Perfusion MRI

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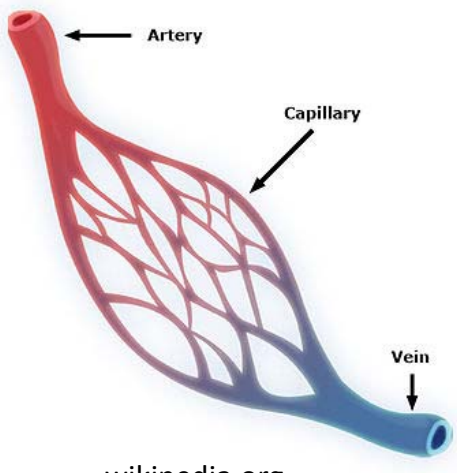
Blood Vessel

Component of circulatory system transporting blood throughout the body

- Artery: carry blood away from the heart
- Capillaries
  - Convey blood between artery and vein
  - Site of exchange of water and chemicals between blood and tissue
- Vein: carry blood back to the heart



wikipedia.org

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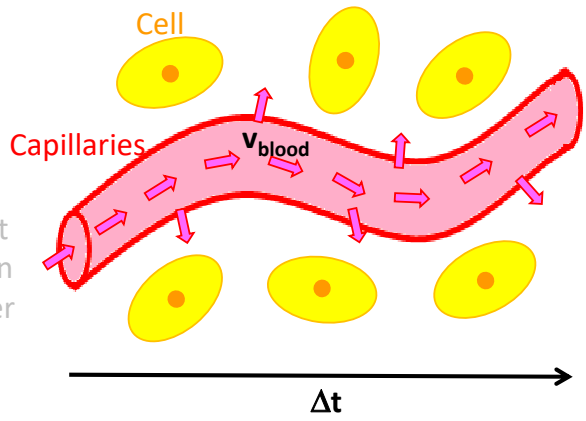
Perfusion

- The delivery of blood to a capillary bed in tissue
- Perfusion parameters
  - Blood flow: the rate of blood supply to the brain in ml/100g/min
  - Blood volume: the volume of blood per unit tissue mass in ml/100g or unitless fraction
  - Mean transit time: the average time a tracer resides within the system in second
  - Vessel permeability: the volume of blood transferred from intravascular space to extravascular-extracellular space per unit time



Perfusion

- Clinical relevance

  - hyper/hypo metabolism & ischemia: blood flow

  - abnormal vascularization (i.e. angiogenesis): blood volume, mean transit time

  - BBB breakdown in high grade tumor: vessel permeability

MRI Method

No ionizing radiation!

- Endogenous contrast (blood)
  - Freely diffusible including interior of cells
  - Arterial Spin Labeling (ASL) MRI

- Gd-based contrast agent (GBCA)
  - 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

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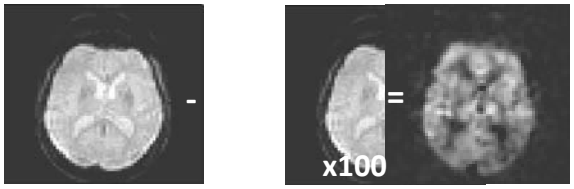
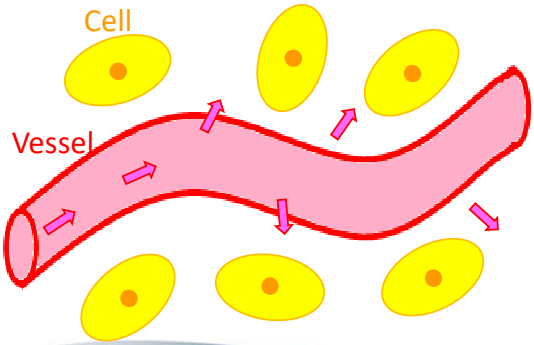
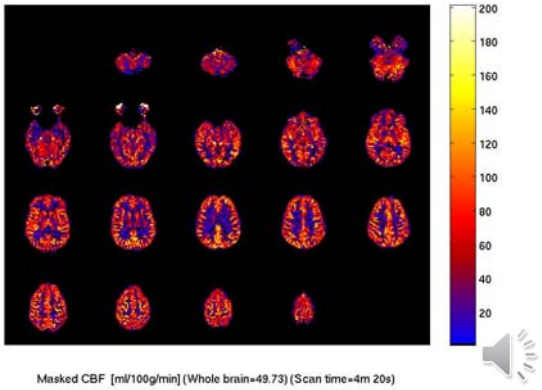
Arterial Spin Labeling (ASL)

