Trends in MR Angiography

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Angio procedures in the last 15 years: MRA

Angio procedures in the last 15 years: MRA vs CTA

Many MR Angiography applications
Outline

- Review of basic MRA principles
  - Contrast enhanced
  - Non-enhanced
- Building blocks of pulse sequences
- Advanced acceleration techniques
- Clinical MRA pulse sequences

Fundamental requirements of MR Angiography

1. Maximize the signal in desired vessel (e.g., artery)

2. Minimize the signal in
   - Background muscle
   - Undesired vessel (e.g., vein)
   - Fat

Properties of arteries that can be used for contrast

- Arterial blood
  - $T_1 \approx 1200 \text{ ms}$
  - $T_2 \approx 250 \text{ ms}$
  - Pulsatile flow

- Venous blood
  - $T_1 \approx 1200 \text{ ms}$
  - $T_2 \approx 250 \text{ ms}$
  - Slow constant flow

- Fat
  - $T_1 \approx 250 \text{ ms}$
  - $T_2 \approx 70 \text{ ms}$
  - No motion (relatively static)

- Background muscle
  - $T_1 \approx 1000 \text{ ms}$
  - $T_2 \approx 60 \text{ ms}$
  - No motion (relatively static)

T1W imaging?

- Arterial blood
  - $T_1 \approx 1200 \text{ ms}$

- Venous blood
  - $T_1 \approx 1200 \text{ ms}$

- In presence of contrast agent, blood
  - $T_1 \approx 50-100 \text{ ms}$

T2W imaging?

- Arterial blood
  - $T_2 \approx 250 \text{ ms}$

- Fat
  - $T_2 \approx 70 \text{ ms}$

- Venous blood
  - $T_2 \approx 250 \text{ ms}$

MRA: different techniques

Using T1 shortening contrast agents

- Appropriate timing to avoid venous T1 shortening
- Still need to account for fat
Using T1 shortening contrast agents

- Appropriate timing to avoid venous T1 shortening
- Still need to account for fat

Non-contrast techniques

- T2W image

Properties of arteries that can be used for contrast

- Arterial blood
  - No motion (relatively static)
  - Static flow
  - Spin echo washout
  - Gradient echo enhancement
  - Phase contrast MRI

- Venous blood
  - Slow flow, no out-flow
  - Short TE in sequence

- Background muscle
  - No motion (relatively static)

Time of flight effects in MRI

- Spin Echo (SE)
  - TE = TR / 2
  - 180° pulse
  - Out-flow effect
  - Distance = v_{blood} * TE / 2

- Gradient Echo (GRE)
  - GRE signal
  - TE = TR

Spin echo washout effect

- Complete outflow: TE/2 > AS

Question

T₁ Spin Echo - Short TE

- Arterial blood: complete out-flow
- Venous blood: slow flow, no out-flow

Different (dark / bright) vessel signal?
Question

What happens to arterial signal in

1. Systolic phase (fast blood flow)
   - High or low?
   Answer: low

2. Diastolic phase (slow blood flow)
   - High or low?
   Answer: high

Gated subtracted techniques


Comic relief

Toilet flush analogy to MRI

- Turn the liver → Excitation
- Water gushing in bowl → Signal
  - “Choke” fast with “T2” (~10 seconds)
- Wait for the flush tank to fill again
  - “T1 recovery” (~60 seconds)
  - Takes longer than “T2” decay

What happens if you turn the liver again within 10 seconds?

GRE in-flow enhancement effect

Flow
Static spins saturated by repeated excitation
In flow of ‘fresh’ spins

Gradient Echo: In-Flow Effect

TOF sequence

QISS sequence
Phase contrast MRI

**Flow-Encoding**
- Phase ~ local velocity & bipolar gradient
  - phase of static spins + phase of moving spins

**But:** unknown background phase
- Reference-Measurement & Subtraction
  - Flow in 1 direction: 2 measurements

**Phase contrast MRI**

**Signal Phase – Flow**
- Measurement of blood flow

**Phases contrast MRI**

- Velocities encoded in phase difference image

**Summary of different MRA techniques**

**Using T1 shortening contrast agents**
- Appropriate timing to avoid venous T1 shortening
- Still need to account for fat

**Non-contrast techniques**
- T2W
- Veins visible

**Advanced acceleration techniques**

**MR pulse sequence menu**

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**Courtesy of Dr. Peter Killman, NIH**
Basic principles of Contrast-Enhanced MRA

- Injection of contrast-agent
- T1 shortening of blood
- T1-weighted imaging protocols
- Fast protocols to get data from arterial phase only

How it works

- Low signal of background tissue
  - saturation of spins with long T1
- High signal intensity of blood
  - no saturation of blood due to T1-shortening

Contrast Agent Options for CEMRA

Standard Extra-Cellular Agents
First pass
Double dose for steady-state imaging of veins

High Relativity Agents (Gadobenate, Gadobutrol)
Higher SNR or decreased contrast agent dose

Blood Pool Agents (Gadofosveset, Ferumoxytol)
First pass
Steady-state imaging for high resolution imaging of arteries, venous imaging
FDA approved MRI contrast agents

Blood pool agents

- First pass => separates arteries and veins, short scan time allows breath-holding
- Steady-state => no time constraint on scan time, higher spatial resolution, veins well seen (but may overlap the arteries)

Timing considerations in CE-MRA

Test Bolus
Alternatively: "Care-Bolus"

