**TOF MRA**

11. Internal carotid a. (ICA)
2. Cavernous sinus part
3. Temporal bone part
1. Anterior cerebral a. (ACA)
4. Posterior cerebral a. (PCA)
13. Anterior communicating a. (ACoA)
7. Posterior communicating a. (PCoA)
9. Middle cerebral a. (MCA)
8. Branch on the surface of the insula
12. Vertebral a. (VA)
5. Basilar a. (BA)
6. Superior sagittal sinus
10. Ophthalmic a.

**Blood supply of the brain**


**Circle of Willis**

本週課程內容 [http://www.ym.edu.tw/~cflu](http://www.ym.edu.tw/~cflu)

- 動態磁化率對比影像 (Dynamic Susceptibility Contrast, DSC)
- 動態對比增強影像 (Dynamic Contrast Enhancement, DCE)
Perfusion imaging

- The information on the capillary microcirculation of tissue
- Three major techniques
  - Dynamic susceptibility contrast (DSC) MRI
  - Dynamic contrast enhancement (DCE) MRI
  - Arterial spin labeling (ASL) MRI
- Quantitative measurements
  - Blood volume (BV)
  - Blood flow (BF)
  - Temporal data (MTT, TTP)
  - Parameters of the pharmacokinetic model ($K_{trans}$, $v_p$, $v_e$, $K_{ep}$)

Contrast agent and permeability

- Chelates have a high affinity for metal ions.
- Gd chelates are paramagnetic and relatively safe.
  - Shorten T1 and T2 relaxation time
- In a patient with normal renal function, the biological half-life of Gd chelates is 2 hours.
- Majorly excreted by the renal system.
DSC MRI

- bolus tracking of Gd-DTPA contrast agent, reduce T2 and T2* relaxation time

Serial DSC images

1-8 sec
9-16 sec
17-24 sec
25-32 sec
33-40 sec
41-48 sec
49-56 sec

Imaging Parameters

- A multi-slice gradient-echo echo-planar imaging
- Transverse (axial) imaging
  - TR/TE = 1000/60 ms
  - FOV = 240 x 240 mm², matrix = 128 x 128,
  - slice thickness/gap = 5/5 mm
  - 70 images per slice location with a one second temporal resolution (TR = 1000 ms).
Contrast Agent Administration

- Twenty ml of Gd-DTPA-BMA (Omniscan™) followed by 20 ml of normal saline were delivered administratively using a power injector at a flow rate of 3–4 ml/s in the antecubital vein.

DSC MRI

- T2-weighted SE-EPI: specific to the micro-vascular compartment
- T2*-weighted GRE-EPI: also take into account larger vessels

- Post-processing
  - Extract the first pass signal (gamma-fitting) and remove the recirculation signal
  - Define the arterial input function (AIF)
  - Deconvolution of tissue concentration-time curves by the AIF

DSC Processing

An approximate linear relationship exists between tissue contrast agent concentration and change in T2 relaxation rate

\[ \Delta R_2(t) \propto C_r(t), \quad C_r(t) = -\frac{k}{T_E} \cdot \log \left( \frac{S(t)}{S(0)} \right) \]

Hemodynamic maps

Relative Cerebral blood volume

\[ rCBV = \frac{\int_{\text{pass}} \Delta c(t) dt}{\int_{\text{pass}} \Delta c(t) dt} \]

Relative Cerebral blood flow

\[ C_r(t) = rCBF \cdot Ca(t) \otimes R(t) \]

Mean transit time

\[ MTT = \frac{rCBV}{rCBF} \]
Tissue Classification using DSC

99% stenosis of right internal carotid artery


T2* DSC-MRI of Mixed Mullerian Tumor

Typical acquisition 1-2 mins, DSC
(Quoted from Dr. Anwar Padhani’s slides)

T1W DCE-MRI of Mixed Mullerian Tumor

Typical acquisition 5-8 mins, DCE
(Quoted from Dr. Anwar Padhani’s slides)
T2* versus T1W Perfusion MRI

(Quoted from Dr. Anwar Padhani’s slides)

Signal Enhanced by Contrast Agent

\[ T_1 = \frac{1}{T_2 + r_1 C} \]

\( r_1 \) is the relaxivity, and usually an in-vitro value of 4.5 s\(^{-1}\) mM\(^{-1}\) is used. Often it is more convenient to use the relaxation rate:

\[ R_1 = R_{10} + r_1 C \]

The signal \( S \) from a spoilt gradient echo sequence (i.e. FLASH) is:

\[ S = S_0 \frac{1 - e^{-TR/T_1}}{1 - e^{-TR/T_1} \cos \theta} \]

where \( S_0 \) is the relaxed signal (TR > T1, =90°), and \( \theta \) is the FA. \( S_0 \) can be found from the measured pre-Gd signal (before injection of CA).

