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School of Medicine

Perfusion MRI

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Perfusion

- The delivery of blood to a capillary bed in tissue
- Perfusion parameters
  - Blood flow: the rate at which blood is delivered to tissue in ml/100g/min
  - Blood volume: the volume of blood per unit tissue mass in ml/100g
  - Mean transit time: the average time a tracer residing within the system in sec.
  - Vessel permeability: the transfer of a tracer from intravascular space to extravascular-extracellular space

- Clinical relevance
  - hyper/hypo metabolism & ischemia: blood flow
  - abnormal vascularization (i.e. angiogenesis): blood volume, mean transit time, time-to-peak
  - BBB breakdown: vessel permeability

MRI Method

- Endogenous contrast (blood)
  - Freely diffusible including interior of cells

  - Arterial Spin Labeling (ASL) MRI

- Gd-based contrast agent
  - Gadolinium: paramagnetic element causing T2/T2*/T1 shortening
  - Extracellular tracer: passing through vessel walls but not in the brain due to blood brain barrier

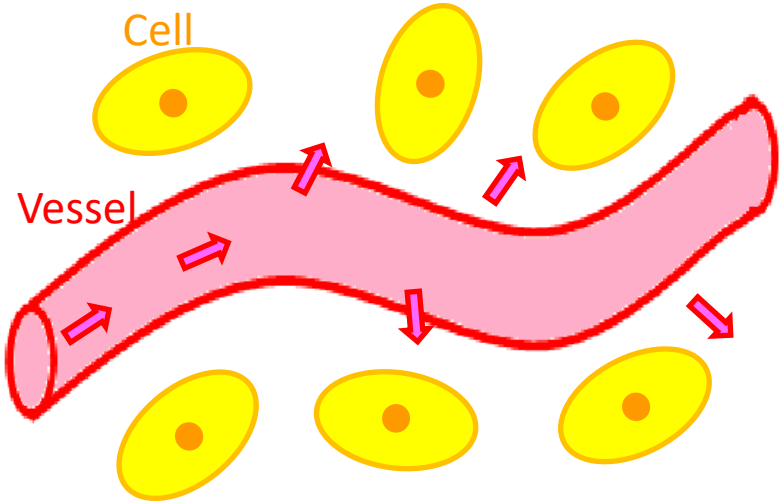
  - Dynamic Susceptibility Contrast (DSC) MRI
  - Dynamic Contrast Enhanced (DCE) MRI

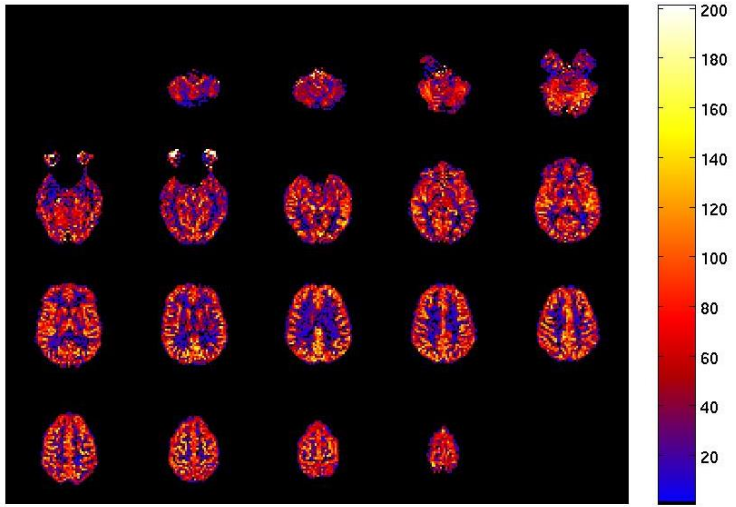
Gd-DTPA

Gd-BOPTA

Arterial Spin Labeling (ASL)

- A method for measuring blood flow
- Blood signal inverted in tag but not in control
- ASL signal from subtraction of tag/control

