto \frac{\int_0^\infty C_t(t)dt}{\int_0^\infty C_a(t)dt}$$

$$C_t(t) \propto F \cdot \int_0^t C_a(\tau) \cdot R(t-\tau)d\tau$$

$$rMTT = \frac{rCBV}{CBF}$$

central volume theorem

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Tissue Classification

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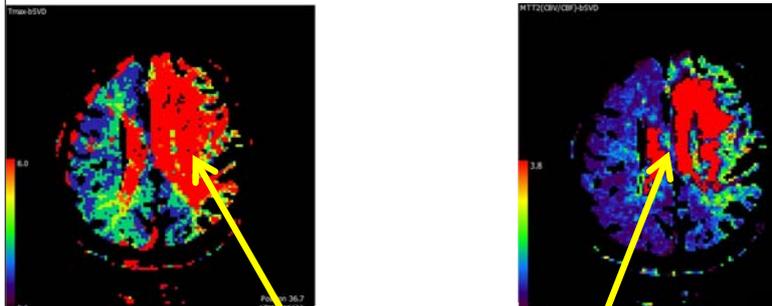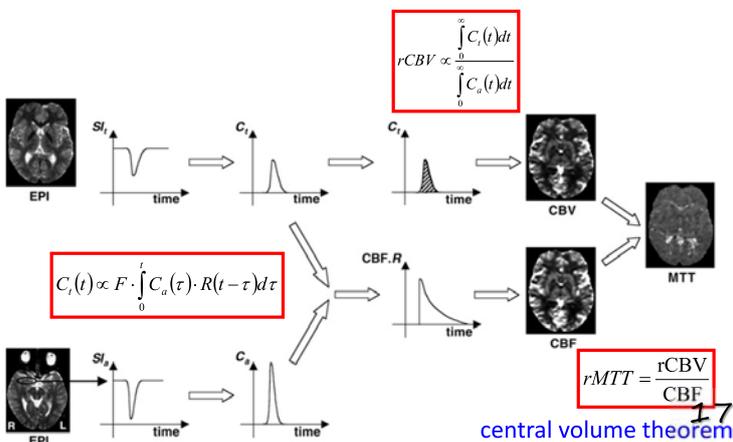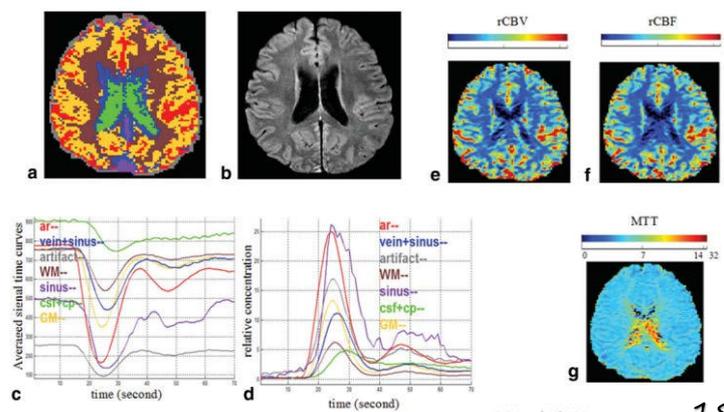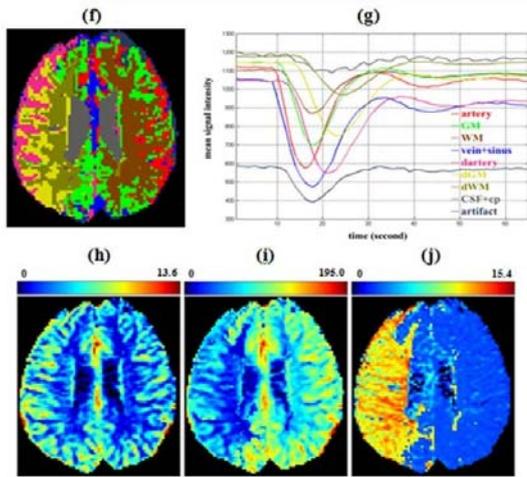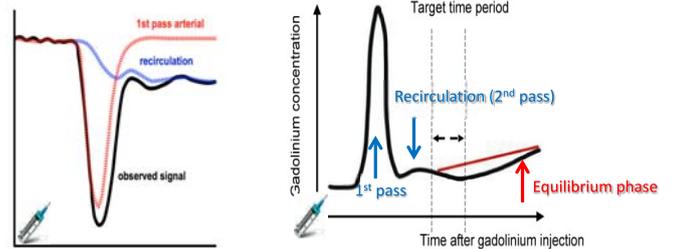
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Tissue Classification

