血管攝影與對比劑
A Course of MRI
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本週課程內容-MR Angiography (MRA)

• 非對比劑增強MRA(Unenhanced MRA)
  • Time-of-flight (TOF) angiography
  • Phase-contrast (PC) angiography

• 對比劑增強MRA(Contrast-enhanced MRA)
  • 腦血流灌注(Brain MR perfusion imaging)

References
• Magnetic Resonance Angiography: Principles and Applications, Carr et al, 2012 by Springer
• Magnetic Resonance Angiography: Techniques, Indications and Practical Applications, Schneider et al, 2005 by Springer

非對比劑與對比劑增強MRA
Unenhanced and Contrast-enhanced MRA

Unenhanced MRA
• Rely solely on flow effects (the movement of blood)

• Amplitude effects
  • Blood flowing into or out of a chosen slice has a different longitudinal magnetization compared to stationary spins.
  • Depend on the duration of stay (time-of-flight) in the slice

• Phase effects
  • Blood flowing along the direction of a magnetic field gradient changes its transverse magnetization compared to stationary spins.
### Outflow-related signal loss

- Washout effect, \( v \geq \frac{s}{TE/2} \rightarrow \) T2 flow void

![Spin-echo sequences](image)

Blood flowing within the imaging plane are not affected by this phenomenon.

- The intensity of the vascular signal declines with
  - Decreasing slice thickness, \( s \)
  - Increasing echo time, \( TE \)
  - Increasing flow velocity, \( v \)

**Axial T2W SE image**

Basilar artery

**Thrombosis After thrombolysis**

### Outflow-related signal loss

- Only observed for SE sequences and is most pronounced on T2-weighted imaging (longer TE).

- The washout effect does not occur in GRE techniques.
  - Only one RF pulse

### Inflow-related signal enhancement

- With short TR (TR < T1) of GRE sequence, the spin signals can be saturated.

![Magnetization](image)

- Spins outside the excited slice are not influenced by the RF pulses, and therefore are fully relaxed.
- Flowing blood gives rise to higher signal intensity relative to that of the saturated spins in the stationary tissue.
Inflow-related signal enhancement

• \( v > \frac{s}{TR} \rightarrow \text{flow enhancement} 
• \text{Replace the vessel spins by unsaturated spins in the time interval TR} 
• \text{The signal intensity of flowing blood increases with} 
  - Decreasing slice thickness, s 
  - Increasing flow velocity, v 
  - Increasing TR  
  (Signal of stationary tissue ↑)

TOF Angiography

• Spoiled GRE sequences 
  - No washout phenomenon 
  - Short TR (<40 msec) to efficiently saturate stationary tissues 
  - Short TE (< 5 msec) to reduce spin dephasing 
  - Short acquisition time to acquire 3D datasets 
  - Flow compensation 
• TOF techniques can be divided into 3 groups 
  - Sequential 2D multi-slice method 
  - 3D single-slab method 
  - 3D multi-slab method

Flow compensation gradients

• Laminar flow with a parabolic flow profile 
  - An increased velocity from the border towards the center. 
  - Intravoxel dephasing of spins with different velocities 
• TOF employs additional gradients on the slice-selection and frequency-encoding directions to refocus unwanted phase accumulations.
Flow compensation gradients

- Avoid dephasing in flows at constant velocity


Sequential 2D technique

- Larger flip angle (30°–70°)
- Thicker slice thickness (2–3 mm) to achieve better SNR
- Best suited for imaging vessels that are straight and perpendicular to the slices.
  - Carotid arteries or vessels in the lower extremities.
- It is necessary to synchronize the acquisition of data to the cardiac cycle (ECG gating).

Spatial saturation pulse

- Superior saturation pulses are used to suppress the signal from veins above the heart, and arteries below the heart
- Inferior saturation pulses are used to suppress the signal from arteries above the heart and veins below the heart

3D TOF MRA

- Smaller voxels (<1 mm), isotropic voxels, shorter TE, and higher SNR
- Because a slab is imaged, a small flip angle (<30°) must be used so the signal from blood that remains in the slab does not become too saturated.
- A small flip angle also leads to preserve undesirable signal from stationary tissues.
**3D TOF MRA**

- The extent of saturation depends on the length of time in which the blood stays inside the volume.
  - Slow flow vessels → signals diminish even for a short cover distance
  - Fast flow vessels → signals remain visible for a greater cover distance
- The maximum slab/volume thickness should be kept as small as possible.
  - Just matched to the size of the vessel region of interest
- Larger vessel sections → 3D multi-slab technique

**3D multi-slab method**

- Retains the advantages of 3D TOF and also has reduced saturation effects like 2D TOF
- Multiple overlapping thin slab acquisition (MOTSA) (4~6 cm)
  - 20~30% overlapping
- Longer acquisition time

**3D multi-slab method**

- Presaturation slab above the imaging volume suppresses the signal of venous flow.
Background-blood contrast

- Magnetization transfer contrast (MTC)
- MTC can further suppress background signal.
  - Reduction of gray and white matter signal by 15-40%
  - But not in blood
- Fat suppression