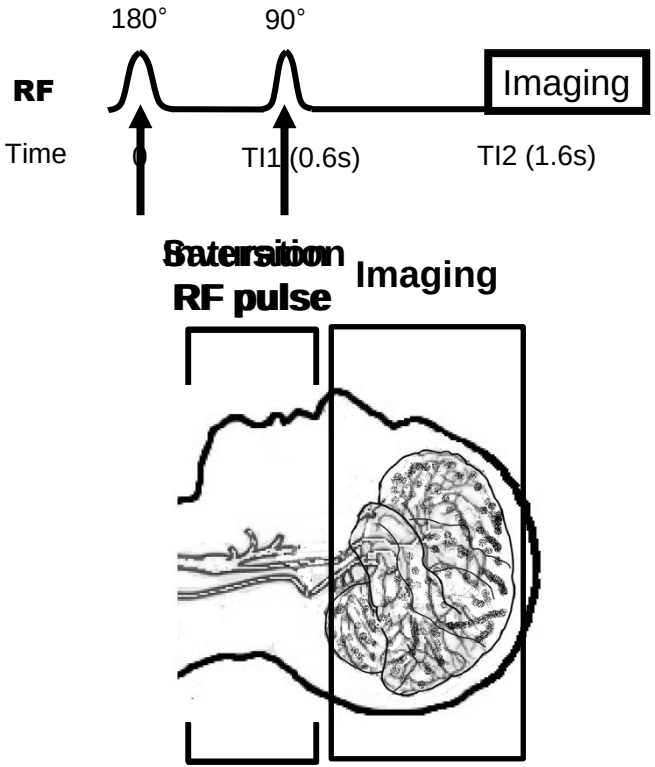




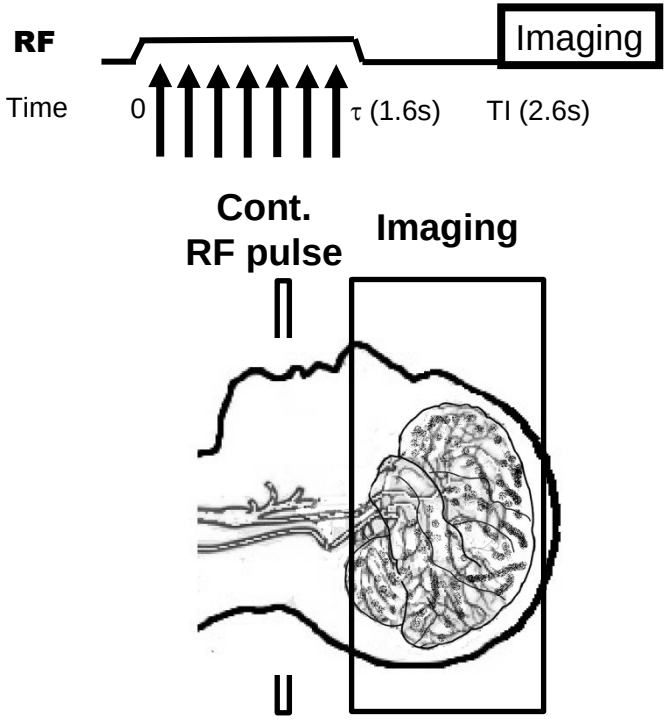
Masked CBF [ml/100g/min] (Whole brain=49.73) (Scan time=4m 20s)

Arterial Spin Labeling (ASL)

- Pulsed ASL

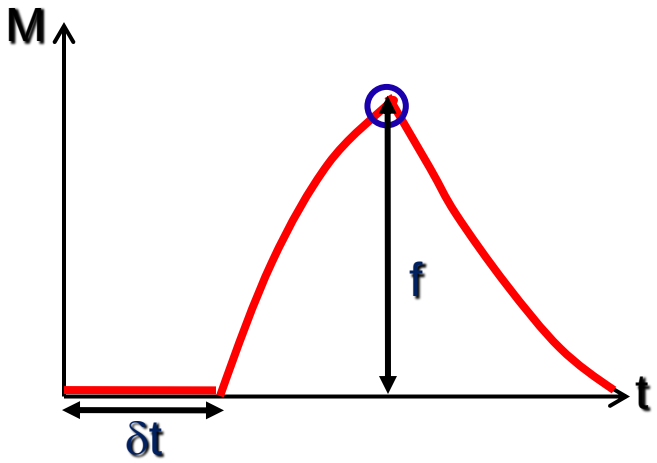


- Continuous ASL or Pseudo-continuous ASL



Arterial Spin Labeling (ASL)