DSC-MRI for measuring Vascular permeability (K2)
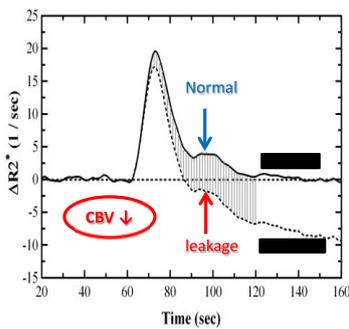

Bang et al., Ann Neurol 2007;62:170–176

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

Detect contrast agent leakage by DSC-MRI

• 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.

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

Methods for Measuring Leakage by DSC-MRI

• Preloading Dose (Opts) + Weisskoff model

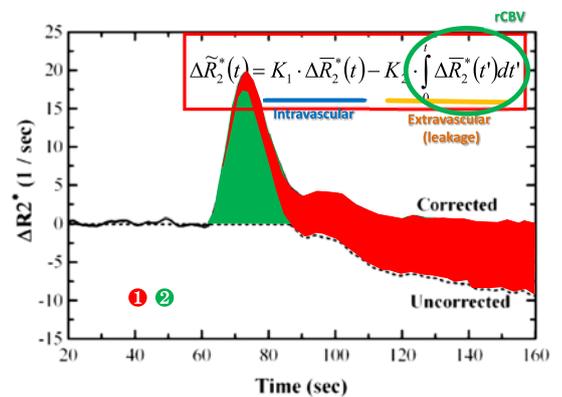• Dual echo (spin and gradient echo, SAGE) + Vonken model

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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.
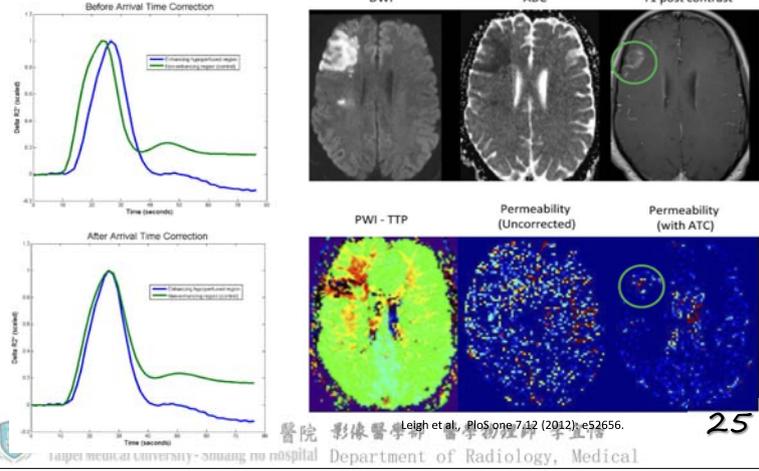 – Too high dose may collide the assumptions of Weisskoff model.

Weisskoff Model

$$\Delta \widetilde{R}_2^*(t) = K_1 \cdot \Delta \overline{R}_2^*(t) - K_2 \cdot \int_0^t \Delta \overline{R}_2^*(t')dt'$$

Boxerman et al., AJNR, 2006

Arrival time correction (ATC)

Leigh et al., PloS one 7.12 (2012): e52656.

