Acquisition

ASL BASICS II

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Outline

• Arterial spin labeled perfusion MRI: basic theory
• ASL data acquisition: the ASL pulse sequence
  – Labeling strategies: CASL, PASL, and PCASL
  – Arterial transit time effects on ASL
  – Multi Ti/PLD acquisitions
  – Readout options
  – Background suppression
  – Bipolar gradients for intravascular signal suppression
  – ASL protocol

Learning Objectives

• To understand the pros and cons of various image acquisition approaches
• To understand the general differences between 2D and 3D approaches
• To understand the effect of background suppression
• To be able to choose the appropriate imaging sequence, depending on the application
• To be able to prepare an ASL protocol
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The ASL Pulse Sequence

- ASL module (preparation)
- Delay time
- Image acquisition (readout)

Imaging Readout

- In general, the ASL preparation and imaging readout are independent
- High SNR, low sensitivity to motion
- T2* weighting not necessary or desirable
- Single shot
  - Motion correction
  - Perfusion time series (fMRI or fcMRI)
  - Lower resolution
- Multi shot
  - Higher resolution
- Most frequently used: 2D EPI, 3D GRASE, 3D FSE-spiral
2D versus 3D

- Sequential slice acquisition (ascending order)
- Slice dependent PLD
- Slice dependent perfusion SNR

- Volume excitation
- No slice dependence of perfusion SNR
- Higher SNR efficiency
- Facilitates the use of BS
- Most 3D ASL sequences based on FSE readouts
- Blurring in the slice direction

EPI Sequence Scheme

ASL preparation → PLD → readout

multi-slice 2D-EPI

RF slice 1 → RF slice 2 → RF slice 3 → RF slice 4

PASL EPI

EPI-readout, 60 averages, measurement time = 5 min,
3T MR-Scanner

Wen-Ming Luh et al., MRM 41:1246–1254 (1999)
PCASL EPI

Signal loss and distortion artifacts

3D-GRASE Sequence Scheme

ASL preparation
PLD
readout

single-shot 3D-GRASE

RF
180°
180°
180°
180°

3D-GRASE Sequence Scheme

PASL 3D GRASE

FAIR and single-shot 3D GRASE data set
Measurement time: 2 min, TI =1600 msec

Blurring in slice direction
CASL 3D GRASE

Single shot 3D GRASE with acceleration factor of 2
4 mm isotropic resolution, whole brain coverage

PCASL Single-shot 3D GRASE

Snap-shot ASL
Single shot 3D GRASE with PCASL

PCASL 3D GRASE

Single-shot

Multi-shot
(4 segments)
Reduced blurring in z
Increased SNR (shorter TE)
PCASL Segmented 3D GRASE
High resolution ASL 2x2x4, 8 shots

TIM Trio 3T

3D-RARE Spiral Sequence Scheme
IAS preparation PLD readout

3D-RARE spiral (also called 3D-FSE on GE-scanners)

3D RARE-Spiral ASL
High resolution 2x2x4
Whole-brain
Segmented 8 shots
### bSSFP Sequence Scheme

**balanced SSFP** (trueFISP, FIESTA)

- RF
- **+**
- **-**

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### bSSFP ASL

**ASL in the brain, healthy male volunteer**

Segmented true FISP ASL images acquired using eight averages, $\text{TI}=1200\text{ms}$, measurement time for single slice $2.5\min$

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### Readout Comparison

<table>
<thead>
<tr>
<th></th>
<th>2D EPI</th>
<th>3D GRASE</th>
<th>3D RARE spiral</th>
<th>bSSFP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition scheme</strong></td>
<td>2D multi-slice</td>
<td>3D</td>
<td>3D</td>
<td>Single-slice</td>
</tr>
<tr>
<td><strong>SNR</strong></td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Middle</td>
</tr>
<tr>
<td><strong>Image quality</strong></td>
<td>Off-resonance artifacts</td>
<td>Good in-plane blurring along z</td>
<td>Good in-plane blurring along z</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Other remarks</strong></td>
<td>Broad availability, quasi standard</td>
<td>BS Segmentation to reduce blurring</td>
<td>BS Segmentation to reduce blurring Lower sensitivity to motion (oversampling of k-space center) In-plane blurring due to off-resonance</td>
<td>Inflow-weighted (bright vessels!)</td>
</tr>
</tbody>
</table>
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ASL signal (blood signal) very small compared to tissue signal (e.g. about 2-3% in human brain)
→ small fluctuations in tissue signal corrupt ASL signal

Idea of BS: reduce tissue signal by (closely) nulling it at time of readout
→ tissue signal and ASL signal of same order
→ small fluctuations in tissue signal does not corrupt ASL signal

Mani et al. MRM 37: 898-905 (1997)
Ye et al. MRM 2000

Background Suppression

Blood signal
Tissue signal
Blood signal
Tissue signal

No BS images

BS images
Background Suppression

- Signal is nulled at time of readout, using an extension of an inversion recovery sequence.
- BS pulses attenuate the ASL signal due to T2 and T1 decay.
- Number of BS pulses: trade-off between degree of suppression, ASL signal attenuation and SAR.