- Quantification into Blood Flow
  - Assume the entire labeled signal delivered to tissue
  - Estimate blood magnetization (M_{0blood}) from a reference signal (tissue or CSF)



- PASL

$$CBF = \frac{\Delta M \; 6000}{2\alpha M_{0blood} TI_1 e^{-TI_2/T1_{blood}}} \; [\text{ml/100g/min}]$$

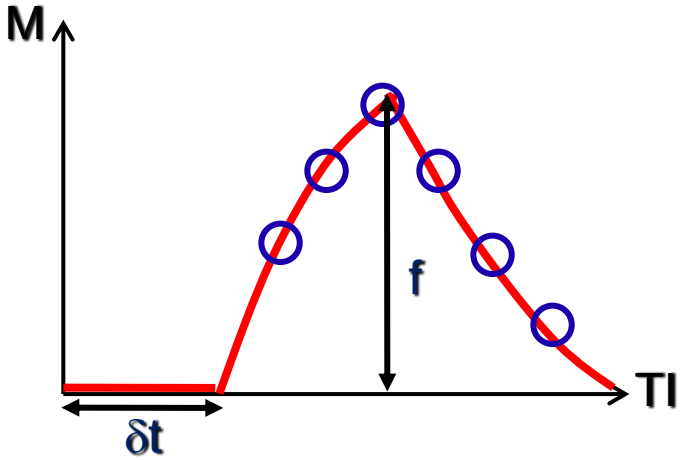
- CASL or PCASL

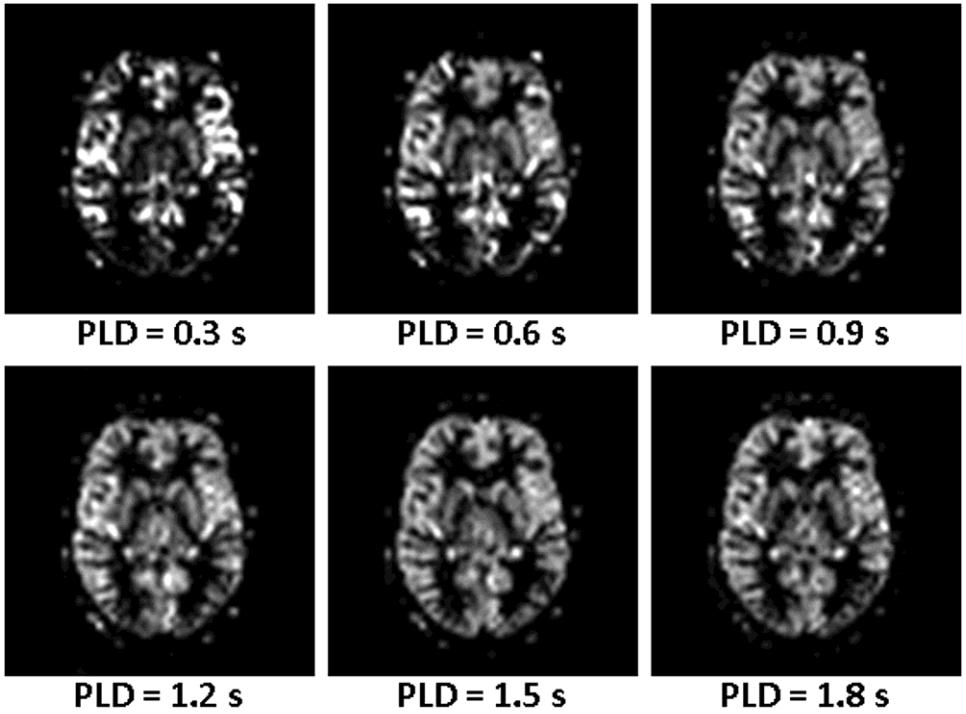
$$CBF = \frac{\Delta M \; 6000}{2\alpha M_{0blood} \; TI_1 T1_{blood} e^{-\frac{TI}{T1_{blood}}} (e^{\frac{\tau}{T1_{blood}}} - 1)}$$

ΔM = perfusion weighted signal (control – tag), α = tagging efficiency, $T1_{blood}$ ≈ 1.66s @3T

Arterial Spin Labeling (ASL)

- How long to wait?