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Weisskoff Model Correction
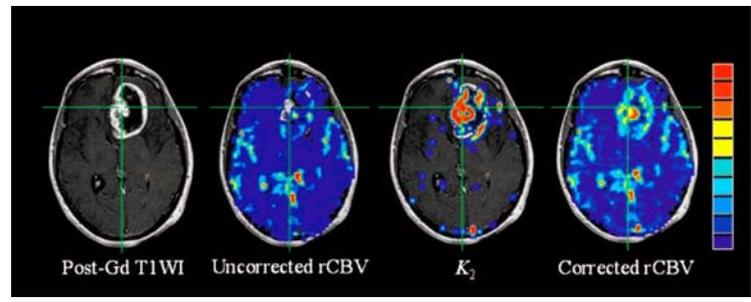
Post-Gd T1WI   Uncorrected rCBV K_2 Corrected rCBV

Boxerman et al., AJNR, 2006

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Lung meta with chemotherapy
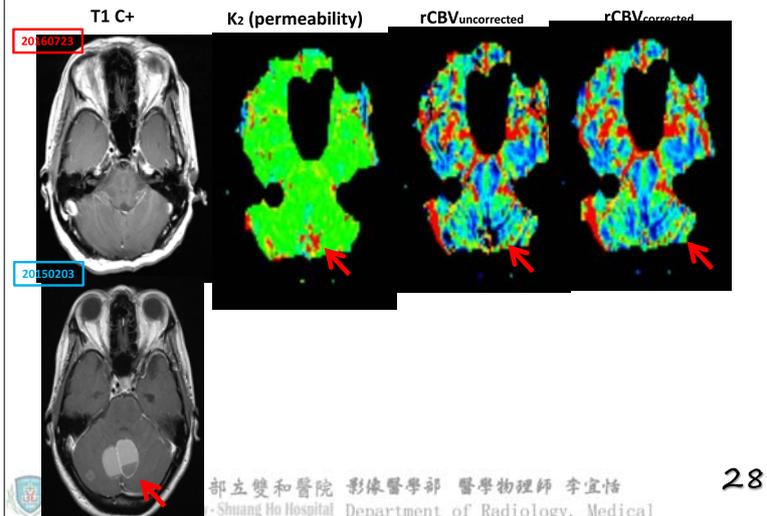
T1 C+ K_2 (permeability)   rCBV$_{uncorrected}$ rCBV$_{corrected}$

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Lung meta with chemotherapy

T1 C+ K_2 (permeability)   rCBV$_{uncorrected}$ rCBV$_{corrected}$

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Lung meta with chemotherapy
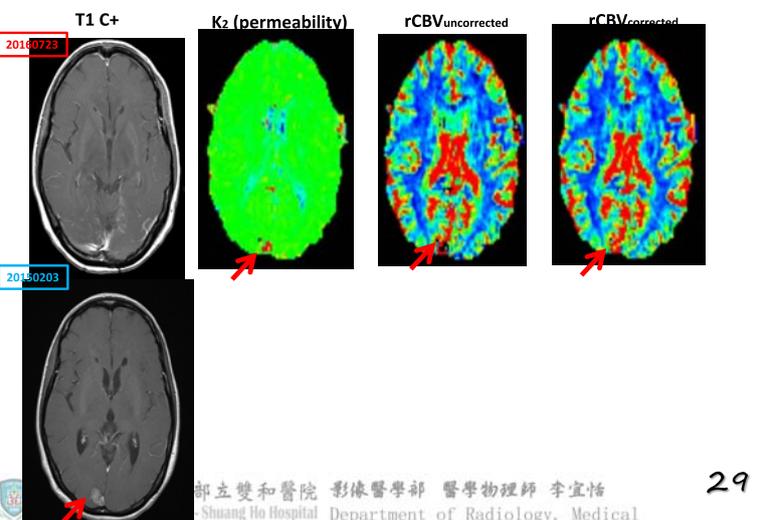
T1 C+ K_2 (permeability)   rCBV$_{uncorrected}$ rCBV$_{corrected}$

