Contrast enhanced body magnetic resonance angiography

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Abstract

The use of gadolinium contrast for body MRA is reviewed. Considerations for timing of the bolus of contrast are discussed. The utility of this technique is illustrated through clinical examples. Contrast enhanced MRA is rapidly replacing conventional angiography for many applications.

Abbreviations: DSA – digital subtraction angiography, GRE – gradient recalled echo, MIP – maximum intensity projection, MPR – multiplanar reformation, TOF – time of flight

Introduction

There are several major techniques commonly used for MRA in the body. Time of flight (TOF) is primarily used for peripheral angiography [1]. Phase contrast angiography has limited applications in the body. Its modification to quantitate flow is generally more useful and permits the determination of the gradient across a stenosis, and the pulmonary to systemic flow to quantitate shunts [2]. Since Prince [3, 4] first introduced the use of gadolinium for 3D MRA, contrast MRA has rapidly gained favor for most body applications.

The idea is to make use of a 3D T1-weighted gradient recalled echo (GRE) pulse sequence and “opacify” the blood vessels with gadolinium contrast. Modern MRI scanners permit adequate spatial resolution to be achieved within a breath hold. The suppression of venous enhancement is achieved entirely by timing the bolus such that maximum contrast is within the arteries before the transit into the venous system.

Considerations for bolus timing

There is considerable variation in the contrast kinetics of a contrast bolus in patients so it is best to time the arrival of contrast [5]. We find that more reproducible results can be achieved with a power injector than hand injection. Optimal timing can then be determined from a test bolus in the region of interest [5]. Alternatively, a pulse sequence can be designed to sense the arrival of contrast (e.g. Smart PerpTM) to trigger the pulse sequence [6, 7]. If a test bolus is used, it is critical to inject at the same rate as intended for the MRA and to use a similar saline flush. A rapid T1-weighted GRE pulse sequence axial to the vessel of interest is performed simultaneously with the test bolus obtaining images every 1–2 seconds. The time at which contrast appears within the artery is defined to be TB (Figure 1). The bolus will have a duration, BD, which is a function of the rate and volume of contrast administered for the angiogram as well as dispersal of the bolus. A delay time, TD, must be specified for starting the MRA sequence after the injection of contrast. For a pulse sequence acquisition time of TA, the bolus will be centered during the image acquisition if $TD = \frac{TB}{2} + \frac{BD}{2}$ [8].
There are several common sense observations which may be made concerning the bolus injection. If $BD > TA$, contrast is wasted as there is transit of contrast in the arteries when there is no imaging. However, if $BD < TA$, there will be a transient increase of signal during the image acquisition which can give rise to ringing artifacts particularly if the central portion of k-space is acquired without contrast [9]. Moreover, there will be less signal-to-noise for the arteries (similar to half-Fourier imaging). Thus it is generally best to match $BD$ to $TA$ providing that venous transit is not so fast as to become problematic. For a sequential ordering of k-space, one may start imaging before the arrival of contrast providing at least 60% of the image acquisition takes place while contrast is within the artery to minimize venous enhancement [9].

Generally, it seems that larger doses of contrast are required for slow acquisition times. Early work advocated “double” or “triple” (2–3 mmol/kg) of gadolinium [3, 4, 6]. With more rapid imaging with modern scanners, single dose appears to be adequate for breath hold applications [8, 10, 11]. In the extremities where slower sequences may be

\[ TD = TB - TA/2 + BD/2 \]

*Figure 1.* Estimation of delay time, TD, for imaging after injection of contrast. A test bolus determine, TB, the time that the bolus appears. The bolus has a duration of BD. TA is the acquisition time of the pulse sequence. The bolus will be centered in the acquisition window if $TD = TB - TA/2 + BD/2$.

*Figure 2.* Example of MR venogram. The first breath hold acquisition (A) is predominantly arterial whereas the second breath hold (B) has both arterial and venous enhancement. A venogram (C) is obtained by subtracting the first from the second acquisition. There is thrombosis of the left subclavian vein. Note that the portal and hepatic veins are clearly seen with this technique.