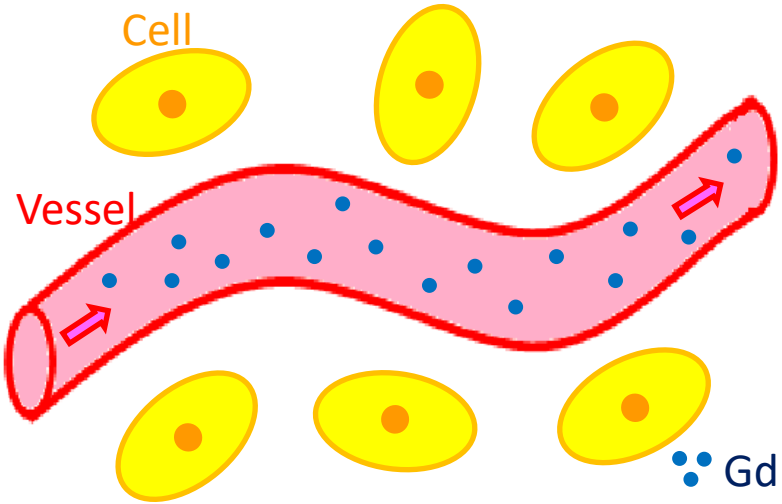


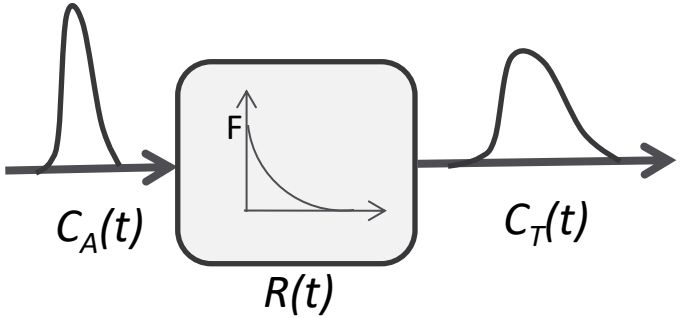


Transit delay effect!

Dynamic Susceptibility Contrast (DSC)

- **Kinetic Model**





$$C_T(t) = R(t) \otimes C_A(t)$$

CBF ∝ F (by deconvolution)

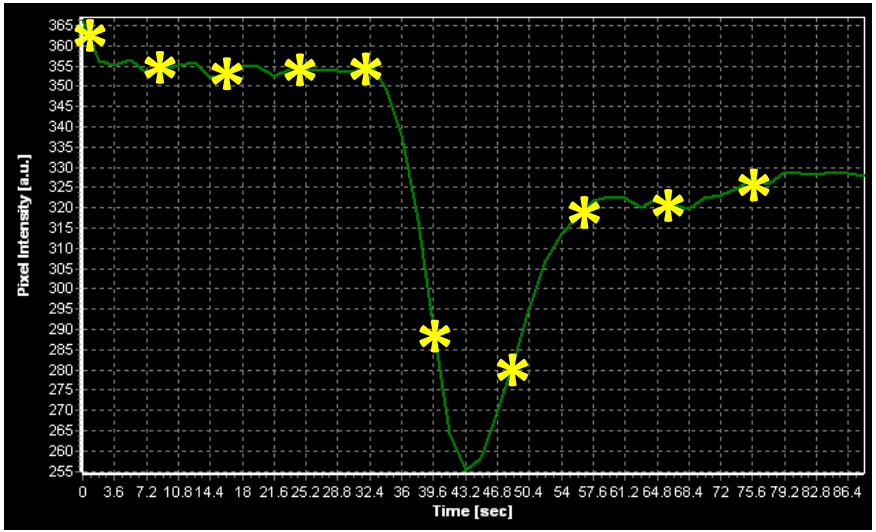
CBV = $\int_0^\infty C_T(t)dt \,/\, \int_0^\infty C_A(t)dt$

