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CHAPTER TWO

Body MRA Imaging: Bolus Detection Techniques

After completing this chapter, the reader will be able to:

- **Explain the fundamentals of different bolus detection techniques**
- **Identify the advantages and disadvantages of different bolus timing methods**
- **Describe the two types of stepping tables**

Gadolinium contrast bolus timing in MR body applications is critical to the success of the exam. As we will show later, dynamic-contrast imaging of the liver is essential for proper diagnosis as the series requires precise contrast bolus timing. Likewise, MR angiography comprises a large component of body applications. Body MRA applications include ascending, thoracic, and abdominal aorta; renal arteries; superior mesenteric artery; and MRA "runoffs" (abdominal, iliac, femoral, popliteal, lower leg, and feet arteries). Bolus timing for these areas, as with dynamic liver imaging, must be precise. A discussion about differing bolus detection and timing techniques follows.

OVERVIEW

Because of ongoing advances in technology, **MRA** continues to be one of the fastest-growing applications in MR imaging in general and in body applications in particular. As recently as the mid-2000s, advanced MRA was far from customary. Outside of routine intercranial MRA imaging, more advanced MRA imaging, such as contrast-injected carotids and MR peripheral runoffs, were fraught with pitfalls, including difficult set-up and variable results.

More powerful gradients, more sophisticated software, specialized coils, and faster reconstruction processors have all made MRA fast and easy to prescribe by the technologist, resulting in more consistent, highly diagnostic images.

BOLUS DETECTION TECHNIQUES WITH TIME-OF-FLIGHT IMAGING

The use of a gadolinium-based contrast agent (**GBCA**) for imaging the vascular system changed the way MRA examinations were performed. Until the mid 1990s, the vast

POINTS FOR PRACTICE

1. Why is the use of a gadolinium-based contrast agent especially beneficial for imaging of the vascular system?
2. List the primary methods for predicting and detecting the arrival of the bolus of contrast. Which is the most effective, and why?
3. What are the benefits of ultrafast scanning?

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majority of MRA scanning was done using non-contrast-enhanced 2D or 3D time-of-flight (**TOF**) imaging. With these techniques, the scanning sequence uses a gradient-echo series in the plane most perpendicular to the flow direction of interest. For example, if the carotid arteries are the vessels of interest, the scan plane is typically in the axial direction, which is perpendicular to the flow (carotid arteries run inferior to superior). In this example, imaging would create contrast in the image based on the flow-related enhancement of flowing blood into an axial slice plane, where magnetization of the blood is at its greatest. The resultant images show darker (non-flowing) stationary tissues against very bright flowing blood. Images are then postprocessed into maximum intensity pixel (**MIP**) projections in a 3D display. While 2D and 3D TOF imaging is robust, it is not without its disadvantages:

- TOF can overestimate the degree of stenosis.
- Flow that is not perpendicular to the imaging plane can become saturated with RF energy, appearing dark and falsely resembling a stenotic vessel.
- Flow that is slow also may become saturated with RF and appear dark.
- Long scan times (four to six minutes for a 2D TOF and six to nine minutes for a 3D TOF) increase the risk of patient motion and consequently blur the images.
- Specific to body applications, images of the lower extremities are often badly smeared due to naturally occurring **tri-phasic flow** velocities, where arterial flow moves in three distinct phases: fast forward, short reverse, then fast forward.

See Figures 11 and 12 for examples of flow-related enhancement and 3D TOF.

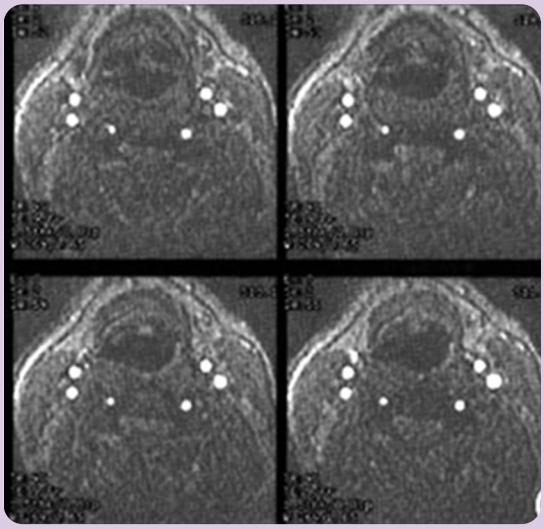

Figure 11. Axial view of 4 images acquired perpendicular to the carotid and vertebral arteries. A short TR and a high flip angle ensure heavy saturation of stationary tissues while providing maximum flow-related enhancement of the carotid and vertebral arteries. These "source" images are then post-processed into a 3D MIP projection.

