How to do MRA: basic questions

1. What are the different MRA techniques?
2. What are the fundamental principles?
3. How to increase spatial and temporal resolution?
4. How to expand anatomic coverage?
5. What are typical artifacts and how to avoid them?

http://www.ma.uni-heidelberg.de/inst/ikr/RSNA2007/MRAacquisition

Fundamental principles: TOF MRA

Inflowing, previously un-saturated spins (e.g. blood) produce a stronger signal than stationary spins

1. Pre-saturation of imaging plane
2. Magnetization transfer pulse for background suppression
3. Inflow of blood (90° angle to the imaging plane)
4. Insensitive for inplane flow

3D Acquisition

Readout of k-space line (1st dimension)

Readout of k-space plane (2nd dimension)
3D Acquisition

Readout of k-space volume (3rd dimension)

3D Acquisition: 3D Time-of-flight

Readout of k-space volume (3rd dimension)

3D Time-of-flight @ 3 Tesla

Time-of-flight 3T versus 7T

0.3mm x 0.3mm x 0.5mm

Advantages / disadvantages of TOF MRA

**Advantages**
- No contrast media
- Easy, completely non-invasive technique
- Acquisition of 3D data sets possible

**Disadvantages**
- Long acquisition times → motion artifacts
-Insensitive for slow flow and inplane flow
- High background signal

Contrast-enhanced MRA

**Advantages**
- High contrast due to contrast media application
- Fast acquisition
- High isotropic spatial resolution up to 1mm³
- Acquisition of 3D data sets
- Minimum artifacts
- Flow-independent b/o CM → imaging of slow flow
- State-of-the-art in clinical routine for most applications
Application of contrast agents

Technical principles of MRA

Image
Rawdata

Fourier-Transformation

Image
Rawdata

Technical principles of MRA

Image
Rawdata

Fast (< seconds)

Technical principles of MRA

Image
Rawdata

K-space ↔ bolus-timing

- Central parts of k-space → CM bolus
- Timing too late → venous overlay
- Timing too early → poor vessel contrast
- Determine time between injection and CM peak at the level of the target vessel → test-bolus, automatic detection, fluoroscopic real-time visualization

Image
Rawdata

Central parts of k-space

CM bolus

Timing too late

venous overlay

Timing too early

poor vessel contrast

Determine time between injection and CM peak at the level of the target vessel

test-bolus, automatic detection, fluoroscopic real-time visualization
Too early: "Ringing" artifact  
Too late: Venous overlay

Timing is everything

Test-Bolus technique

Automatic Gd Detection: Smartprep®

Fluoroscopic assessment: Care Bolus®, Bolustrak®, MR Fluoroscopy®

Problem: delay (1-5 s) for online switch between fluoroscopy and MRA acquisition

MRA: problem of spatial resolution

Intravascular contrast agent (SHU 555C)

CE MRA – Increase of spatial resolution / decrease of scan time

- (Zero Filling)
- Partial Fourier Imaging
- Elliptical centric acquisition
- Parallel Imaging
- Higher field strength
- Radial Imaging
Zero Filling
Fill periphery of k-space with zeros → Interpolation of image matrix → Acquisition time ↓

Partial Fourier techniques
• K-space is nearly symmetric
• Acquisition of k-space parts with mirroring of the data → number of phase-encoding steps ↓ → acquisition time ↓

Partial Fourier techniques
60% of k-space → no artifacts, slight blurring

Partial Fourier techniques & zero-filling
40% of k-space → few artifacts, details ↓

Partial Fourier techniques & zero-filling
20% of k-space → severe truncation artifacts, details ↓

Elliptical centric acquisition: higher spatial resolution
Elliptical centric: aneurysm of ACA

Parallel acquisition techniques (PAT)

2x faster

Image
Rawdata

Parallel acquisition techniques (PAT)

Aliased image
Reconstructed image

Parallel acquisition techniques (PAT)

Coil-Sensitivity-Profiles

Parallel acquisition techniques (PAT)

PAT-Reconstruction

Coil-Sensitivity-Profiles

High-res. MRA: cross-sectional reformats

Voxel size: 3.4 $\rightarrow$ 0.7 mm$^3$

High-res. MRA: cross-sectional reformats


26 s (PAT 2) 0.9 x 0.8 x 1.0 mm 19 s (PAT3)

Michaely HM, ... Schoenberg SO. JMRI 2006; 24: 95-100

PAT (GRAPPA ×2)
26 s acquisition time
Artifacts: GRAPPA vs. mSENSE

CE MRA – Increase of temporal resolution

- Parallel Imaging (PAT): higher acceleration factors
- View-sharing: TRICKS (time-resolved imaging of contrast kinetics)
- View-sharing + PAT: TREAT
- Variable k-space sampling + PAT: TWIST

Time-resolved MRA using TRICKS

Problem:
Low spatial resolution of time-resolved imaging

Solution:
Periphery of k-space is less frequently sampled than k-space center

Korosec F et al. MRM 1996

TREAT
(time-resolved echo-shared angiographic technique)

