MR Angiography in 2012
Basic principles, post-processing & pitfalls

Introduction

Why invasive imaging?
- Major advantages of catheter angiography
  - Real-time cinematic imaging
  - Greater spatial & temporal resolution
  - Immediate interpretation of images
  - Selective catheterization
- But also...
  - No direct visualization of plaque, underestimation of atherosclerosis
  - Invasive, larger threshold for examination
  - Not suitable to confirm normal findings

Why invasive imaging?

<table>
<thead>
<tr>
<th>Puncture site complication</th>
<th>Reported rates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematoma (requiring further attention)</td>
<td>0.0 - 0.68</td>
</tr>
<tr>
<td>Pseudoaneurysm - AV fistula</td>
<td>0.04 - 0.20</td>
</tr>
<tr>
<td>Occlusion</td>
<td>0.0 - 0.76</td>
</tr>
<tr>
<td>Gross contrast</td>
<td>0.0 - 0.75</td>
</tr>
<tr>
<td>Arterial dissection/subintimal passage</td>
<td>0.45</td>
</tr>
<tr>
<td>Substantial contrast pretension</td>
<td>0.0 - 0.64</td>
</tr>
<tr>
<td>Major cardiac necrosis</td>
<td>0.0 - 0.28</td>
</tr>
<tr>
<td>Contrast media related nephrotoxicity</td>
<td>0.2 - 1.4</td>
</tr>
</tbody>
</table>
Modern MRA expectations

- Faster Scans
  - Cover large anatomic volume in minimum amount of time
  - Less motion artifacts

- High spatial resolution
  - Submillimeter isotropic resolution at all times

- Confident diagnosis
  - High sensitive examination
  - Specificity is improving, but depends on indication

Acquiring the data

Question

- 3D TOF is...
  a. A technique typically used for evaluation of renal artery stenosis
  b. A non-contrast enhanced MR angiography technique
  c. Can underestimate a stenosis
  d. Excellent for evaluation of large aortic aneurysms

Answer: B

MR angiography

MR angiography: technique

- Time-of-flight (TOF) MRA
  - One the earliest MRA techniques
    - Gradient echo
  - Low signal of stationary tissue
    - Weak signal due to partial saturation of spins
  - High signal of flowing blood
    - Strong magnetization due to inflow of non-saturated spins

Technique

- Time-of-flight
  - Unsaturated spin
  - Imaging section
  - Repeated RF excitations
  - Short TE
  - Pre-saturation pulse
Technique

- Time-of-Flight

MR angiography: technique

- Time of flight MRA
  - Long scan times
  - Difficult breathhold imaging \(\rightarrow\) misregistration artifacts
  - More sensitive to through-plane flow than to in-plane flow
  - Difficult evaluation of mesenteric vasculature
  - Triphasic nature of splanchic arterial blood flow
  - Signal diminishes during retrograde diastolic flow
  - Overestimation of stenosis

MR angiography: technique

- Phase-contrast (PC) MRA
  - Direct quantitative evaluation of
    - Flow direction
    - Flow velocity

- Gradient
  - Superimposed magnetic field
  - Switched on during time \(T\)
  - Field strength depends (linearly) on position

MR angiography: technique

- Changed magnetic field
  - Changes "rotational frequency" of protons (precession)
  - Therefore introduces phase shift along gradient direction

- Gradient
  - Superimposed magnetic field
  - Switched on during time \(T\)
  - Field strength depends (linearly) on position

MR angiography: technique

- Bipolar gradient
  - Gradient with strength \(G_x\) switched on during time \(T\)
  - Followed by gradient of equal strength but opposed direction during equal time \(T\)
  - For a stationary spin \(G_x\) is equal but opposite and \(x\) and \(T\) are equal, so there is no net phase change

- Bipolar gradient – moving spins
  - Spins moving along the gradient direction
  - Different magnitude or direction in the second gradient compared to the first
  - Introducing a net phase shift
  - Phase shift is a measure of speed
MR angiography: technique

- PC MRA - Phase images
  - voxel with phase shift = flow = vascular
  - sensitive to the direction of flow
  - velocity quantification
  - along the gradient direction
  - Velocity x cross-sect. area
  - = flow quantification

MR angiography: technique

- PC MRA - Velocity images
  - Repeat
  - flow sensitization along all 3 orthogonal directions
  - Compose:
    \[ v = \sqrt{v_{\text{read}}^2 + v_{\text{phase}}^2 + v_{\text{slice}}^2} \]

Curve profiles

Moderate stenosis
High grade stenosis

MR angiography: technique

- Phase contrast MRA
  - Advantages
    - especially useful in quantitative evaluation of arterial stenosis
    - renal artery blood flow gradient

MR angiography: technique

- Advantages
  - Signal loss due to magnetic susceptibility artifacts
  - deoxyhemoglobin, hemosiderin and ferritin
  - partially thrombosed aneurysms
- Full PC MRA measurement is time-consuming
- Gd-sulfur hexafluoride PC-MRA
- Sensitive to motion artifacts
- Niche technique
  - quantification of flow (renal arteries)
  - Venous occlusive disease

MR angiography: technique

- Contrast-enhanced MRA
  - Introduced by Martin Prince in 1993
  - Exploits differences in longitudinal magnetization
  - T1 shortening effect of intravenous Gd:
  - Contrast is relatively independent of flow dynamics
  - Saturation effects are substantially reduced
  - First pass effect
  - timing is everything!