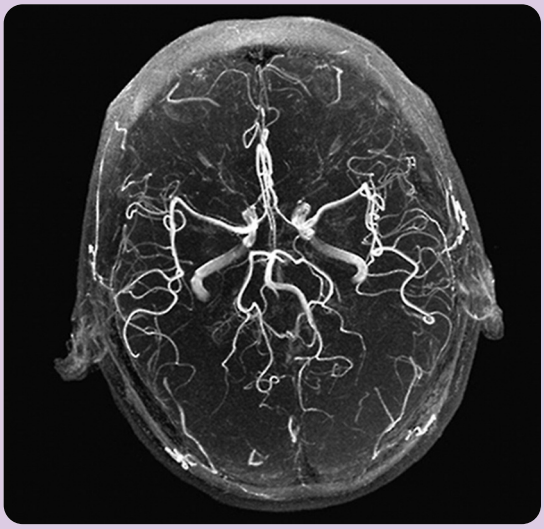

Figure 12. Collapsed MIP projection of the intercranial arteries. This time-of-flight image takes advantage of the flow-related enhancement of the fast-flowing blood. The individual source images are displayed as a singular MIP projection to visualize the entire vasculature.

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Role of Gadolinium Contrast in Vascular Imaging

The introduction of gadolinum contrast enhancement in vascular imaging dramatically altered the methods used to perform most MRA examinations. Because gadolinum is paramagnetic, it does not rely on flow-related enhancement to provide strong (bright) signal, and the scan plane orientation is no longer required to be perpendicular to the flow. The use of ultrafast 3D gradient-echo sequences significantly reduces scan times while increasing resolution. Finally, the occurrence of tri-phasic flow is no longer a factor because the gadolinum does not saturate with RF energy such that it does not emit the absorbed RF energy (saturated tissues, like stationary soft tissue in a TOF sequence, emit little signal and appear dark on the image). The technical challenge of using contrast was delivering the bolus of contrast at the exact time of imaging, timing the acquisition to obtain images of the vessels of interest precisely upon contrast arrival.

SPECIFIC BOLUS DETECTION TECHNIQUES

Methods for predicting or detecting the arrival of a bolus of contrast into the vessel of interest typically fall into one of three categories:

- Manual Timing
- Computer-aided Detection
- Visual Detection

Manual Timing

Manual timing is very effective in determining bolus arrival. It allows facilities without dedicated bolus detection software to acquire a high-quality MRA. The technologist sets up a scanning series so that a single slice is prescribed to be imaged multiple times. This multiphase series is performed while a small amount of contrast (2–3 mL) is injected over two to three seconds. After the series is complete (typically ~1 minute), the technologist reviews the images to determine which image has the greatest degree of contrast in the vessel of interest by using a region-of-interest (**ROI**) tool that displays the actual pixel values of the contrast entering the vessel. Once a specific image is identified, the technologist calculates the time it took for the bolus to arrive by looking at the time stamp on the image (provided on all MR systems). The challenges of manual timing for the technologist are correctly calculating timing, as well as determining if a small amount of contrast used in the test bolus lingered in the venous system and obscured some arterial vessels. But, to be sure, a well-timed, manually calculated bolus series is indistinguishable from the more automated methods discussed next.

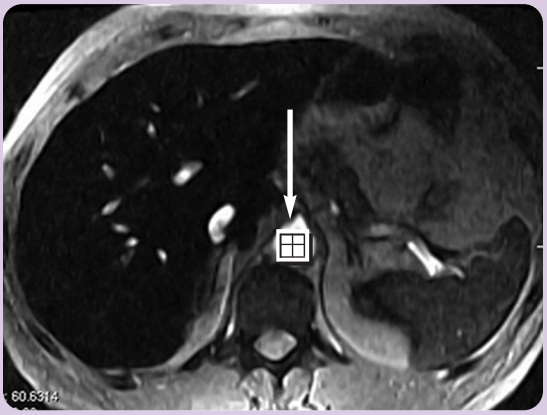

Figure 13. Axial image showing abdominal aorta with a graphically prescribed 3D "tracker" pulse cube. The area inside the cube is monitored in real time for rapid increases in pixel signal intensity resulting from gadolinium in-flow. When a set threshold of signal increase is reached, data acquisition of the 3D MRA begins.

