Magnetic Resonance Angiography

Module 6

Magnetic Resonance Angiography

- exploits flow enhancement of GR sequences
- saturation of venous flow allows arterial visualization
- saturation of arterial flow allows venous visualization

MR Angiography

MRA is not a look at the actual anatomy.
MRA is a physiological record of blood flow.
If there is no blood flow there will be no MR angiographic visualization of the vessel.
MRA

MRA is a record of blood flow. Any disturbance in blood flow will be recorded in the image.
Small arrow - faster flowing blood.
Large arrow - slower flowing blood.

Introduction

• MR angiography can provide screening of the vascular anatomy of the head, neck, body, and periphery.

• Clinical information should be supplemented with conventional MR images

Time-of-Flight

• Time-of-Flight
  • A vascular imaging technique usually for fast flow. The slab or slice (2D vs 3D) is saturated by repeated RF excitation.
  • The saturation of the spins cause tissues to be darkened.
  • Unsaturated blood entering the slab or slice will not be saturated and therefore will be bright.
  • This is also called a rephase technique.
Time-of-Flight

- TOF is the time it takes for blood to flow through an imaging slice and the effect it has on the signal from blood.
- When using spin-echo pulses time-of-flight blood is dark.
- When using gradient echo sequences time-of-flight bright blood results.
- Time-of-flight refers to the effect of allowing blood to flow into or out of a slice between excitations.

2D TOF

- GR images used
  - short TR (~ 20-40 msec)
  - very short TE
    - shortest TE times minimize intravoxel dephasing resulting in maximum flow effects
  - small to medium flip angles
2D Time Of Flight (TOF) Benefits

• Both arteries and veins can be visualized.
• Shorter acquisitions times lend itself to abdominal vascular imaging using breath-hold techniques.
• Background tissue suppression is superior to 3D TOF imaging.
• Extremely slow flow velocity blood can be adequately visualized.
• Large area of coverage

2D Time Of Flight (TOF) Disadvantages

• Resolution limitations (smaller available slice thickness) cause an increase in partial volume effects.
• MIP projections tend to suffer due to thicker individual slices.
• Longer TE times and larger voxel volumes may result in an inappropriate decreased in signal following an area of stenosis.
• If the vessel is not quite perpendicular to the slice, or if it changes directions within the slice, saturation of the vascular signal occurs.

3D TOF

• 3D TOF imaging volumetrically acquires contiguous thin slices by the usual 3DFT method.
• 3D TOF imaging is the method of choice for imaging fast flowing blood that does not particularly follow a straight course.
• The TE times tend to be shorter than with the 2D TOF method resulting in minimized flow-turbulent related artifacts.
• In addition, high resolution images can be acquired lending easily to high resolution MIP images.
3D TOF Benefits

- High resolution vascular imaging
- High SNR
- Rapid acquisition of 3-5 cm area
- High resolution MIP images possible
3D TOF Disadvantages

- Blood must traverse the volume quickly in order not to become saturated along with the background tissue (saturation of in-plane flow).
- Short T1 tissues in the background may not become saturated completely thereby simulating a vessel.
- Coverage

Phase Contrast

- Phase Contrast
  - A vascular imaging technique where sets of images are encoded with different phase velocities and are then subtracted.
  - Background subtraction is complete.
  - This technique is used for slow flow as in the extremities.
  - This is also known as phase shift.
  - Available 2D and 3D imaging

Phase Contrast / PSI Angiography

- The greater the velocity of motion, the more phase shift, and the brighter the appearance of blood in the image. Therefore, complete suppression of stationary tissue can be achieved with PC.
In phase contrast (PC) MRA, signal is based on the phase gained (or lost) as the spins move through a magnetic field gradient. Spins that are moving in the same direction as a magnetic field gradient develop a phase shift that is proportional to the velocity of the spins. This is the basis of phase-contrast angiography. This phase is subtracted from the background phase to determine the portion of the phase that is only due to motion.
Phase Contrast Angiography

• The strength of the phase encoding gradient is determined by setting a parameter called the "encoding velocity" or "VENC".
• Phase sensitization has to be performed along the x, y, and z gradients.
• Then each is subtracted from a baseline image (without gradient activation).
• This sequence typically takes 4 times longer than a TOF technique with the same TR and matrix.