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







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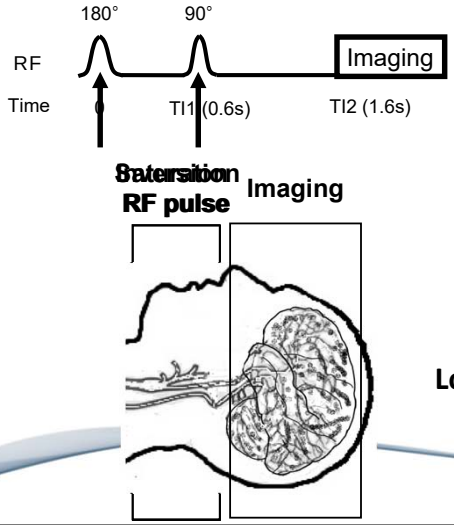
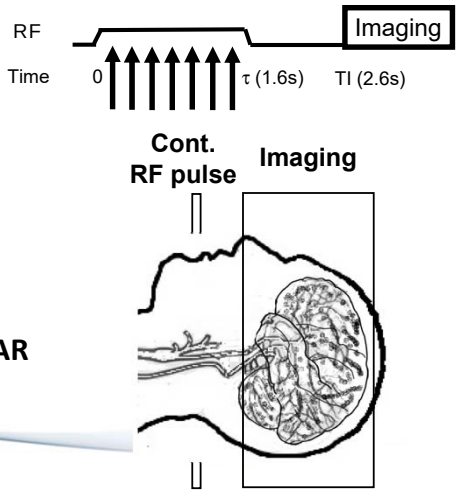
Arterial Spin Labeling (ASL)

- Pulsed ASL



- Continuous ASL or Pseudo-continuous ASL



Lower SAR **Higher SNR**

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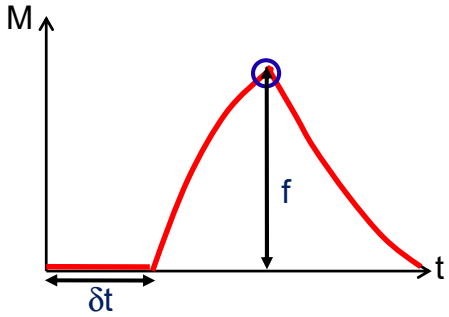
Arterial Spin Labeling (ASL)

- 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

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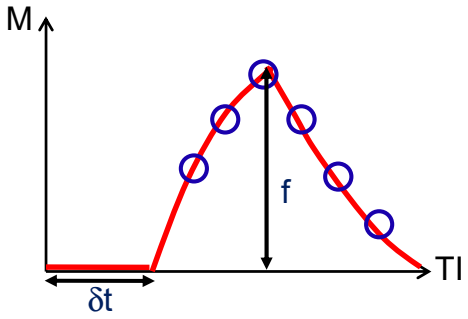
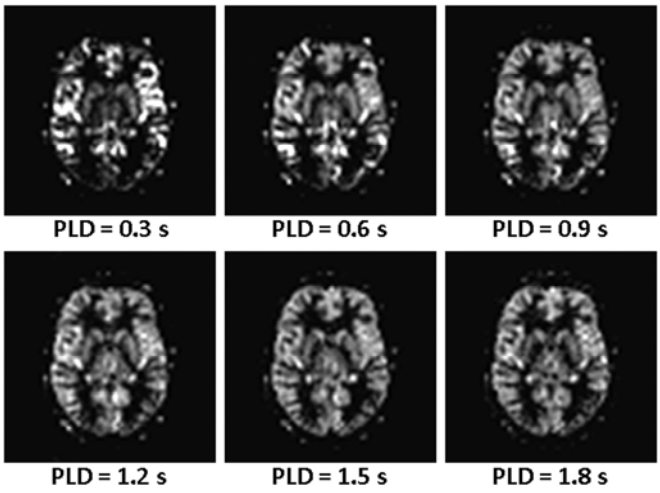
Arterial Spin Labeling (ASL)

- How long to wait?





Transit delay effect!