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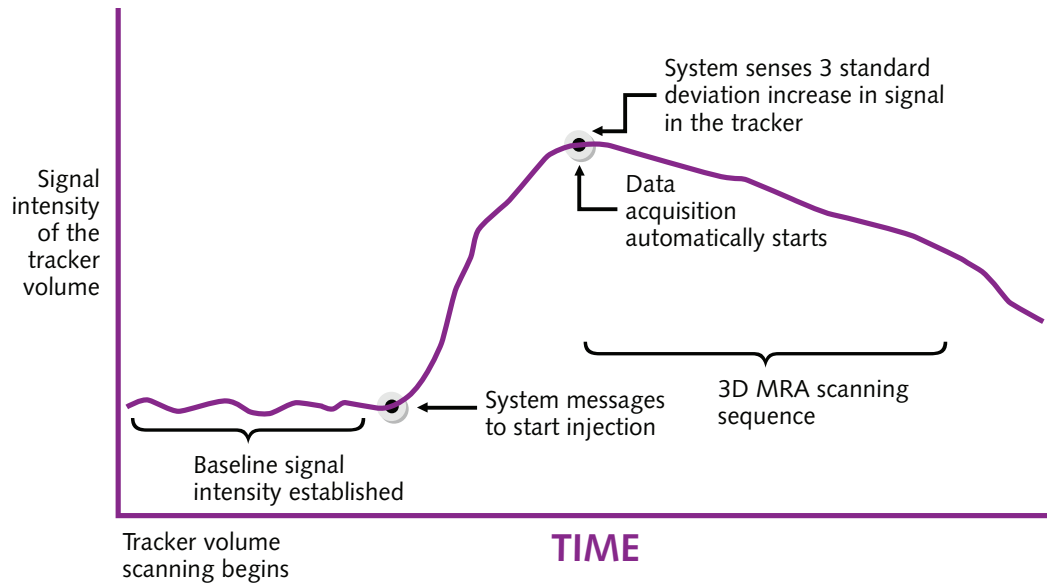

Figure 14. Time course of events in an automated bolus detection technique.

Computer-aided Detection

MRI is a versatile imaging modality, capable of analyzing signal data from the patient in near-real time. The ability to perform real-time data processing is extremely useful in the MRA application for determining when a contrast bolus arrives at the area of interest.

The automated bolus detection method requires the technologist to prescribe a small volume area of interest (10 mm x 10 mm x 15 mm) on a **scout image** – such as the abdominal aorta for renal MRA – and the fully prescribed area to be scanned when the contrast is delivered. The scanner begins the imaging sequence and analyzes the pixel intensity from the small volume, often called the "tracker" (Figure 13). Once the system determines the average pixel value of the volume (the baseline of pixel values), the technologist injects the contrast. The system continues to monitor the tracker volume. When the bolus arrives in the area of interest, the pixel values from the tracker quickly increase in dramatic fashion, signaling the MR system that the bolus has arrived. The system then launches the ultrafast gradient-echo sequence for the contrast MRA series (Figure 14).

Automated computer-aided bolus detection methods are highly effective, producing excellent contrast MRA studies. The technique is automated, with little outside intervention and no manual calculations required. There is no contamination of the images from small amounts of test bolusing in the venous system.

The challenge of the automated computer-aided bolus detection method is that it requires precise placement of the tracker volume. If the tracker is misplaced or the patient moves between the time of placement and the time the actual scan begins, the bolus

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may not be detected or may be detected too late, yielding non-diagnostic images. Also, the central *k*-space line of the MRA sequence must be filled first to meet the arrival of the contrast bolus.

Visual Detection

Visual detection methods combine the best of manual timing and computer-aided techniques. Visual detection integrates the real-time display of image data from the automated computer-aided bolus detection with the visual cues of the manual timing method. Visual detection is often referred to as "fluoro-triggered MRA." The area of interest is scanned at first with a very low-resolution technique so that the images are displayed in near-real time—thus, the use of the term "fluoro" as in real-time x-ray imaging. The injection is made during the display of the images in real time, and the technologist can often watch the patient's breathing during an abdominal MRA. The technologist visually inspects the images to note the arrival of the contrast bolus. Once the bolus is seen, the technologist switches the imaging parameters in real time to a higher resolution scan, which produces excellent contrast MRA results.