BS with PASL

Inversion

BS Inversion

Inflow time T1

+ labeling phase

+ control phase

BS Inversion

saturation

readout

saturation slab

Inversion slab

readout slice

BS Inversion

BS with PCASL

BS Inversion

Inversion

post-labeling delay

+ labeling phase

+ control phase
The Effect of Readout and BS on SNR

<table>
<thead>
<tr>
<th>Sequence</th>
<th>2D EPI</th>
<th>3D GRASE</th>
<th>3D GRASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole-brain mean CBF (before calibration)</td>
<td>46.4 ± 8.6</td>
<td>48.9 ± 11.6</td>
<td>38.1 ± 8.0</td>
</tr>
<tr>
<td>Calibration factor (%)</td>
<td>72.2 ± 15.5</td>
<td>72.2 ± 11.3</td>
<td>72.2 ± 11.3</td>
</tr>
<tr>
<td>Perfusion time-series</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.7 ± 1.5</td>
<td>9.0 ± 1.4</td>
<td>10.1 ± 2.1</td>
</tr>
<tr>
<td>SD</td>
<td>3.1 ± 0.2</td>
<td>3.8 ± 0.2</td>
<td>3.1 ± 0.2</td>
</tr>
<tr>
<td>SNR</td>
<td>0.35 ± 0.04</td>
<td>0.28 ± 0.03</td>
<td>0.20 ± 0.03</td>
</tr>
<tr>
<td>GM-WM CBF Contrast</td>
<td>4.9 ± 0.3</td>
<td>5.3 ± 0.2</td>
<td>4.9 ± 0.2</td>
</tr>
</tbody>
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Intravascular Signal Suppression

- In cases of prolonged transit time, PLD can be shorter than arterial transit time
- Intravascular signal from labeled blood on its way to perfuse more distal slices can lead to vascular artifacts (bright spots) and overestimation of perfusion in the current slice

PLD = 1200
PLD = 1500
Vascular Crushers

- Bipolar gradients can be applied to suppress the signal from flowing spins – flow crushers
- The effect of the crushers is determined by V_{enc}
- Spins moving at V > V_{enc} are dephased

Recommended V_{enc} = 4 cm/s

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Outline
**ASL Protocol**

**Required**
- ASL sequence

**Optional**
- Angiogram
- T1 measurement
- Calibration scan for blood $M_0$ estimation
- Calibration scan for coil sensitivity estimation
- PCMRI for efficiency measurement

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**Product ASL - Siemens**

<table>
<thead>
<tr>
<th>ASL preparation</th>
<th>PASL (FAIR, QUIPPS II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout</td>
<td></td>
</tr>
<tr>
<td>VB series</td>
<td>2D EPI</td>
</tr>
<tr>
<td>VD series</td>
<td>3D GRASE</td>
</tr>
<tr>
<td>BS</td>
<td></td>
</tr>
<tr>
<td>VB series</td>
<td>No</td>
</tr>
<tr>
<td>VD series</td>
<td>Yes</td>
</tr>
<tr>
<td>Multi-Ti/PLD</td>
<td>No</td>
</tr>
</tbody>
</table>

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**Product ASL - Philips**

<table>
<thead>
<tr>
<th>ASL preparation</th>
<th>PASL (STAR) PASL (STAR), PCASL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout</td>
<td>2D EPI</td>
</tr>
<tr>
<td>BS</td>
<td></td>
</tr>
<tr>
<td>R3 (achieve), R4 (ingenia)</td>
<td>No</td>
</tr>
<tr>
<td>R5</td>
<td>Yes</td>
</tr>
<tr>
<td>Multi-Ti/PLD</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* PCASL in Clinical Science Key; ** Available end of 2013.
Methodological advances have dramatically improved the quality of ASL perfusion MRI.

- ASL is non-invasive, repeatable, flexible
- In general, ASL preparation and image acquisition are independent
- Optimal combination depends on application, knowledge of available methods necessary
- For single delay time CBF measurements:
  - PCASL is the optimum labeling strategy
  - Segmented 3D readouts are preferred to 2D
Thank you for your attention!