Contrast injection
(full dose)

Image reconstruction

Circumvent timing issues with fast time-resolved CE MRA

Contrast injection (~5 cc at 2 cc/sec)

Avoids issues with timing and venous enhancement

Time-resolved CE-MRA pulse sequence

Aortic dissection

Peripheral run-offs

Peripheral run-offs
Any questions on CE-MRA

Motivations for Non-enhanced MRA

- Provide alternative to CEMRA in patients with poor renal function (avoid NSF risk)
- Reduce cost (e.g., eliminate need for contrast agents, disposables, and point-of-service renal function testing) => $100–$200/patient
- Provide backup in case of technical failure of CEMRA
- Reduce need for specialized technologist expertise (e.g., required for peripheral CEMRA)

MRA: different techniques

Using T1 shortening contrast agents
- Appropriate timing to avoid versus T1 shortening
- Still need to account for fat

Non-contrast techniques
- Flow independent
  - T2W
  - Vessels visible
- Flow dependent
  - Spin echo without GSE enhancement + Prima contrast

Which non-enhanced technique to use?

Factors determining the choice of sequence
- Physiologic motion (breathing/cardiac)?
- Surrounding M?
- Vessel orientation? (vertical/horizontal/tortuous)
- Arteries and veins in close proximity

Head/Neck NCE-MRA

Magnetization preparation
- Inversion Recovery
- Saturation Recovery
- Dark Blood
- STIR
- Fat Suppression
- T2 Preparation
- Diffusion Weighting
- Tagging
- DENSE
- Magnetization Transfer
- Velocity Encoding

Echo formation
- SE
  - Turbo SE
  - SPACE
- GRE
- SSFP
- EPI
  - SE-EPI
  - GRE-EPI
- FID
- K-space trajectory
- Cartesian
  - Linear
  - Centric
- Spiral
- Radial
- BLADE etc.
- TWIST, Keyhole etc.
- K-space segmentation
- Non-segmented
- Segmented
- Single-shot

Image Reconstruction
- Partial fourier
- Parallel Imaging
  - SENSE
  - GRAPPA
  - TSENSE
  - TGRAPPA
  - CAIPIRINHA
  - k-t methods
  - Compressed sensing

Head/Neck NCE-MRA

3D imaging volume
- Volumetric coverage
- High resolution
**3D-TOF Challenges**

- Saturation of blood by repeated slab excitation
- Reduced blood-tissue contrast within 3D volume

**Multiple Slab 3D-TOF**

- Minor saturation effects
- Signal discontinuities at slab borders

**Thoracic – NCE-MRA**

- Factors determining the choice of sequence
  - Physiologic motion (breathing/cardiac)?
  - Surrounding fat?
  - Vessel orientation? (vertical/horizontal/tortuous)
  - Arteries and veins in close proximity

- 3D inflow enhancement
- Fast spin echo
- Inversion Recovery
- Saturation Recovery
- Dark Blood
- STIR
- Fat Suppression
- T2 Preparation
- Tagging
- DENSE
- Magnetization Transfer

- 2D inflow enhancement
- Recent: QISS

- 3D imaging volume
- Arterial Flow

**Coronary artery imaging**

**MRA of great vessels**

**Cardiac and respiratory gating used**
Abdominal – NCE-MRA

Factors determining the choice of sequence
- Physiologic motion (breathing/cardiac)?
- Surrounding fat?
- Vessel orientation? (vertical/horizontal/tortuous)
- Arteries and veins in close proximity

TOF
3D for brain
2D for carotids
Flow-independent
Fast spin echo with subtraction
Recent: QISS → 2D inflow enhancement

Peripheral NCE-MRA

Factors determining the choice of sequence
- Physiologic motion (breathing/cardiac)?
- Surrounding fat?
- Vessel orientation? (vertical/horizontal/tortuous)
- Arteries and veins in close proximity
**Peripheral NCE-MRA**

**Gated fast spin echo**

![Graph showing signal intensity over time after R-wave]

**Peripheral NCE-MRA – Diseased vessel**

![Graph showing signal intensity over time after R-wave for systole, diastole, and subtraction]

**Peripheral NCE-MRA using QISS**

![Diagram showing QISS technique with selective slice]

**46-year-old male smoker with right-sided claudication**

Lack of arterial visualization in the right calf with Subtractive FSE MRA.

**Peripheral NCE-MRA using QISS**

**Inferior Venous Sat In-Plane Sat**

Quiescent Inflow Slice Selective

![Diagram showing QISS technique with selective slice]
Peripheral NCE-MRA using QISS

1. Sensitivity to motion
   - Use of T2 preparation
   - No subtraction
   - High sensitivity to motion

2. Better than CTA in some cases with calcification

3. Summary
   - There are many flavors of MRA, encompassing contrast-enhanced and nonenhanced techniques
   - CEMRA remains the dominant technique for MRA, with ongoing improvements in spatial and temporal resolution as well as novel contrast agents
   - Newer nonenhanced MRA techniques permit screening for vascular disease with no risk and high accuracy, eliminating need for (and cost of) contrast agents in many cases and providing backup in case of technical failure of CEMRA
   - Flexibility and accuracy of MRA, along with minimal to no risk, should allow it to compete successfully with CTA

4. Easy workflow
   - No contrast
   - No subtraction
   - Set'N'Go
   - Output: all images - one series (CT like)