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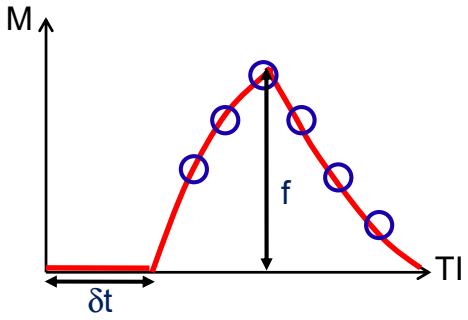
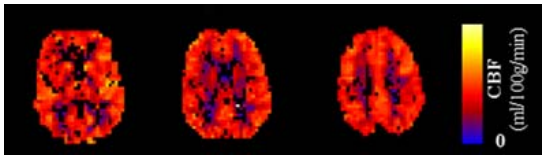
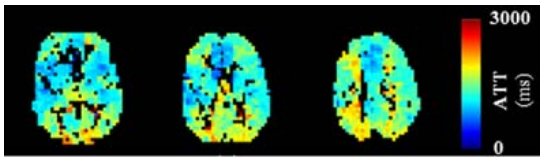
Arterial Spin Labeling (ASL)

- Multi-TI acquisition





More accurate estimation of CBF



Clinically relevant information
A time from tagging plane to tissue

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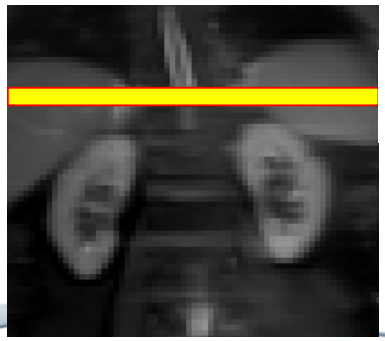
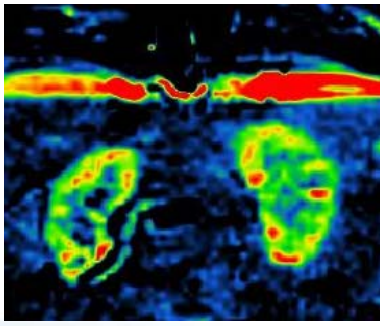
Arterial Spin Labeling (ASL)

- Renal ASL
  - GBCA contraindicated in patients with kidney dysfunction
  - can be only perfusion technique for kidney disease



Labeling Plane



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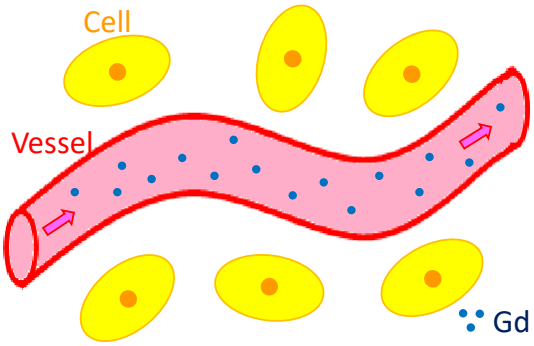
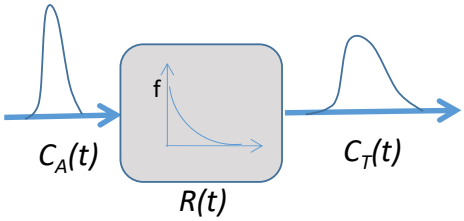
Dynamic Susceptibility Contrast (DSC)

- **Kinetic Model**





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

CBF $\propto$ max(R(t)) (by deconvolution)

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

MTT = CBV/CBF

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

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Dynamic Susceptibility Contrast (DSC)

Image Acquisition

- T2/T2* changes at first passage
- A series of T2/T2* weighted images
- High temporal resolution (≤1.5 sec) is desired to sample contrast dynamics
- Long TR is desired to minimize T1 effect
- Single-shot Echo Planar Imaging is preferred

  - T2*: 2D GRE EPI w/ ~50ms TE @ 1.5T & ~1.5sec TR)
  - T2: 2D SE EPI w/ ~70ms TE @ 1.5T & ~1.5sec TR)

- Acceleration methods (Parallel or Multiband imaging) are used for a broader coverage or a higher spatial resolution