- Combination of parallel imaging and view-sharing

2,0x2,0x2,0 mm
1 Bild / 2 s
5 ml KM

TWIST: time-resolved angiography with interleaved stochastic trajectories

SNR_R = SNR / \sqrt{R}

Higher field strength
Contrast-enhanced MRA at 3T

Signal ratio: contrast-enhanced arterial blood – fat tissue

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1.5 T</th>
<th>3.0 T</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR, ms</td>
<td>1250</td>
<td>1650</td>
</tr>
<tr>
<td>$T_1$, arterial blood, ms</td>
<td>343</td>
<td>382</td>
</tr>
<tr>
<td>$T_1$, fat, ms</td>
<td>4.1</td>
<td>3.7</td>
</tr>
<tr>
<td>$R_1$, Magnevist, ms</td>
<td>47</td>
<td>52</td>
</tr>
<tr>
<td>$R_1$, blood + Gad (5 mmol/L)</td>
<td>5.15</td>
<td>5.30</td>
</tr>
</tbody>
</table>

Better background (fat) suppression for MRA
- Higher vessel contrast!
- Decrease contrast amount by 10%-20%

High-resolution MRA @ 3 Tesla

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1.5T MRA</th>
<th>3.0T MRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR / TE [ms]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flip angle [°]</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Bandwidth [Hz/Px]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOV [mm²]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase Oversampling [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voxel size [mm³]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial resolution [mm³]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scan time [s]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partitions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parallel imaging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPPA factor 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

from spatial to temporal resolution

Spatial resolution 1.4 x 1.4 x 1.5 mm, 10 ml CM
Temporal Resolution 2.9 s (PAT4)

From spatial to temporal resolution

TWIST @ 3 Tesla

Courtesy of Mike Notohamiprodjo MD and Christian Glaser MD, LMU Munich

(2D-)PAT and image geometry
Further gains in acquisition speed:
Parallel imaging with acceleration in 2D (PAT²)

Arteriogram (PAT 6 – 3x2): mild disease
Venogram (PAT 6 – 3x2)

Courtesy of Paul Finn MD PhD, UCLA
Fechel M, Invest Radiol 2006
Willinek WA, ISMRM 2006

Radial acquisition

Radial acquisition: Streak artifacts

32x faster
but severe streak artifacts

Extended anatomic coverage

- Moving-table technique
- Whole-body scanners
- Continuous table movement (move during scan)

Whole Body MRA

standard MR System

Courtesy of Anna Gerlach, MD, Katherinenhospital Stuttgart
Conflict to current clinical approaches

1. Lower Calf/Forefoot
   - 1.4x0.7x0.9 mm
   - 32 sec/phase

2. Pelvis
   - 1.5x1.5x1.5 mm
   - 19 sec

3. Thigh
   - 1.5x2.1x2.5 mm
   - 18 sec

4. Proximal Calf
   - 1.5x0.7x1.4 mm
   - 13 sec

Recent studies on whole-body MRA

<table>
<thead>
<tr>
<th>Author</th>
<th>Field strength</th>
<th>Minimum acquired resolution [mm]</th>
<th>Accuracy for significant disease ≥50% (*≥70%)</th>
<th>Interobserver variability [κ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nael 2007</td>
<td>1.5 T</td>
<td>1.6 x 1.0 x 1.5</td>
<td>SN 96%, SP 95%</td>
<td>0.92</td>
</tr>
<tr>
<td>Nael 2007</td>
<td>3T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goyen 2006</td>
<td>1.5 T</td>
<td>1.7 x 1.5 x 2.9</td>
<td>SN 93%, SP 97%</td>
<td>0.84</td>
</tr>
<tr>
<td>Hansen 2006</td>
<td>1.5 T</td>
<td>1.76 x 1.76 x 4.0</td>
<td>SN 83%, SP 94%</td>
<td></td>
</tr>
<tr>
<td>Fenchel 2005*</td>
<td>1.5 T</td>
<td>1.6 x 1.0 x 1.5</td>
<td>SN 95%</td>
<td>0.93</td>
</tr>
<tr>
<td>Fenchel 2005*</td>
<td>3T</td>
<td>1.6 x 1.0 x 1.5</td>
<td>SN 96%, SP 95%</td>
<td></td>
</tr>
</tbody>
</table>

Whole-body MRA: 1.5 vs. 3 Tesla

 wb-MRA ready for clinical routine

B1-Inhomogeneity

“Move During Scan” MR Angiography @ 3Tesla

Courtesy of Harald Kramer MD, LMU Munich
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http://www.radiologie-lmu.de/RSNA2006/MRAacquisition

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- Department of Radiology, Cornell University: Martin R Prince MD PhD
- Department of Radiology, University of Wisconsin: Thomas Grist MD
- Department of Radiology, University of Michigan: Frank Londy RT

http://www.ma.uni-heidelberg.de/inst/ikr/RSNA2007/MRAacquisition

Question to Dr. Martin Prince

*How do you prevent venous overlay?*

- Thigh cuffs with long extension tubing
- Inflation pressure = 60 mmHg
- Inflate just prior to mask acquisition
- Venous contamination is delayed
- ↑ calf station to 60 seconds

Zhang et al: AJR 2004; 183:1041-10


Meaney et al: US Patent 5,924,987

Herborn et al: Radiology 2004; 230:872-8


Decreased Venous Contamination Using Thigh Compression on Peripheral MRA

Question to Dr. Tom Grist

*When do you use time-resolved imaging?*

Benefits of time-resolved imaging protocol

Left Popliteal Occlusion
Benefits of time-resolved imaging protocol

Causes of early venous enhancement
- Ulceration
- Phlebitis
- Neuropathic joint
- Reduced muscle mass

58 year-old male post repair of ASD and PAPVR
Incidentally diagnosed Right Pulmonary Venous Varix

Radial acquisition: HYPR
- HYPR: Highly constrained back-projection
- Single radial readout used to reconstruct projection data
- Very efficient for time-resolved MRA