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ICA stenosis & normal perfusion with infarct
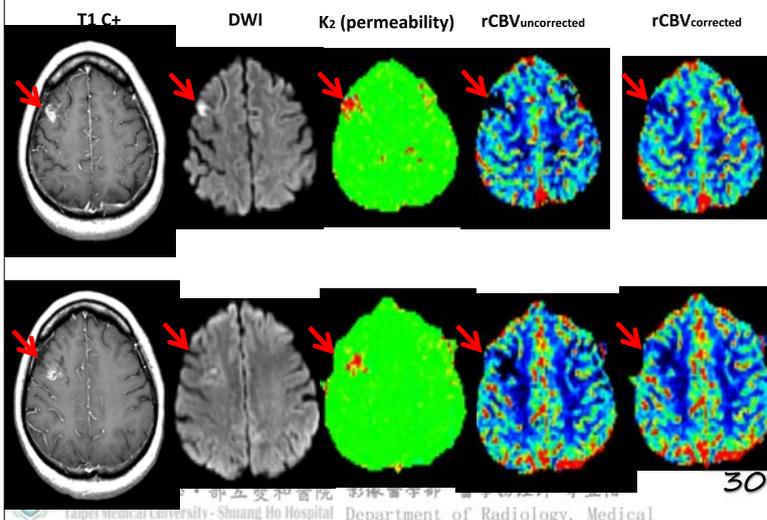
T1 C+   DWI K_2 (permeability)   rCBV$_{uncorrected}$ rCBV$_{corrected}$

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Radiation necrosis or recurrent tumor?

T1 C+ | K2 (permeability) | rCBV$_{uncorrected}$ | rCBV$_{corrected}$
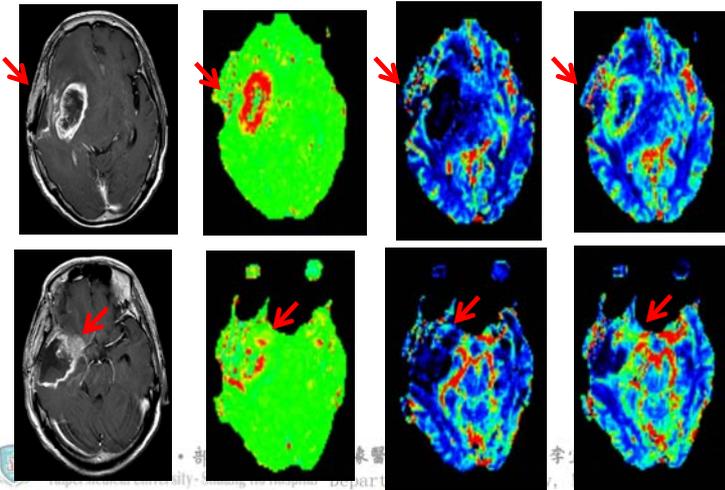
1

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.

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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

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(Pseudo) Continuous ASL

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

Transit time

RF pulse
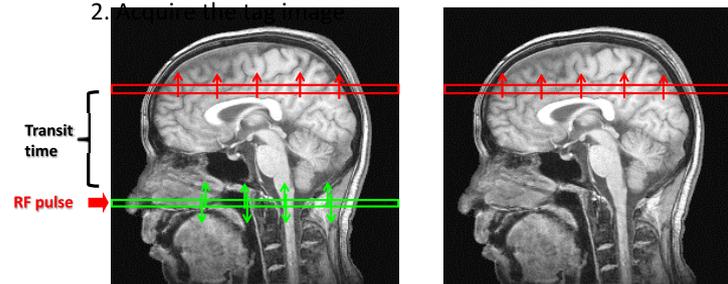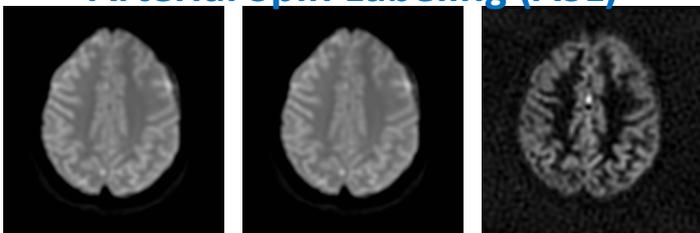
Tagging   **Control**