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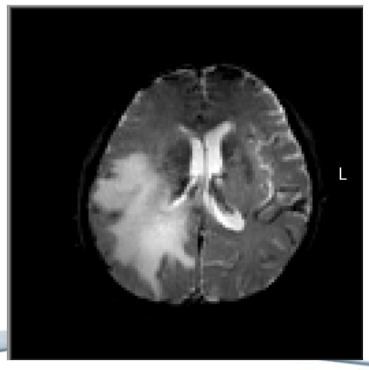
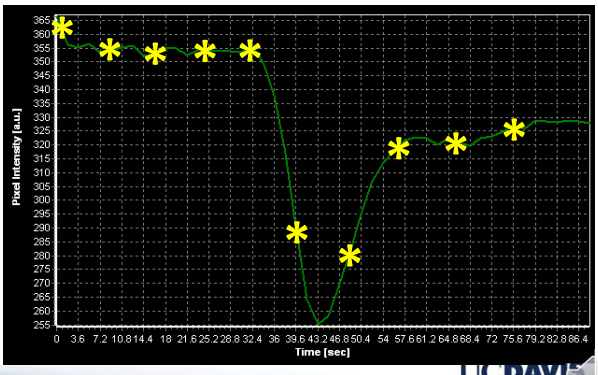
Dynamic Susceptibility Contrast (DSC)

- An example of DSC time series





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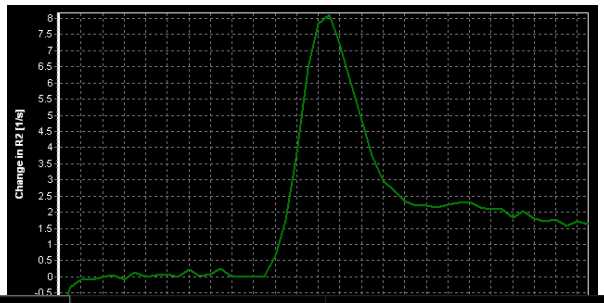
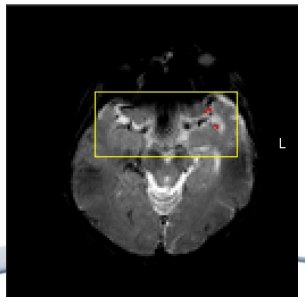
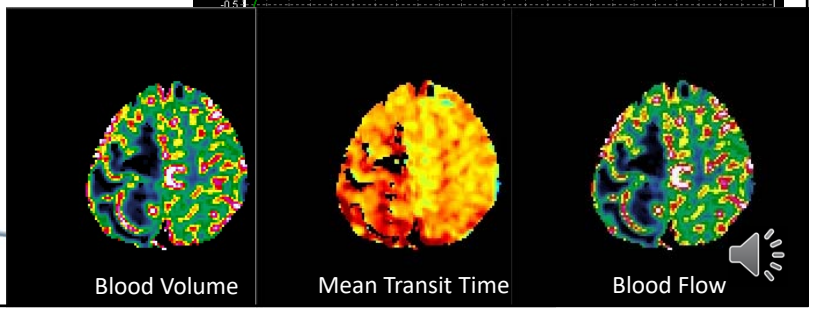
Dynamic Susceptibility Contrast (DSC)

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







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Dynamic Susceptibility Contrast (DSC)

- **GRE vs. SE**

- Change in GRE relaxivity (ΔR2*) higher than change in spin-echo relaxivity (ΔR2)

→ GRE DSC-MRI has higher SNR and sensitivity than SE DSC-MRI

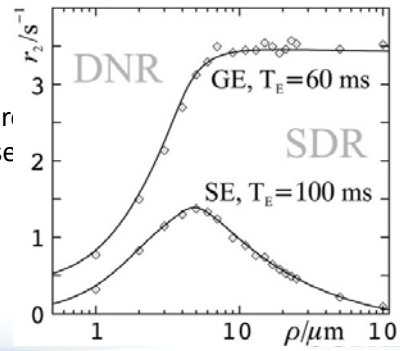
- R2*is linear with respect to [Gd] over a broader range of vessel sizes than R2

→ GRE DSC-MRI inherently more accurate than SE DSC-MRI.

→ GRE DSC-MRI more large vessel dominant.

- GRE is more prone to magnetic susceptibility artifacts (signal dr
distortions) arising from the skull base, paranasal sinuses, or rese

*GRE DSC-MRI generally preferred for tumor imaging while SE DSC-MRI immune to susceptibility artifacts.