- Most commonly used MRA technique

MR angiography: technique

- Contrast-enhanced MRA
  - Dry run
  - Visual bolus triggering

Contrast-enhanced MRA

Subtraction
Contrast-enhanced MRA

- Advantages
  - Excellent image quality
  - Large FOV and volume of interest coverage
  - Short acquisition times
  - Absence of flow-related, saturation and T1-related artifacts
  - Good temporal resolution
  - Minimally invasive character

Question

- Maximum intensity projection is...
  a. The best processing technique for visualization of 3D structures
  b. Only useful with contrast-enhanced MRA techniques
  c. Can underestimate a stenosis
  d. Provides the best visualization of the distal segments of the renal arteries

Answer: D

MR angiography: technique

- Maximum Intensity Projection
  - Projection technique
  - Selection of voxel with highest density
  - Basically a 2D technique
Post-processing

- Maximum intensity projection

Full volume MIP  Segmental slab MIP

Where is the AV shunt?

Post-processing

- Volume Rendering (VR)

True 3D visualization of anatomy

Volume rendering

- Transfer-function
  - Uses full dataset
  - Each voxel within specified range has a contribution
  - Interactive and modifiable powerful parameters
  - Powerful data-segmentation
  - Reliable representation of reality

- True 3D view
  - 3D effect of MIP is false!

- Less detail
  - Smaller vessels better depicted with MIP

Contrast-enhanced MRA

- Disadvantages
  - Hardware requirements
    - Powerful & fast gradients
  - Suboptimal spatial resolution of small vascular structures
  - Variable & unpredictable individual hemodynamic variations
    - requiring a test bolus study or automatic triggering
  - Possibility of magnetic susceptibility artifacts

Clinical applications
Question

- When evaluating an abdominal aortic aneurysm
  a. The best processing technique is MIP
  b. 3D TOF will overestimate the size of the aneurysm
  c. The best processing technique is volume rendering
  d. Only native images can reveal the full extent of the pathology

Answer: D

Aortic aneurysm

Always look at the native images!

Vascular Stents

- Look out for artifacts!

This is not a stenosis...

Question

- When screening for renovascular hypertension, the MRA examination result is normal or non-significant in:
  a. 50 %
  b. 60 %
  c. 80 %
  d. 90 %

Answer: D

Renovascular disease

- Causal relationship between renal artery stenosis (RAS) and its clinical consequences
  - Hypertension
  - Renal failure
  - Complex relation between RAS and hypertension

Etiology of RAS

- Atherosclerosis: 90 %
- Fibromuscular dysplasia: 10 %
- Other: aorta arteritis, thrombosis, dissection...

Clinical applications

Protocol

- MR angiography in renovascular disease
  - Evaluation of
    - Adrenal glands
    - Kidney morphology & dimensions
    - Renal arteries
    - Vessel wall

- Axial T1- & T2-weighted images (T1 in- and out of phase)
- Coronal TrueFisp images
- Contrast-enhanced MRA
- Phase-contrast MRA
Clinical applications

- Renovascular disease

Clinical applications

- Renovascular disease

Clinical applications

- Fibromuscular dysplasia

Clinical applications

- Fibromuscular dysplasia

Insufficient evaluation of the distal segments

Improving image quality

Useful tricks & common pitfalls

Question

- Which option is the easiest to improve MRA quality
  a. Decrease your flip angle
  b. Raise your TR-time
  c. Use a high relaxivity contrast agent
  d. Use 3T MR imaging system

Answer: C
Improving image quality

- High Field Imaging (3T)
  - Better spatial resolution in same examination time
  - Better temporal resolution

New developments

- High relaxivity contrast agents
  - Gadobutrol (Gadovist, Bayer Shering)
  - Double Gd-concentration 1.0 M compared to conventional contrast agents (0.5 M)
- Lower dose volume
  - Typical <10 cc for one body region
- Compact contrast bolus
  - High arterial contrast
  - Excellent image quality
3T

- Excellent for MR-A

New developments

- Time-resolved CE-MRA

pelvic varicosities

What about 2012?

MRA of children

- Always technically challenging

- Small FOV
- Motion
- IV access
- SNR
- Off-label use of CM

MRA & children

- Age guidelines
  - <3 years
    - Sedation in pediatric department
    - Chloral hydrate
    - Transportation to MR department when sleeping
  - >3 years
    - Sleep-induced anesthesia
    - Presence of anesthesiologist

- Monitoring
  - ECG & respiratory monitoring
  - Visual access

Non-contrast enhanced MRA

- Inflow-enhanced b-SSFP technique

Free-breathing & non-contrast MRA

Non-contrast MRA

- ECG-gated respiratory-triggered 3-D SSFP
- Free breathing & non-contrast MRA


The endpoint is a diagnosis!
- Beware of 3D images in suboptimal conditions
- Do not underestimate axial images
  - HASTE, TrueFISP
  - Perfect for anatomy evaluation
    - Vascular anomalies
    - VCI agenesis/hypoplasia
- Use common sense

Last question

- The favorite Belgian beer of yours truly is:
  a. Heineken
  b. Duvel
  c. Budweiser
  d. West-Malle Trappist

Answer: B

Thank you!