☐ Imaging slice   ☐ Tagging plane

Courtesy from CGMH Prof. Liu Ho-Ling

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Arterial Spin Labeling (ASL)

Control — Labeling = ΔM

- 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

Courtesy from CGMH Prof. Liu Ho-Ling

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# Potential Confounds in CBF Quantification with ASL Imaging

- Intra-arterial signal effects

- Transit/ Trailing time effects

- Relaxation effects

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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**
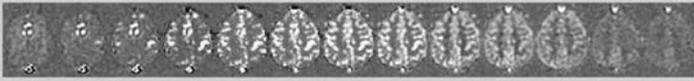
With Gradient Crushers

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

Courtesy from CGMH Prof. Liu Ho-Ling

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Intra arterial signal effects

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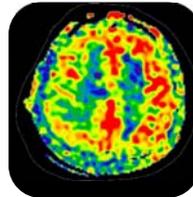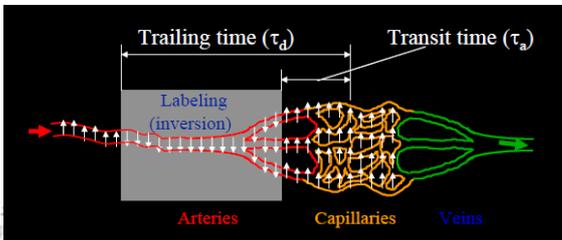

Intra-arterial blood (Slow flow)?
L't hyperperfusion?

R't hypoperfusion?
Tagging artifact (Stent cases)

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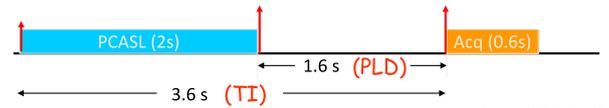

Transit/ Trailing Time Effects

- 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
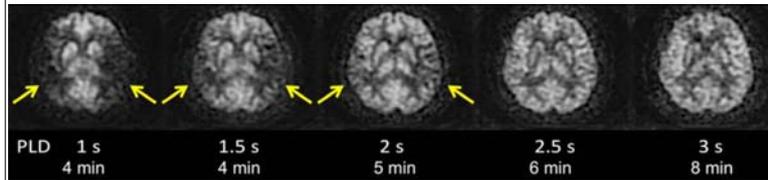 2. Blood Traveling time from arterials to capillaries.

Trailing time (τ_d)   Transit time (τ_a)

Labeling (inversion)

Arteries   Capillaries   Veins

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Post Labling Delay

PCASL (2s)   Acq (0.6s)

1.6 s (PLD)

3.6 s (TI)

Courtesy CGMH Prof. Liu Ho-Ling

PLD   1 s   1.5 s   2 s   2.5 s   3 s
      4 min   4 min   5 min   6 min   8 min

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

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

Solution to Transit Delay

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

Longer PLD

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1.5T VS 3T

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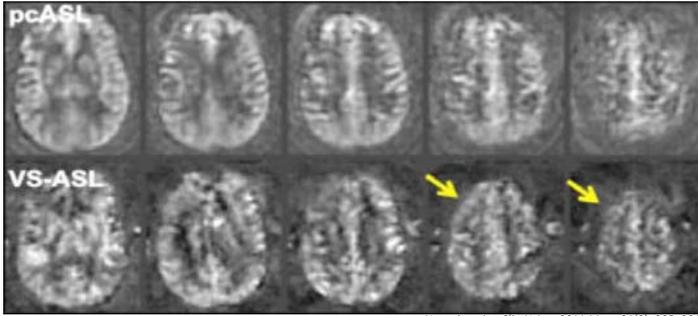 - Longer blood T_1: Allow longer post labling delay
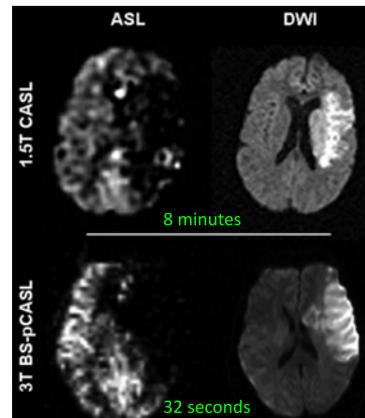
ASL   DWI

1.5T CASL

8 minutes

3T BS-pCASL

32 seconds

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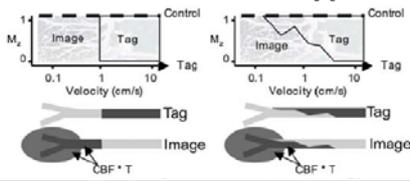
Neurotherapeutics. 2007 July ; 4(3): 346–359.