Pharmacokinetic modelling

(Toft’s two-compartment model)

The flow of Gd across the endothelium into the EES is:

\[ \nu_e C_p(t) = K^\text{trans} (C_e(t) - C_p(t)) \]

The total tissue concentration is:

\[ C_t(t) = \nu_c C_p(t) + K^\text{trans} \int_0^t C_e(\tau) e^{-\eta_e \rho_d \tau} d\tau \]

Parameters in DCE modelling

<table>
<thead>
<tr>
<th>Quantity</th>
<th>symbol</th>
<th>units</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flip angle</td>
<td>FA</td>
<td>degrees</td>
<td>fixed</td>
</tr>
<tr>
<td>Haematocrit</td>
<td>He</td>
<td>%</td>
<td>fixed (42%)</td>
</tr>
<tr>
<td>Onset time</td>
<td>t_onset</td>
<td>s</td>
<td>free</td>
</tr>
<tr>
<td>Rate constant</td>
<td>k_u</td>
<td>min(^{-1})</td>
<td>free</td>
</tr>
<tr>
<td>Transfer constant</td>
<td>k_m</td>
<td>min(^{-1})</td>
<td>free</td>
</tr>
<tr>
<td>T1, metanality</td>
<td>r_1</td>
<td>s(^{-1}) mM(^{-1})</td>
<td>fixed (4.5 s(^{-1}) mM(^{-1}))</td>
</tr>
<tr>
<td>T1, of blood</td>
<td>T_1</td>
<td>s</td>
<td>fixed (1.4 s)</td>
</tr>
<tr>
<td>T1, of tissue</td>
<td>T_2</td>
<td>s</td>
<td>fixed</td>
</tr>
<tr>
<td>TR</td>
<td>s</td>
<td></td>
<td>fixed</td>
</tr>
<tr>
<td>Fractional volume of EES</td>
<td>( v_e )</td>
<td>( v_{EES} &lt; 100% )</td>
<td>free</td>
</tr>
<tr>
<td>Fractional volume of blood plasma in tissue</td>
<td>( v_p )</td>
<td>( v_{blood} &lt; 100% )</td>
<td>free</td>
</tr>
</tbody>
</table>

Effects of $K^{\text{trans}}$ and ve

- Increasing $K^{\text{trans}}$, with fixed ve = 10%.
- Increasing ve, with fixed $K^{\text{trans}} = 0.1 \text{ min}^{-1}$.

Imaging Parameters

- Repeated 3D T1-weighted images
- Transverse (both sides) or sagittal (unilateral) imaging
- TR = 2~20 s (if blood curve of arterial input function is demanded, use TR of 3s or less; It can be 60 sec for breast DCE imaging)
- Imaging duration: 5~8 minutes
- Flip angle 5~30°
  - FA↓, signal↑ at low concentration
  - FA↑, wider dynamic range

Breast DCE imaging

- Differentiate the tumor malignancy by DCE profile.

Cerebral DCE imaging

- Differentiate the tumor malignancy by DCE profile.
## Comparisons between DSC, DCE, ASL

<table>
<thead>
<tr>
<th></th>
<th>DSC</th>
<th>DCE</th>
<th>ASL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full name</strong></td>
<td>Dynamic Susceptibility</td>
<td>Dynamic Contrast</td>
<td>Arterial Spin Labeling</td>
</tr>
<tr>
<td></td>
<td>Contrast</td>
<td>Enhanced</td>
<td></td>
</tr>
<tr>
<td><strong>Use of gadolinium?</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Data acquisition</strong></td>
<td>1 pass of intravascular</td>
<td>3 pass continuous</td>
<td>Continuous arterial</td>
</tr>
<tr>
<td></td>
<td>gadolium through</td>
<td>accumulation of gadolium in</td>
<td>spin labeling</td>
</tr>
<tr>
<td></td>
<td>regional circulation</td>
<td>extracellular space</td>
<td></td>
</tr>
<tr>
<td><strong>Relaxation</strong></td>
<td>Signal due to T2* susceptibility from intravascular gadolium</td>
<td>Signal due to T1 shortening by gadolium in blood and tissue</td>
<td>Signal due to magnetization exchange from labeled H2O</td>
</tr>
<tr>
<td><strong>Imaging sequence</strong></td>
<td>T2*-weighted gradient-echo</td>
<td>T1-weighted gradient-echo</td>
<td>Custom intravascular 2D EPI or FSE hybrid sequence with spin echo imaging or saturation module</td>
</tr>
<tr>
<td></td>
<td>or EPI</td>
<td>or EPI</td>
<td></td>
</tr>
<tr>
<td><strong>Acquisition time</strong></td>
<td>Short (2-2 min)</td>
<td>Long (5-10 min)</td>
<td>Intermediate (3-5 min)</td>
</tr>
<tr>
<td><strong>Clinical use</strong></td>
<td>Most widely used for brain (stroke/hematomas) and heart (ischemia)</td>
<td>Still largely experimental, most widely used for evaluating tumors/ response to therapies in brain, breast, pancreas</td>
<td>Best technique (CASL, pCASL, QSPAT) not yet established; used to measure blood flow of brain, heart, kidneys, muscle</td>
</tr>
</tbody>
</table>