Velocity Encoding (VENC)

• The velocity of blood flow is defined by the distance traveled between the positive and negative lobe of the velocity-encoding gradient (a 180° phase shift will produce maximum signal intensity).
• It is shown in cm/sec.

VENC

• The VENC value chosen will cause the blood flow traveling at exactly that value, in the direction of the positive lobe, to be assigned the maximum pixel value.
• Blood flow in the opposite direction will be dark. Choose a VENC value slightly higher than the predicted velocity of blood being observed to reduce the possibility of aliasing.
Phase Contrast Advantages

- Sensitive to flow within FOV
- Background suppression is superior
- Can evaluate blood flow velocity
- Can evaluate blood flow direction (magnitude and phase images)

Phase Contrast Disadvantages

- Scan times are long due to acquisition methods.
- Less sensitive to unpredictable flow

Contrast enhanced MRA

- Often in-plane flow and motion artifacts can degrade MRA images.
- Contrast MRA has therefore become the standard in MRA imaging.
- These sequences are generated with T1 weighted gradient echo images with bolus injections of gadolinium.
- Dynamic imaging are acquired before, during and after injection timed based on the vascular consideration.
The patterns of blood flow through branching and twisting vessels is like that of water flowing down the winding path of a stream. Pools of slow blood can form in out-of-the-mainstream pockets. One such “whirlpool” of slow moving blood is seen in the carotid bulb.

Blood Flow

LAMINAR FLOW

Blood flow that has a parabolic profile, in which the velocity of the protons in the center of the vessel is greater than the velocity of protons moving adjacent to the vessels walls.
Laminar Flow

Laminar flow is usually found in veins and small arteries. MRA most accurately represents laminar flow.

Turbulent Flow

Turbulent flow, in which blood is not moving at a constant velocity, and may actually be “mixing” and moving in more than one direction. Turbulent flow is often found in tortuous sections of vessels and distal to bifurcations and stenosis. In regions of turbulent flow there is a great deal of dephasing of protons; which is depicted as signal loss in the images. MRA does not obviously represent turbulence well and areas of stenosis are often overestimated.

Flow-related enhancement is an enhancement of flowing blood seen on gradient echo pulse sequences as well as in entry slices of multi-slice spin echo sequences. This enhancement is a result of inflow of unsaturated (completely relaxed) spins into a slice plane or imaging volume between RF excitations.
Example of Flow Enhancement

- The slower flowing blood during later diastole shows markedly less signal due to partial saturation.

Scan Parameters

- GRE sequences are required for bright blood
- Thin slices decrease the velocity necessary for 100% inflow of unsaturated blood as well as improve resolution
- Flow compensation refocuses motion related dephasing resulting in a brighter signal

Scan Parameter Optimization

- **TR**
  - TR must be kept short to minimize acquisition time but long enough to allow for presaturation use or provide adequate SNR.
  - The TR and flip angle compliment each other so changes in TR may require a corresponding change in flip angle.
  - However, TR and flip angle cannot exceed a maximum value without compromising the time of flight effect.
Scan Parameter Optimization

• TE’s
  – Must be kept short to avoid loss of signal from turbulence.
  – If different TE choices are available, TE will be chosen by size of vessel to be imaged and pathology expected.

Scan Parameter Optimization

• Flip Angle
  – Flip angle and TR are complimentary for adequate suppression of background tissues.
  – Flip Angle also will affect the saturation of the inflowing blood.
  – The longer the vessel must remain unsaturated, the shorter the FA will need to be (e.g., the coronal or para-coronal acquisition of the proximal carotid arteries.
  – If the FA is too large, the time of flight effect will be reduced.