The advantage of the visual method is that the technologist is in control of the start of the scan, eliminating the need for a test bolus, and breathing commands can be tailored to individual needs. The only potential drawback is that the technologist must be vigilant in watching the images in order to track the arrival of the bolus. Again, as mentioned

Contrast Injection

The contrast used in MRI is safe in almost all cases, but some people do experience side effects. Every technologist should read and familiarize themselves with the Prescribing Information that is enclosed with the contrast media used at their facility. Care must also be taken to know the serum creatinine levels of all patients with kidney disorders in order to evaluate the risk of nephrogenic systemic fibrosis (NSF). See Prescribing Information form enclosed in all contrast media containers for FDA recommendations.
Courtesy of Stephen Dashnaw, ARMRIT, Columbia University

The following is not a complete list of possible contrast reactions, but contains the most common side effects.

- **A slight to severe burning pain at the sight of the injection, dependent upon the amount of contrast material infiltrated between the skin and vessel**
- **Headache**
- **Metallic taste**
- **Dizziness**
- **Vomiting**
- **Vasovagal reaction. A vasovagal reaction is not due to contrast media. It is not fully understood by the medical community, but every technologist should recognize the symptoms: cold sweats, increased pulse rate, decreased blood pressure, and fainting. Elevate the patient's legs and provide a cool, wet cloth until the symptoms pass.**

For in-depth discussion of the different types of contrast media, their uses, and potential side effects, please refer to *MRI for Technologists, Module 2, Chapter Five.*

Table 1. Contrast Injection

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above, the central *k*-space lines need to be sampled first in order to meet the arrival of the contrast bolus.

See Table 1 for a list of possible side effects of gadolinium-based contrast and a warning about the rare but potential development of nephrogenic systemic fibrosis.

ULTRAFAST SCANNING CAN ELIMINATE BOLUS TIMING

Imagine scanning so fast that:

- entire 3D volumes are acquired as fast as a single slice.
- one simply prescribes the required 3D volume of interest and then tells the system how many times to scan this volume.
- the course of a bolus of contrast is captured as it progresses through the vasculature of interest.
- it does not matter when the bolus arrives because the scanner is already acquiring the data before, during, and after peak enhancement.
- this technique takes no longer than the typical 3D time-of-flight sequence.

This technique is now used on many high-end MR scanners. Referred to by various manufacturer names (GE – TRICKS; Siemens – TWIST, TREAT; Philips – 4D-TRAK), this rapid technique is finding its way into the mainstream. It requires very fast and high performance gradients (to acquire the data quickly) and very fast array processor reconstruction engines. In less than five minutes, 1,000 or more individual images can be acquired, making ultrafast reconstruction processors an absolute requirement.

In essence, the technologist prescribes the 3D volume of interest of, for example, the patient's lower legs. The technologist determines the number of times the volume will be scanned. Each of these scans is referred to as a "phase." The technologist must then balance the spatial resolution with the necessary temporal resolution, that is, how fast each 3D volume must be acquired. (As spatial resolution increases, temporal resolution decreases.) Once set, the technologist simply injects and starts the scan at the same time as the injection. As each 3D volume is acquired, usually in a matter of seconds, it is quickly reconstructed and processed into a MIP that is then displayed on the screen while the subsequent 3D volume is acquired. Each 3D MIP displays an increasing, then decreasing amount of contrast in the vasculature (Figure 15).

STEPPING TABLES

Mobile MR tables, also called "stepping tables," are now widely available on all new MR systems and are usually standard equipment on high-field magnets. The primary application of a stepping table is to provide an automated method for doing the MR peripheral runoff exam. In this application, a bolus of contrast is injected and then, through careful timing, the patient is imaged in stations to essentially chase the bolus from the mid-abdominal aorta to the feet. Most MR systems can be retrofitted with a stepping table if not originally equipped with one.

The automated stepping table is motorized and controlled remotely from the MR console without need for intervention in the scan room. Most high-field systems are equipped with an automated stepping table designed and installed into the MR hardware system. The scan operator can reposition the table and perform multiple scans directly from the scan console without entering the scan room or repositioning the table or the patient, which increases patient safety and comfort.

