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
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: may pass through vessel walls not into the neurons
  - Dynamic Susceptibility Contrast (DSC) MRI
  - Dynamic Contrast Enhanced (DCE) MRI

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

![Arterial Spin Labeling Diagram](image)
Arterial Spin Labeling (ASL)

- Quantification into Blood Flow
  - T1 decay of blood ($T1_{blood}$)
  - Estimate blood magnetization ($M_{0,\text{blood}}$) from a reference signal (tissue or CSF)

$$CBF = \frac{\Delta M \times 6000}{2\alpha M_{0,\text{blood}}T1_{\text{blood}}} e^{\frac{T(t)}{T1_{\text{blood}}}} (e^{\frac{T1_{\text{blood}}}{T1_{\text{blood}}}} - 1)$$

$\Delta M$ = perfusion weighted signal (control – tag), $\alpha$ = tagging efficiency

$1.66$ s @ $3T$

Arterial Spin Labeling (ASL)

- How long to wait?

$\Delta M$ = perfusion weighted signal (control – tag), $\alpha$ = tagging efficiency

$1.66$ s @ $3T$

Transit delay effect!
Arterial Spin Labeling (ASL)

• Multi-TI acquisition

![Graph showing M against t with δt and f labels.]

More accurate estimation of CBF

![Brain images showing Arterial Transit Time (or Bolus Arrival Time).]

A time from tagging plane to tissue
Arterial Transit Time (or Bolus Arrival Time)
Clinically relevant information

Dynamic Susceptibility Contrast (DSC)

• Kinetic Model

![Diagram with Cell, Vessel, and Gd labels.]

\[ C_T(t) = R(t) \otimes C_A(t) \]

\[ \text{CBF} \propto \max(R(t)) \] (by deconvolution)

\[ \text{CBV} = \int_0^\infty C_T(t)dt / \int_0^\infty C_A(t)dt \]

\[ \text{MTT} = \text{CBV} / \text{CBF} \]

or \[ \int_0^\infty R(t)dt \]
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

Dynamic Susceptibility Contrast (DSC)

- An example of DSC time series
Dynamic Susceptibility Contrast (DSC)

- Analysis of the dynamic curve per voxel
  - Conversion into $\Delta R2^*$ or $\Delta R2$ signal ($[Gd] \propto \Delta R2^*$ or $\Delta R2$)
  - Finding AIF
  - Calculation of CBF, MTT, & CBV

Dynamic Susceptibility Contrast (DSC)

- **Contrast leakage**

Leakage correction or a preload (⅓ or ¼ dose) is required!
Dynamic Contrast Enhanced (DCE)

- Contrast Agent Leakage

\[
\frac{\text{CBV}}{\text{CT}(t)} = \frac{\text{R}(t) \otimes \text{CA}(t)}{\text{V}_e}
\]

\[
R(t) = K_{\text{trans}} e^{-k_{\text{ep}} t}, \quad k_{\text{ep}} = \frac{K_{\text{trans}}}{V_e}
\]

**Tofts model**

Dynamic Contrast Enhanced (DCE)

- Contrast Agent Leakage

\[
\frac{\text{CBV}}{\text{CT}(t)} = \frac{\text{R}(t) \otimes \text{CA}(t)}{\text{V}_e}
\]

\[
R(t) = K_{\text{trans}} e^{-k_{\text{ep}} t}, \quad k_{\text{ep}} = \frac{K_{\text{trans}}}{V_e}
\]

**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° 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
Dynamic Contrast Enhanced (DCE)

- Analysis of the dynamic curve per voxel
  - Conversion of signal into [Gd]
    \[
    ([\text{Gd}] \propto \Delta R1, \text{T1w Signal} = M0 \frac{\sin(1-e^{-TRR1})}{(1-\cos \alpha e^{-TRR1})}) \rightarrow \text{tissue T1 map or assumed value}
    \]
  - Finding AIF
  - Calculation of \(K_{\text{trans}}, V_e, V_p, k_{\text{ep}} (= \frac{K_{\text{trans}}}{V_p})\)
  - \(K_{\text{trans}}\) related to permeability, surface area & flow

Dynamic Contrast Enhanced (DCE)

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

- High chance of tumor malignancy
## Summary

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<td>O</td>
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<td>T2w SE or T2*w GRE</td>
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<td>CBF, CBV, MTT</td>
<td>$k^{\text{trans}}, k_{\text{ep}}, V_p, V_e$</td>
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<td>Repeatable, Ease of quantification</td>
<td>Short scan time, Large signal change</td>
<td>Evaluation of Leakage</td>
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<td>Transit delay effect Low spatial resolution</td>
<td>Low spatial resolution Susceptibility artifact</td>
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<td>Most widely used for brain (strokes/tumors)</td>
<td>Most widely used for evaluating tumors/response to therapy</td>
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