Kiselev et al, MRM,2005

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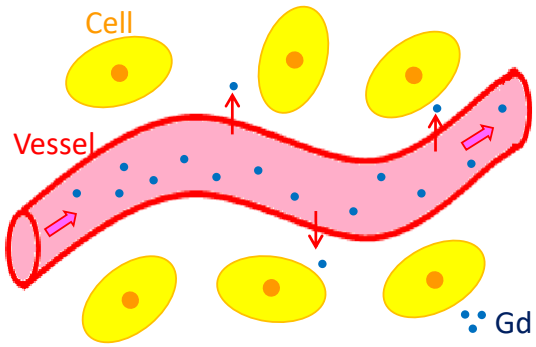
Dynamic Susceptibility Contrast (DSC)

- **Contrast leakage**



Leakage correction or
A preload (⅓ or ¼ dose)
is required!

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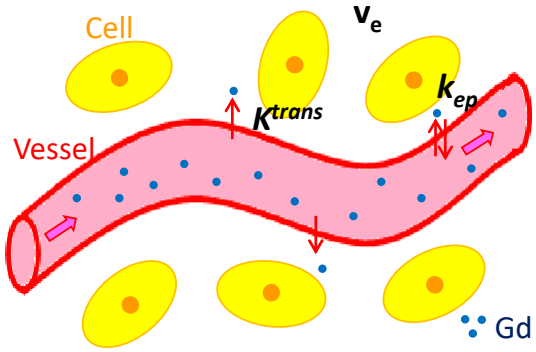
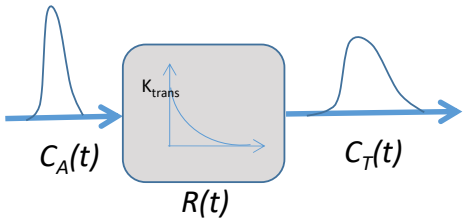
Dynamic Contrast Enhanced (DCE)

- **Contrast Agent Leakage**





CBV ≈ 0

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

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

Tofts model

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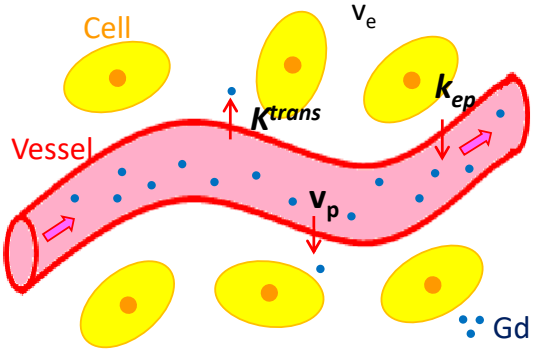
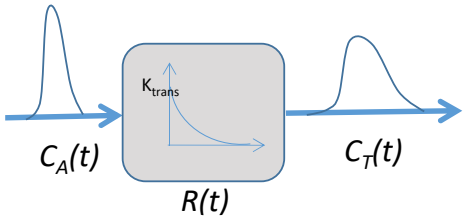
Dynamic Contrast Enhanced (DCE)

- **Contrast Agent Leakage**





CBV ≈ 0

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

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

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

Extended Tofts model

Dynamic Contrast Enhanced (DCE)

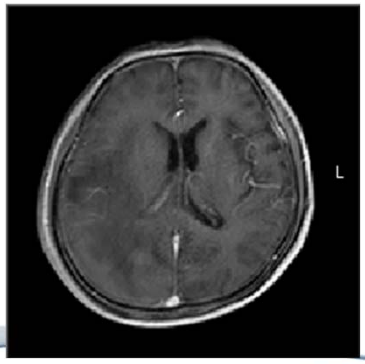
Image Acquisition

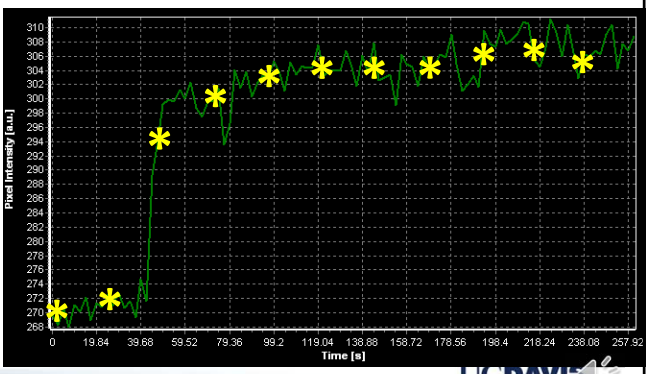
- A series of T1 weighted images
- Longer scan time for relatively slower response
- Minimum TE to minimize T2*shortening effect
- Short TR for T1 weighting and acquisition speed
- 3D SPGR w/ short TE (~5ms), short TR (~12ms), 15~30^o flip angle, ~5 sec temporal resolution, ~5 min scan time