Scan Condition Optimization

• Voxel size
  – The voxel is the cubic portion of data as prescribed by the slice thickness and matrix.
  – Smaller voxels reduce the turbulent signal loss as well as provide higher resolution of the vessels.
Scan Condition Optimization

• Slab thickness
  – The slab thickness should never be thicker than the vessel segment of interest.
  – The size of the slab is also related to the direction of flow.
  – If the slab is perpendicular to the direction of flow in the vessel of interest, the distance the blood must flow is an essential consideration.
  – Signal from blood flow will be saturated out of the slab if too thick.

Multiple Overlapping Thin Slice or Slab Acquisition (MOTSA)

• Multiple 2 to 3 cm thick 3D-TOF slabs covering the anatomy of interest.
• MOTSA combines the best features of 2D- and 3D-TOF MRA, because it has the unlimited coverage of 2D-TOF and the high spatial resolution of 3D-TOF.

Image Processing & Display

Most approaches to MRA data acquisition have in common the end result of high signal intensity blood vessels superimposed over a background of unwanted material. The solution to this problem is maximum intensity projection (MIP).
The maximum intensity projection algorithm is responsible for projecting the brightest pixels, from an anatomical stack of 2D or 3D base images, onto a plane, to generate an image of the projected view of the vessel(s) of interest.
MRA Optimization

- Saturation bands are planar regions parallel to and adjacent to imaging planes or slabs.
- Within them blood that we do not want to see is saturated with repeated RF signals before it enters the imaging volume, emitting no signal.

Spatial Saturation

To limit a study to either the arteries or veins, a saturation pulse may be added to the MRA pulse sequence to eliminate the inflowing blood from irrelevant vessels.
Saturation

- To see blood in the carotid arteries, which is flowing up from the heart to the head.
- We do not want to see blood in the jugular veins, which is flowing down from the head to the heart.
- Place a saturation band above the imaging plane or volume so that venous blood within the plane or slab is saturated and does not contribute any signal, while carotid arterial blood entering the volume from below is fresh and produces the desired bright signal.

Saturation Bands

- To saturate Venous Flow - from heart
  - If below heart: inferior presaturation band
  - If above heart: superior presaturation band

- To saturate Arterial Flow - from heart
  - If below heart: superior presaturation band
  - If above heart: inferior presaturation band

Saturation Bands

- Walking saturation bands
  - Places a new saturation band adjacent to each new imaging plane or slab as it is acquired in sequence so that each scan has been presaturated.

- More sophisticated placements include use of multiple bands and placement at oblique angles to optimize presaturation and exclusion of signals.
MRA Optimization

• Two main areas that require great care when producing MRA images are the carotid bifurcation and the circle of Willis.
• The common carotid artery on the left is usually the second major vessel originating from the aortic arch, whereas on the right side, the common carotid arises from the proximal innominate artery.
• The common carotid arteries usually bifurcate into the external and internal carotid arteries.

MRA Optimization - Carotids

○ The bifurcations are important to visualize as the internal carotid arteries provide major blood flow to the brain.
○ Turbulence and high-velocity blood flow effects produce complex flow patterns that can make MRA difficult.

Circle of Willis

○ The circle of Willis is a polygon-shaped arterial network formed from branches of the anterior (carotid) and posterior (basilar) circulations.
○ The circle of Willis is horizontally oriented and situated in the suprasellar area.
Circle of Willis

- The best way to visualize the circle of Willis is to place the middle slab of a three-slab MOTSA sequence.
- Avoid placing the interslab interface cross the circle of Willis.
- Any time-of-flight apparatus can produce a circle of Willis using a stack of 2D or a 3D slab acquisition.
- Phase-contrast MRA may be used to show anatomic relationships and can provide information about the direction and velocity of flow (normal and abnormal) in the COW.

MOTSA through Circle of Willis

MOTSA through a normal Circle of Willis.

The vessels that form the circle of Willis include:
- Two internal carotid arteries
- Horizontal segments of the proximal and anterior cerebral arteries
- Anterior cerebral arteries
- Two posterior communicating arteries
- Basilar artery

Saturation bands should be set to block venous blood signals that are moving forward from the large sinuses on their way to the jugular and other veins.