TOF Angiography

- Vein: slow flow
- Artery: fast flow

**Table 3. Comparison of 2D TOF and 1D TOF angiography**

<table>
<thead>
<tr>
<th>2D TOF</th>
<th>3D TOF</th>
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</thead>
<tbody>
<tr>
<td>Strong inflow effect, minimal saturation</td>
<td>More saturation effects</td>
</tr>
<tr>
<td>• sensitive even to slow flow (veins)</td>
<td>• sensitive to rather fast flow (arteries)</td>
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<tr>
<td>Relatively poor signal-to-noise ratio</td>
<td>High signal-to-noise ratio</td>
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<tr>
<td>Short scan times</td>
<td>Poor background suppression</td>
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<tr>
<td>Relatively thick slices</td>
<td>Thin slices, allows isotropic vessels</td>
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<tr>
<td>• suitable for large vessels</td>
<td>• suitable for small vessels</td>
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<tr>
<td>Poor in-plane flow sensitivity</td>
<td>• for straight, unidirectional flow</td>
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<tr>
<td>Long echo times</td>
<td>Short echo times, less dephasing</td>
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<td>Step artifacts at the vessel wall</td>
<td>Smoother vessel walls</td>
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</tbody>
</table>

Phase effects

- Phase effects concern the transverse magnetization.
- Apply a pair of gradients with identical strength and duration but opposite sign (bipolar flow-encoding gradient).
- Stationary spins → zero net phase shift
- Flowing spins → a non-zeros phase shift

**Phase shift** \[ \Phi = \gamma \cdot B \cdot t \cdot v \]

**Magnitude contrast method**

- Acquire two datasets
  - Flow-rephased images: flow compensation, bright-blood image

**Phase contrast method**

- Acquire two datasets
  - Flow-rephased images (S1): flow compensation, bright-blood image
  - The flow-sensitive gradient is weak enough to avoid complete phase dispersion arising from the velocity distribution of the spins.
  - Complex subtraction (S1-S2) $\Rightarrow$ the difference vector $\Delta S$

**Phase contrast method**

- A direct quantitative measure of the velocity of the flowing blood
- No restriction on image orientation (not dependent on inflow effects)
- Velocity encoding (VENC)
  - The velocities between $-VENC$ and $+VENC$ are encoded by the phase shifts between $-180^\circ$ and $+180^\circ$.
  - The flow velocity exceeded the VENC value $\Rightarrow$ aliasing
- General velocity
  - Arterial flow 40~60 cm/s
  - Venous flow 20~30 cm/s

**Phase contrast MRA**

- Phase-encoded images
  - X direction
  - Y direction
  - Z direction
  - Subtraction & Sum magnitude
Phase contrast MRA

Limitations

- Highly sensitive to motion artifacts → ECG gating
  - Heart beats and breathing

TOF vs. phase contrast MRA

Contrast-enhanced MRA

- Avoidance of blood signal saturation
- Better turbulent flow imaging
  - Injection a contrast material intravenously (IV) to selectively shorten the T1 of the blood → brighter signal in T1W images.
- Gadolinium-chelate (Gd) contrast agents
  - Seven unpaired electrons → paramagnetic, shorten T1 and T2
  - Injection rate: 0.5–4.0 ml/s
  - Injection volume: 0.1–0.3 mmol/kg body weight, typically 20–40 ml
  - Computer-controlled power injector
  - Examine the patient's renal function before scanning!
Contrast-enhanced MRA

- 3D, RF-spoiled, fast gradient-echo imaging sequences ➔
  T1W images (FSPGR, FLASH, or T1 FFE)

Applications areas of MRA

<table>
<thead>
<tr>
<th></th>
<th>3D-TOF</th>
<th>2D-TOF</th>
<th>3D-PC</th>
<th>2D-PC</th>
<th>Magnitude contrast</th>
<th>CE MRA</th>
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<tr>
<td>Intracranial:</td>
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<td>- Arteries</td>
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<td>- Veins</td>
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<td>- Carotids</td>
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<td>Peripheral vessels</td>
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*** Method of choice; ** second-best alternative or for additional information; * working technique, but with sub-optimal results

TOF MRA: Time-of-Flight MRA; PC MRA: Phase Contrast MRA; CE MRA: Contrast enhanced MRA

Blood supply of the brain

Arterial system

Venous system

Vascular Territories

TOF MRA

1. Internal carotid a. (ICA)
2. Cavernous sinus part
3. Temporal bone part
4. Posterior cerebral a. (PCA)
5. Anterior communicating a. (ACoA)
6. Posterior communicating a. (PCoA)
7. Middle cerebral a. (MCA)
8. Branch on the surface of the insula
9. Vertebral a. (VA)
10. Ophthalmic a.
Brain perfusion imaging

- The information on the capillary microcirculation of tissue
- Quantitative measurements
  - Blood volume
  - Blood flow
  - Temporal data (transit time and time to peak)
- Two major techniques
  - Dynamic-susceptibility-contrast (DSC) MRI
  - Arterial spin labeling (ASL) MRI

DSC MRI

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

DSC MRI

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

Post-preprocessing

- 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

Hemodynamic maps

- Cerebral blood volume
  \[ rCBV = \frac{\int_{\text{first pass}} \cdot c(t) \, dt}{\int_{\text{first pass}} \cdot c(t) \, dt} \]
- Cerebral blood flow
  \[ CBF(t) = rCBF \cdot C_a(t) \otimes R(t) \]
- Mean transit time
  \[ MTT = \frac{rCBV}{CBF} \]
### ASL MRI

- Arterial spin labeling uses arterial blood water as an endogenous contrast agent.
- Blood is "tagged" or magnetically inverted which changes its magnetic properties and its effect on MR signal.
- Create paramagnetic tracer to suppress MR signal wherever arterial blood is delivered.
- Can be used to quantify CBF (cerebral blood flow) in arterioles and capillaries.

### Principles of ASL

1. Tag inflowing arterial blood by magnetic inversion
2. Acquire the tag image
3. Repeat scanning without tag
4. Acquire the control image

\[ 4(\text{control image}) - 2(\text{tag image}) \propto \text{CBF} \]
THE END
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