- Acceleration method (Parallel imaging in phase encoding and slice encoding directions) is widely used to improve temporal resolution but SNR penalty

Dynamic Contrast Enhanced (DCE)

- An example of DCE time series





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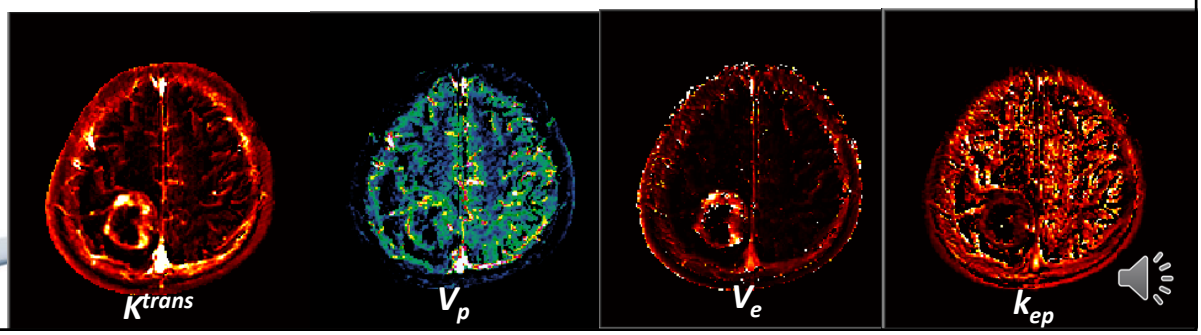
Dynamic Contrast Enhanced (DCE)

- 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



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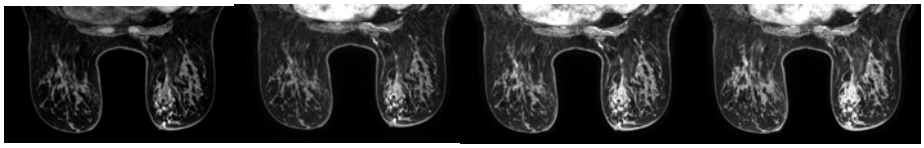
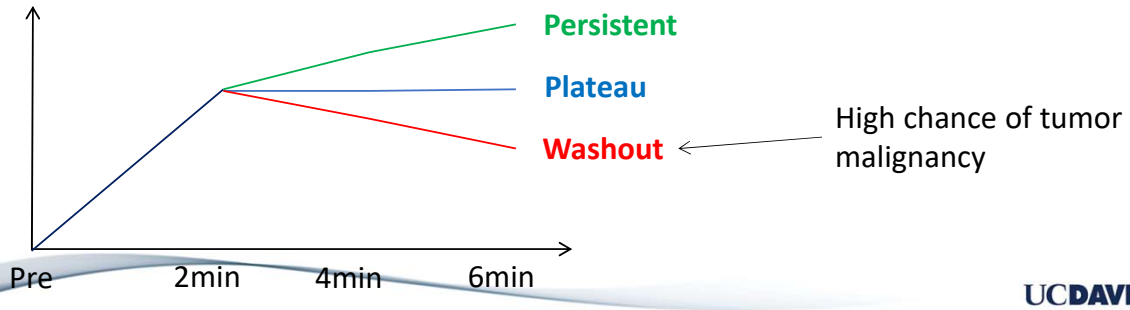
Dynamic Contrast Enhanced (DCE)

- Breast imaging
  - High spatial resolution (1~2mm isotropic), 1~3 min temporal resolution





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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 Leakage
Cons	Transit delay effect Low spatial resolution	Low spatial resolution Susceptibility artifact	Complexity of model
Clinical Use	Used to measure blood flow of brain	Most widely used for brain (strokes/tumors)	Most widely used for evaluating tumors/response to therapy

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