MTT = CBV/CBF or

$$\int_0^\infty R(t)dt$$

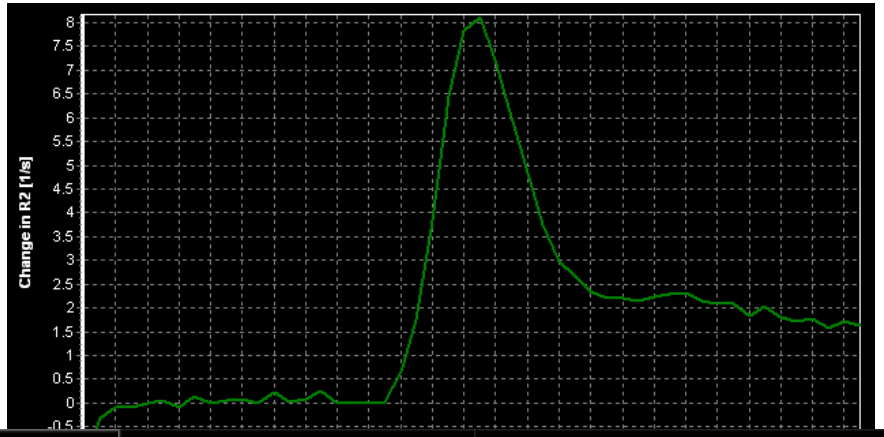
Dynamic Susceptibility Contrast (DSC)

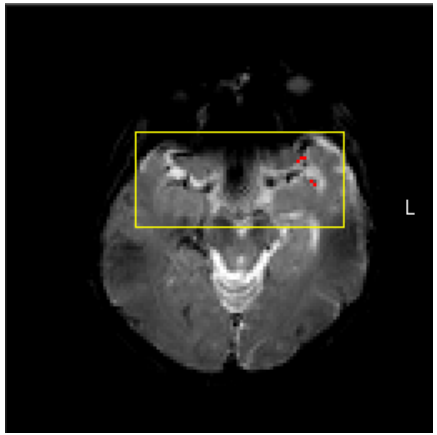
- T2/T2* effect at first passage
- A series of T2/T2* weighted images
  - T2*: 2D GRE EPI w/ ~50ms TE @ 1.5T & ~1.5sec TR)
  - T2: 2D SE EPI w/ ~70ms TE @ 1.5T & ~1.5sec TR)

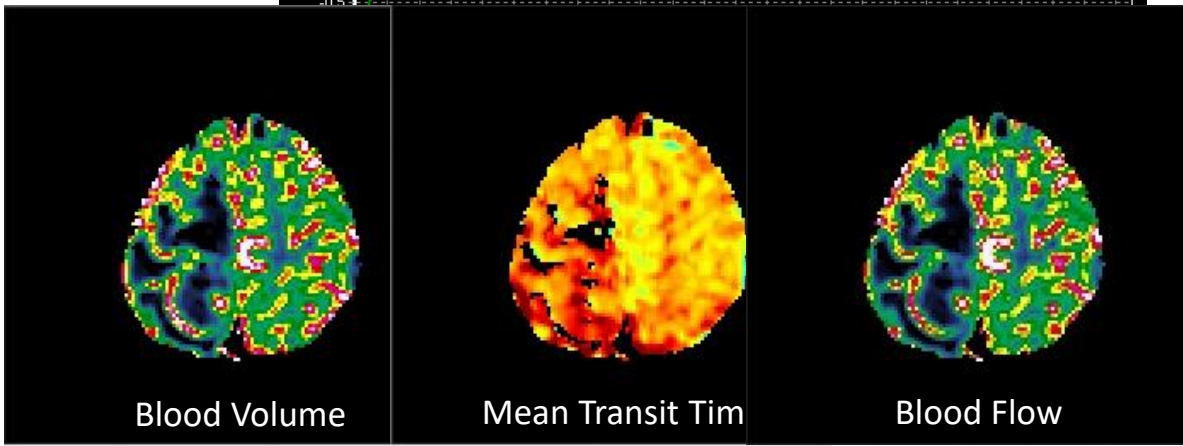


Dynamic Susceptibility Contrast (DSC)