VASL

A patient with Moyamoya disease and bilateral MCA occlusion
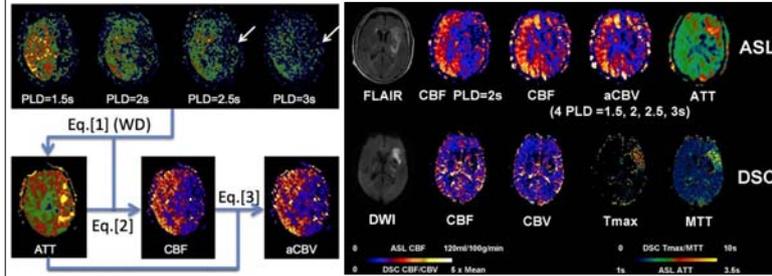
pcASL

VS-ASL

Neuroimaging Clin N Am. 2011 May ; 21(2): 285–301
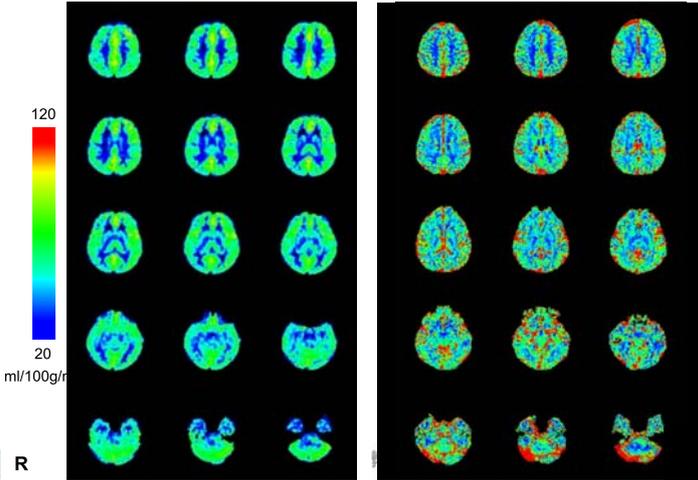
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Multiple PLD

- 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 leptomeningeal MCA territories

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3D ASL   GE-DSC

120

20
ml/100g/m

R

6

3D ASL   SE-DSC

120

20
ml/100g/m

R

7

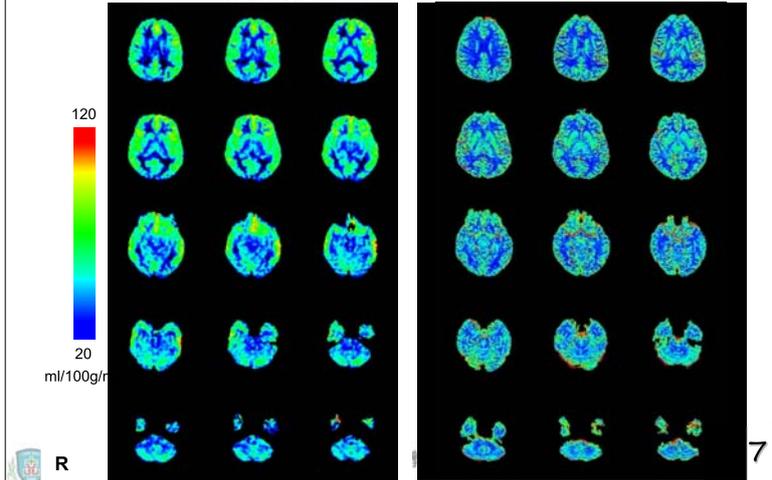
Conclusions

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

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