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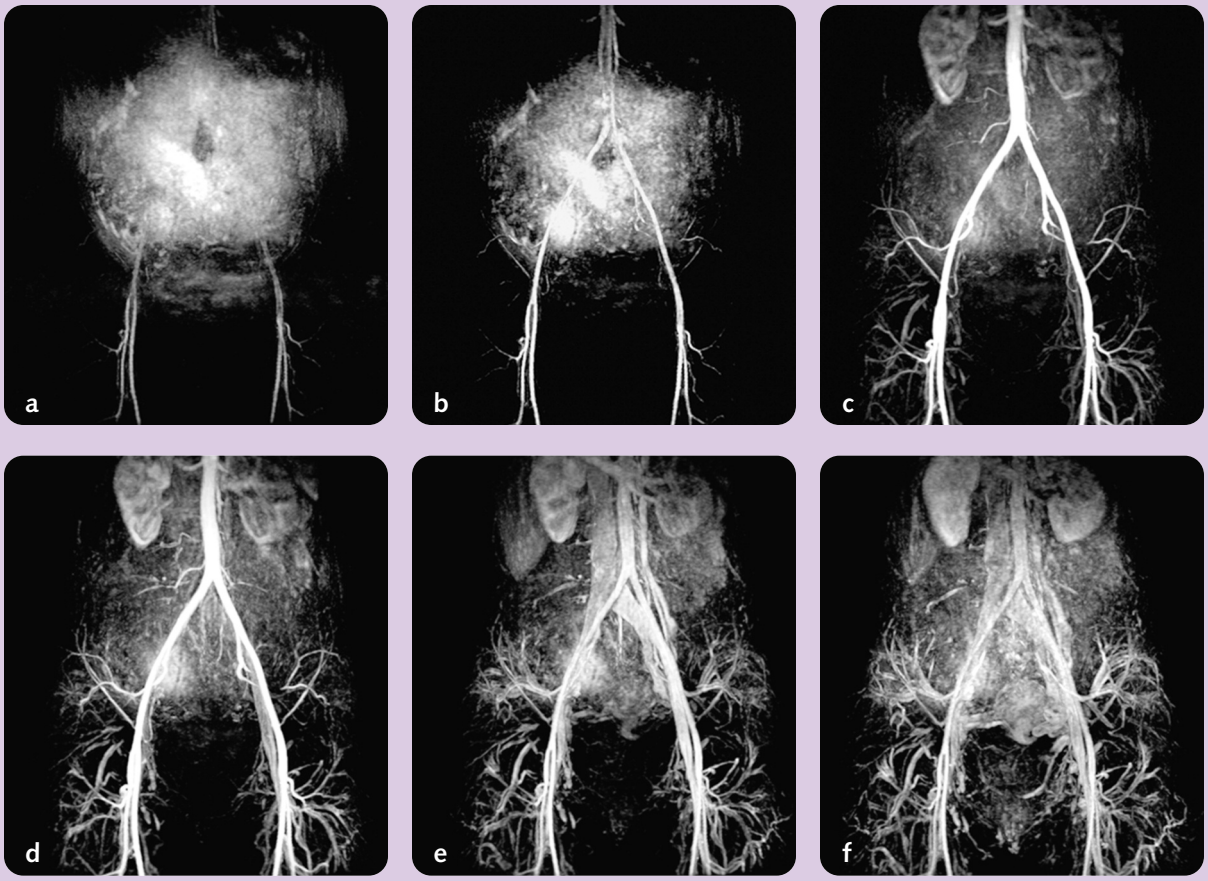

Figure 15. Selected MIP phases of a multi-phase multi-3D pelvic MRA/MRV of a 35-year-old female with pelvic pain. (a) Early arterial phase. (c) Peak arterial phase. (d) Early venous phase. (f) Late venous phase. Note the extensive and prominent pelvic veins consistent with venous pelvic congestion.

Application to Peripheral Runoff MRA

A complete peripheral MRA runoff can be acquired with a single bolus of IV contrast. The patient initially is positioned at the first anatomic station. Contrast is injected and the first set of images acquired. Next, the table is moved a specific distance (typically 30–45 cm) to center the patient towards the lower extremities, and the acquisition is repeated. The process continues until a complete angiographic set is acquired within the single contrast bolus. The entire process can often be completed in as little as 15 minutes of imaging time and cover 75–150 cm of anatomy (Figure 16).