- Analysis of the dynamic curve per voxel
  - Conversion into ΔR2* signal ([Gd] ∝ ΔR2*)
  - Finding AIF
  - Calculation of CBF, MTT, & CBV

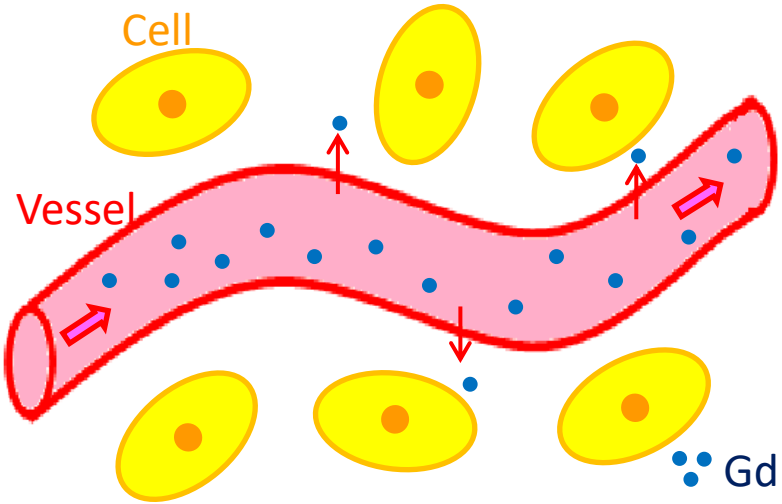






Dynamic Susceptibility Contrast (DSC)

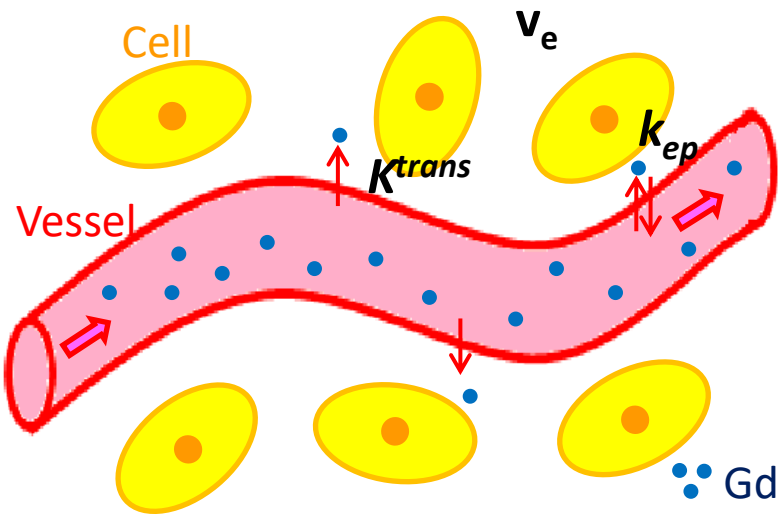
- **Contrast Agent Leakage**

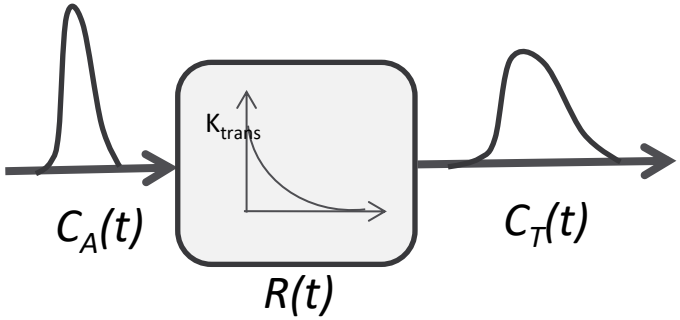


Leakage correction or preload is required!

