MR Angiography in the evaluation of Lower Extremity Arterial Disease

Ted Mau, Harvard Medical School Year III
Gillian Lieberman, MD
Objectives

We will cover:

• Indications for Magnetic Resonance Angiography (MRA)
• Basic principles of how MRA works
• Advantages and limitations
Our Patient

58 yo male with IDDM presents with non-healing right heel ulcer and bilateral claudication

Significant PMH:
s/p right renal transplant 1994,
left renal transplant 2000
Lower Extremity Arterial Insufficiency: Role of Radiology

- Evaluation of disease severity to determine management: *Duplex U/S*  
  *Contrast arteriography (CA)*  
  *MRA*
- Definition of vascular anatomy for pre-procedural planning: *CA*  
  *MRA*
- Intervention: *Percutaneous transluminal angioplasty (PTA) ± endovascular stenting*
Contrast Arteriography: The Gold Standard

Requires:
- Exposure to ionizing radiation
- Arterial puncture
- Iodinated contrast - potentially nephrotoxic (as high as 11% incidence of acute renal failure in patients with renal insufficiency* )

MR Angiography

Advantages:
• No ionizing radiation
• Non-invasive
• Contrast (gadolinium) is not nephrotoxic

Main Indication:  *Renal insufficiency*
Questions

If MRA has these advantages over contrast angiography:
• Why don’t we use it for all patients?
• Does it provide results comparable to contrast angiography?
• What are its pros and cons?

A basic understanding of how MRA works will help us understand the advantages and limitations of MRA. Let’s begin by looking at what flowing blood looks like on MRI.
MRA: How does it work?

Blood has variable intensity on MRI images. How do we use the same machine to selectively look at blood flow?
Excitation and Relaxation: A Tuning Fork

Let’s review the basic concept of excitation and relaxation by looking at a tuning fork. After we strike the tuning fork (excitation), the amplitude of the vibration decreases with an exponential envelope (relaxation).
Excitation and Relaxation: Nuclear Magnetization

The net magnetization of a group of protons can also undergo excitation and relaxation. At equilibrium, the magnetization vector lies in the direction of the magnetic field of the MRI spectrometer. An excitation Rf pulse can flip this vector into the transverse plane.

Note: The model presented here is grossly simplified in order to convey basic concepts. For further info please check out the tutorial “MRI of the Brain” in the head and neck section.
Relaxation: $t = 0$

Once in the transverse plane, the magnetization will immediately start to relax back to its equilibrium orientation. We will plot the longitudinal and transverse components of the magnetization vector as it spirals back to align with the magnetic field. Click through the next few slides.

Follow longitudinal component here

Follow transverse component here
Relaxation 1
Relaxation 2
Relaxation 3
Relaxation 4
Relaxation 5
Relaxation 6
Repetitive Excitation Pulses: 1

In the previous example, we applied only one excitation pulse. The longitudinal component of the magnetization recovers with a time constant of $T_1$. Now we will apply successive pulses. In this example, $T_1$ is 1 sec. We will apply excitation pulses at 5 sec intervals.

As you can see, the magnetization has time to relax almost completely before the next excitation pulse arrives. What happens if we shorten the time interval between pulses?

$$TR = 5 \times T_1$$
Repetitive Excitation Pulses: 2

If we apply successive pulses with shorter time intervals, the magnetization does not have time to recover its full magnitude.

\[ TR = 2 \times T1 \]

What happens if we shorten the time interval (TR) further?
Saturation

With TR intervals significantly shorter than T1, the equilibrium magnetization is substantially reduced. Since the strength of the MR signal is determined largely by the equilibrium magnitude of the longitudinal component, we will get a weakened MR signal. The application of repetitive excitation pulses at short intervals to reduce the MR signal is called saturation.

\[ TR = 0.2 \times T1 \]
Saturation: A means to create contrast

If we saturate a slice of tissue with repetitive excitation pulses, the MR signal from the entire slice will be weakened...

...**EXCEPT** for any protons that just entered the slice and have not been around long enough to be saturated! So protons moving *through* the slice will have a higher MR signal relative to the rest of the slice. Saturation has maximized the contrast between the static spins and the moving spins. Put it another way, moving blood in the vessels move into the imaging plane, is not saturated and therefore shows a stronger MR signal.
2D Time-of-Flight (TOF)

Saturation is the basis for one of the basic MRA techniques, called the 2D time-of-flight.