Acquisition of such a large field-of-view without repositioning the patient is most efficiently performed using an appropriate set of coils. Dedicated peripheral vascular coils are available from a variety of vendors. Alternatively, multiple coils covering the anatomy of interest can be applied simultaneously by manually switching the coil used at each station. Some MR systems are capable of

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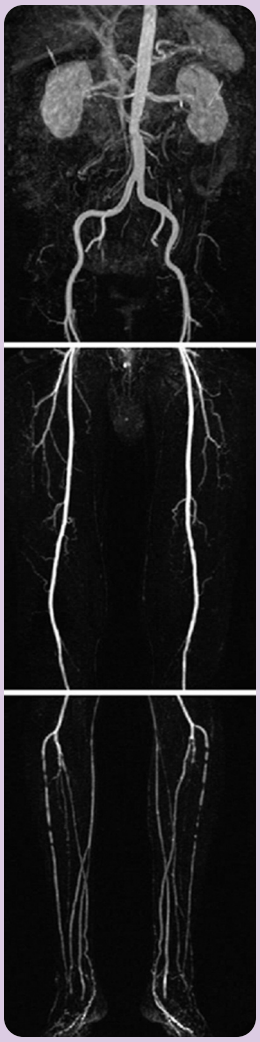

Figure 16. An example of a MR peripheral runoff exam. Note the coverage of the exam from superior to the renal arteries to the level of the feet. Also note the boundaries between "stations" indicating the three levels of scanning from the abdomen (upper station), lower pelvis and femoral areas (middle station), and the lower legs (lower station). *Courtesy of F. Scott Pereles, MD, Northwestern Memorial Hospital.*

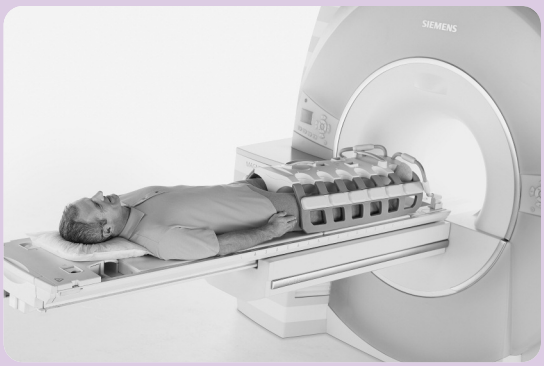

Figure 17. Example of placement of a run-off coil used for imaging blood vessels of the legs. *Courtesy of Siemens.*

automatically switching to the coil set covering the current anatomic station.

Other examinations that take advantage of a stepping table for an extended field-of-view include abdominal and pelvic vascular imaging and whole body imaging for metastatic surveys (Figure 17).

Continuous Table Movement

Recent advances in technology have made it possible to allow the table to continuously advance during the image acquisition. The advantage of a continually moving table is that the data acquisition is continuous through the entire runoff exam. In addition, the speed of the automatic table advance can be adjusted to track the movement of the contrast bolus, ensuring that the timing of the images at each location is correct so that the arterial phase is seen throughout and preventing venous contamination.

SUMMARY

MR angiography remains a very useful application. A typical MRI facility routinely performs MRA examinations every day for many different body areas. The use of contrast enhancement is preferred when imaging areas other than the intercranial vessels. Various methods are employed to time the imaging sequence to coincide with the arrival of a bolus of contrast in the area of interest. Understanding the capabilities and limitations of the particular MRI system is essential for perfecting the techniques for this important examination.

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POINTS FOR PRACTICE

1. **Why is the use of a gadolinium-based contrast agent especially beneficial for imaging of the vascular system?**

   Because gadolinum is paramagnetic, it does not rely on flow-related enhancement to provide strong (bright) signal, and the scan plane orientation is no longer required to be perpendicular to the flow. The use of ultrafast 3D gradient-echo sequences significantly reduces scan times while increasing resolution. Finally, the occurrence of tri-phasic flow is no longer a factor because the gadolinum does not saturate with RF energy such that it does not emit the absorbed RF.

2. **List the primary methods for predicting and detecting the arrival of the bolus of contrast. Which is the most effective, and why?**

   Manual timing, computer-aided detection, and visual detection are the three primary methods. Visual detection combines the best of manual timing and computer-aided detection by integrating the real-time display of the image data with the visual cues of manual timing.

3. **What are the benefits of ultrafast scanning?**

   Ultrafast scanning can eliminate the need for bolus timing. 3D volumes can be acquired in a single slice, and the course of a bolus of contrast is captured as it progresses through the vasculature of interest. The operator prescribes the 3D volume of interest, then tells the system how many times to scan that volume.

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Notes

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