Dynamic Contrast Enhanced (DCE)

- **Contrast Agent Leakage**





$$CBV \approx 0$$

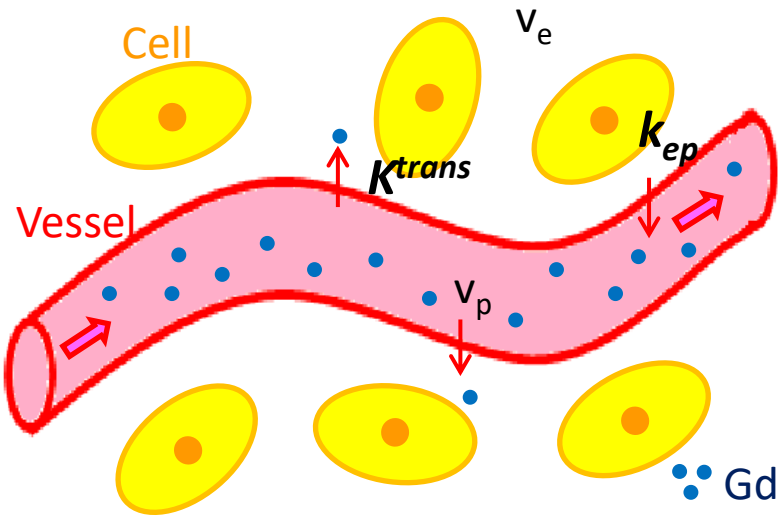
$$C_T(t) = R(t) \otimes C_A(t)$$

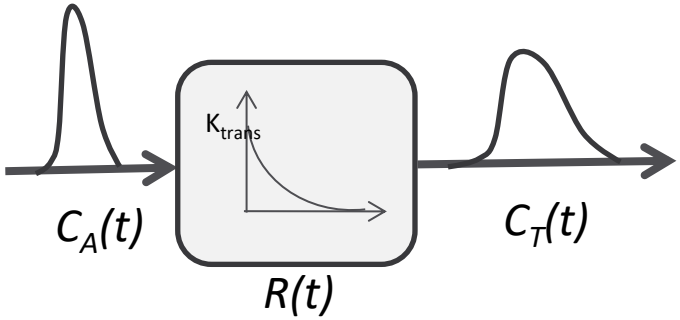
$$R(t) = K^{trans} e^{-\frac{K^{trans}}{V_e} t}$$

Tofts model

Dynamic Contrast Enhanced (DCE)

- **Contrast Agent Leakage**





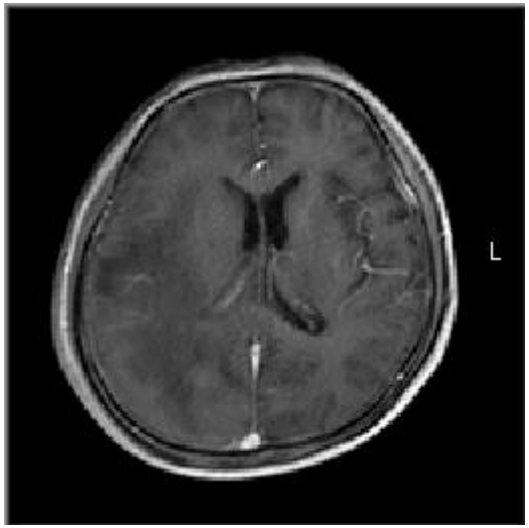
$$C_T(t) = R(t) \otimes C_A(t) + v_p C_A(t)$$

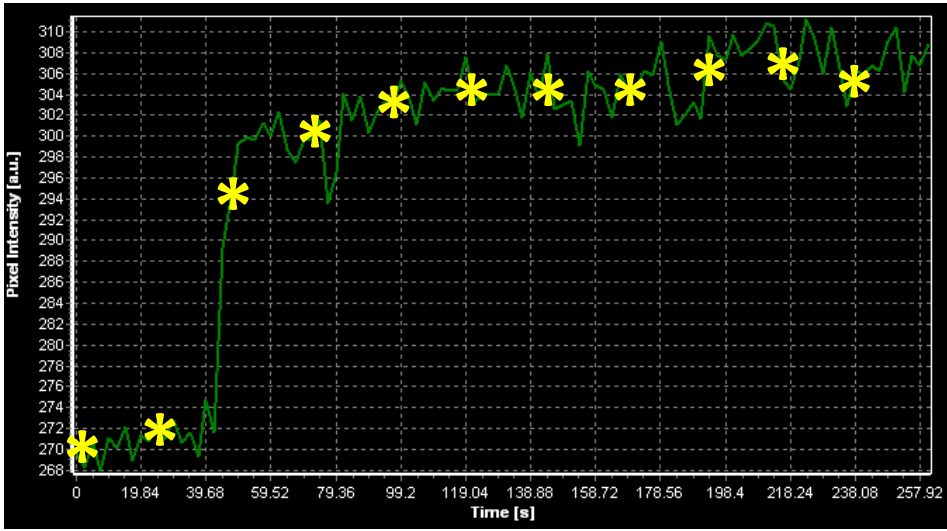
$$R(t) = K^{trans} e^{-\frac{K^{trans}}{V_e} t}$$

