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**
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 (ASL)

- **Pulsed ASL**
  
<table>
<thead>
<tr>
<th>Time</th>
<th>180°</th>
<th>90°</th>
<th>Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>TI1</td>
<td>(0.6s)</td>
<td>TI2 (1.6s)</td>
<td></td>
</tr>
</tbody>
</table>

- **Continuous ASL or Pseudo-continuous ASL**
  
<table>
<thead>
<tr>
<th>Time</th>
<th>0</th>
<th>τ (1.6s)</th>
<th>TI (2.6s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td></td>
<td>Cont. RF pulse</td>
<td>Imaging</td>
</tr>
</tbody>
</table>
Arterial Spin Labeling (ASL)

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

- PASL

$$CBF = \frac{\Delta M \ 6000}{2\alpha M_{0\text{blood}} T_1 \ e^{-T_1/T_{1\text{blood}}}}$$

[ml/100g/min]

- CASL or PCASL

$$CBF = \frac{\Delta M \ 6000}{2\alpha M_{0\text{blood}} T_1 T_1\text{blood} e^{-T_{1\text{blood}}} \left(e^{T_{1\text{blood}}} - 1\right)}$$

$\Delta M$ = perfusion weighted signal (control – tag), $\alpha$ = tagging efficiency, $T_{1\text{blood}} \approx 1.66s$ @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 \(\propto F\) (by deconvolution)

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

\[
\text{MTT} = \text{CBV} / \text{CBF} \quad \text{or} \quad \int_0^\infty R(t) \, dt
\]
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 $\Delta R2^*$ signal
    \[ [\text{Gd}] \propto \Delta R2^* \]
  - 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

\[ \text{CBV} \approx 0 \]
\[ C_T(t) = R(t) \otimes C_A(t) \]
\[ R(t) = K_{\text{trans}} e^{-\frac{K_{\text{trans}}}{V_e} t} \]

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\(^\text{o}\)~30\(^\text{o}\) 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]

\[ ([\text{Gd}] \propto \Delta R1, \text{T1w Signal} = M_0 \frac{\sin \alpha (1-e^{-TR R1})}{(1-\cos \alpha e^{-TR R1})} \rightarrow \text{tissue T1 map or assumed value} \]

- Finding AIF
- Calculation of $K_{\text{trans}}$, $V_e$, $V_p$, $k_{ep} (= K_{\text{trans}}/V_e)$
- $K_{\text{trans}}$ related to permeability, surface area & flow
## Summary

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