Axial MR image acquired with 2D TOF sequence
2D Time-of-Flight (TOF): cont’d

However, both venous and arterial blood flows into and out of the plane being imaged. Both veins and arteries would therefore be visualized, resulting in a “busy” image. How would we suppress the signals from venous blood?

Visualization of veins can be suppressed...
2D TOF: Venous Suppression

...by applying pre-saturation to a slab of tissue distal to the imaging plane:

Distal suppression “cancels” the vein

artery  vein

Artery only
Axial 2D TOF Image: Our Patient

Axial 2D TOF slice from mid-calf

Anterior Tibial   Peroneal   Posterior Tibial

**Diagnosis**: Our patient shows no flow in the right posterior tibial artery
A complete MRA study consists of MR data acquired with several techniques:

- Time-of-flight (TOF),
- phase contrast angiography (PCA)
- 2D, 3D
- contrast-enhanced

The MRA images that follow are acquired with different techniques, not limited to 2D TOF. But first, let’s look at what the contrast angiography of our patient shows...
Our Patient: Contrast Angiography

You can immediately see the reason why we want to limit contrast administration in this patient: *the renal transplant!* The renal artery is anastomosed off the left internal iliac artery.
A little later: Now the remnants of the vascular supply to his first, failed renal transplant also becomes visible, off the right internal iliac artery. This patient relies solely on his second renal transplant!

Note the high grade stenosis in the right common iliac artery and the two low grade stenoses in the left common iliac artery.
Our Patient: MRA

The MRA 3D reconstruction clearly shows the vasculature supplying the left renal transplant and the common iliac stenoses. Let’s take a closer look....
CA vs. MRA: Aorto-Iliac

CA

MRA

BIDMC
MRA: Popliteal

Note 1. the high grade stenosis in the right popliteal artery proximal to the origin of the anterior anterical tibial artery, and 2. the lack of flow in the right posterior tibial artery immediately after its origin. This explains the non-healing right heel ulcer.
MRA: Foot

The plantar arch is not visible in either foot. Note that the right posterior tibial artery apparently reconstitutes and extends into the foot.
MRA vs. CA: Advantages

One advantage of MRA is its potential to provide better definition of runoff vessels distal to a long segment of stenosis:

CA: Apparently occluded left common iliac artery

CA: No runoff vessels seen
From: Baum & Carpenter, in Abram’s Angiography, 4th Ed. (1997)

MRA: Three vessels seen

This patient does have flow to the lower leg in all 3 vessels as demonstrated by MRA. The lack of visualization on CA is because the contrast agent was not concentrated enough or did not arrive in the ankle quickly enough to be visualized on the X-ray.
MRA vs. CA: Disadvantages

• **Artifact problems:**
  There is no blockage. The “gap” is due to a metallic stent artifact.

From: Baum & Carpenter, Chapter 72 in Abram’s Angiography, 4th Ed. (1997)
MRA vs. CA: Disadvantages

- Artifact problems (e.g. metal, movement)
- Difficulty in imaging certain segments: The Fem-Fem bypass was patent and functioning but the transverse direction of flow was not imaged on MRA.

Fem-fem bypass not visualized on MRA because flow is in the plane of acquisition and the signals are saturated.

From: Baum & Carpenter, Chapter 72 in Abram’s Angiography, 4th Ed. (1997)
MRA vs. CA: Disadvantages

- Artifact problems (e.g. metal, movement)
- Difficulty in imaging certain segments
- Overestimation of severity of stenoses (due to local turbulence and resulting saturation)
- Long examination time
- Patient intolerance (e.g. claustrophobia, pace maker)
Will MRA replace CA in the evaluation of LE arterial insufficiency?

- MRA may be more cost-effective\(^1\)
- Some centers have switched over to MRA
- MRA is a viable substitute in certain patients\(^2\)
- As radiologists gain experience with MRA and the technology improves, MRA will gain wider acceptance

Our Patient: Bilateral Iliac Stenting

Based on the MRA evaluation, it was decided to treat the high grade stenosis in the right common iliac artery with an endovascular stent. However, the left common iliac artery was also stented to avoid vascular steal from the renal transplant.
References

**Good introductory articles and chapters:**
- Baum & Carpenter, Chapter 72, in Abram’s Angiography, 4th Ed., 1997

**MRA vs. CA:**
Acknowledgement

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