Extended Tofts model

Dynamic Contrast Enhanced (DCE)

- T1 weighted, longer response.
- A series of T1 weighted images (3D SPGR w/ short TE, short TR, 15~30^{o} flip angle, ~5 sec temporal resolution, ~5 min scan time)

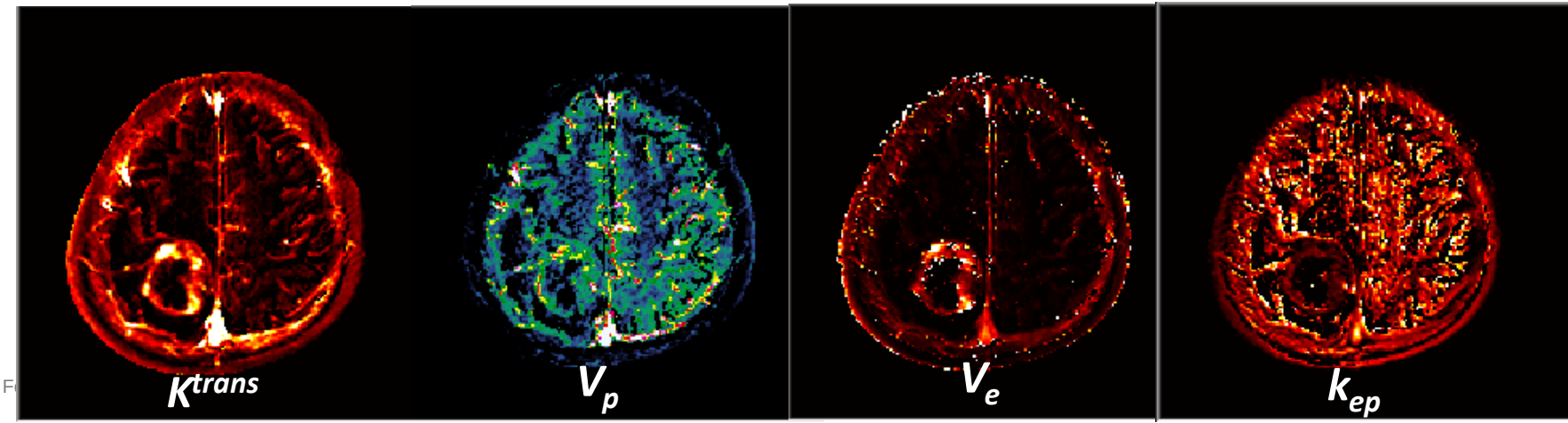




Dynamic Contrast Enhanced (DCE)

- Analysis of the dynamic curve per voxel
  - Conversion of signal into [Gd]

    ([Gd] ∝ ΔR1, T1w Signal = $M_0 \frac{sin\alpha\ (1-e^{-TR\ R1})}{(1-\cos\alpha\ e^{-TR\ R1})}$) → tissue T1 map or assumed value
  - Finding AIF
  - Calculation of K^{trans} , V_e , V_p, k_{ep} (= K^{trans}/V_e)
  - K^{trans} related to permeability, surface area & flow



Summary

	ASL	DSC	DCE
GBCA	X	O	O
Contrast	Blood T1	T2/T2*	T1
Sequence	PASL or PCASL	T2w SE or T2*w GRE	T1w SPGR
Parameters	CBF	CBF, CBV, MTT	K^{trans}, k_{ep}, V_p, V_e
Pros	Repeatable, Ease of quantification	Short scan time, Large signal change	Evaluation of Tumor
Cons	Transit delay effect Low spatial resolution	Low spatial resolution Susceptibility artifact	Complexity of model