

## *MR ANGIOGRAPHY at 3T*

*Neil M. Rofsky, MD*

*Beth Israel Deaconess Medical Center*

*Boston, MA, USA*

MR angiography comprises a series of techniques to depict the blood vessels. Flow based techniques such as time-of-flight and phase contrast for MRA have been largely replaced by contrast-enhanced strategies. The latter, a lumen filling approach, is conceptually more akin towards conventional catheter based angiography in which a finite time exists for capturing the contrast within the vessel of interest. With the extra-cellular fluid contrast agents, a short arterial half life places limits on the effective time one can sample information. Thus, the MR angiographer is posed the classic challenge of deciding about the appropriate balance between spatial and temporal resolution, when selecting or optimizing a protocol.

The inherent doubling in signal-to-noise ratio when compared to 1.5T provides unique opportunities for MR angiography at 3T (1). The augmented SNR can be used to improve anatomic and/or temporal resolution and reduce breath hold time periods while preserving image quality. However, susceptibility, specific absorption rate (SAR), chemical shift dispersion and sensitivity to motion artifacts are also increased at 3.0T (scaling with field strength). Furthermore, the T1 and T2 values of tissues are altered with T1 values becoming longer and T2 values becoming shorter (2).

**T1 relaxation times** of most materials increase with field strength. A greater than expected yield in vessel: background C/N for MR angiography has been observed since the T1 of blood and solutions of gadolinium chelates may not vary as greatly with the field strength (3). Thus for TOF and Gd-enhanced MR angiography, imaging 3T can provide a reduction in the relative signal of the background tissues as compared with the vasculature; the result is improved target (vessel): bkgd contrast to noise.

The increased relaxation time of background tissues augments 3.0T TOF image contrast since more effective background signal saturation at any given TR is achieved at the higher field strength. In this regard the Mayo Clinical investigators, using identical geometry head coils, showed a significantly better visualization of intracranial aneurysms using 3.0T 3D as compared to those seen at 1.5T (3). For venous imaging improved resolution and the delineation of smaller vessels compared with lower field strengths has also been demonstrated (4).

The longer T1 of fat at 3T offers theoretical improvements in CNR for 3T MRA since fat presents the largest relative background signal for body MRA.

Traditionally, T1 shortening of blood can be augmented through increases in injection rate and dose. However, additional factors at 3T influence the options and for T1 shortening contrast agents, one the most important is the increased susceptibility effects at 3T.

**Magnetic susceptibility** can be thought of as a material's tendency to distort an applied field. The net induced magnetization is typically proportional to the applied field. Variations in magnetic susceptibilities within a voxel such as those at air-tissue interfaces produce local inhomogeneities in the magnetic field. These field inhomogeneities produce dephasing which results in T2\* signal loss and such losses are prominent when GRE sequences are being employed. A real concern is the artifacts that can be induced at air-soft tissue interfaces and adjacent to metallic surgical clips and indwelling metallic stents.

We have noticed an **increased sensitivity to the concurrent T2\* shortening** that effects Gd at 3T and in our preliminary assessments, rapid bolus imaging can be contaminated by a confounding T2\* effect. This at best may level off the effects of increasing doses and administration rates, and at worst may actually decrease the CNR. Care should be taken in adopting the 'more is better' philosophy for contrast-enhanced MRA. The higher field strength has implications for the use of iron agents and other agents that can augment the T2 relaxation (5, 6) .

**The safety and artifact sensitivity** to intravascular stents (as well as other in vivo metallic devices) is being investigated and most devices are proving safe at 3T (7-9) . Pulsatility artifacts in healthy vessels appear to be greater at 3.0T compared to that at lower field strengths. This can be mitigated through a reduction in the flip angle. As mentioned before, the C/N tolerance to a lower flip angle makes this an acceptable trade-off. The lower flip angle can be used in diseased vessels to minimize in plane saturation effects while maintaining effective background suppression (recall the longer T1 of background tissues, therefore, lower signal).

While we have had successful imaging results using the body coil without a localized coil, the **availability of more coils and multi-element coils** will allow for more flexibility. Combination of lower doses of contrast, better resolution and faster scanning are being enabled through the SNR synergy of 3T with localized coils.

For MR angiography, power deposition has not been a major issue in our experience. From a **SAR** perspective, fast 3D GRE imaging requires a decrease in flip angle compared to similar TR sequences at 1.5T. However, the longer T1 of background tissues allows for an acceptable trade-off with maintenance of effective target:background contrast. Furthermore, we have been running the scanner at the upper limits of what is permitted by the FDA and this increases the flexibility of the system; workflow is improved by minimizing parameter

adjustments that can be prompted by SAR concerns. Magnetization transfer can also be more easily applied in this mode.

Difficulties related to radiofrequency (RF) **field homogeneity** represent another challenge to clinical MRA at 3T (10). Two factors lead to decreased RF field homogeneity at high field strength (11). One factor is shorter penetration distance or “skin depth” of RF into the sample, because of electrical conductivity. At higher frequencies, RF is dissipated to a greater degree as it passes through the tissues. Based on this, the field should become weaker at the center of the sample. The second factor affecting field homogeneity is the increase in dielectric constants of water and tissue at high field and its effect of shortening the wavelength of RF in the sample. The wavelength of RF at 3T is such that it sets up a resonant cavity or “waveguide” effect within the sample, with the result that the amplitude or phase of the RF varies with position inside the sample. This spatial variation of RF results in center brightening of the image. These two effects have potential to counterbalance each other, but not necessarily in a uniform manner. To cope with the issues of RF penetrance and dielectric constant alternate RF pulse designs (e.g. adiabatic pulses), pulse sequence designs (e.g. phase cycling), and coil designs are being pursued in order to maximize the imaging at 3T. On our scanner a characteristic signal drop occurs at the patient’s left groin when the patient is in the feet first position typical for run-off studies.

**Clinical experience** at 3.0T includes 2D and 3D TOF and 3D contrast enhanced MR angiography with sequential, centric, elliptical centric, and e-TRICKS for a variety of anatomic regions throughout the body. The theoretical gains for MR angiography in S/N and C/N at 3.0T have only begun to be exploited. With additional applications such as parallel imaging (12), higher temporal resolution will be possible, supported by the signal advantage. This provides opportunities to optimize the administration of contrast media, included shorter and tighter boluses of contrast. New combinations of higher temporal and spatial resolution will be made possible as multi-channel receiver systems are integrated into the high field scanners.

**PVD studies** are done in a similar manner as 1.5T, with a hybrid contrast-enhanced approach, cuff compression and multiple injections. Benefits of 3T have been observed in the extremity arteries below the knee (13). Additionally, it has been shown that SENSE accelerated MR-DSA (thick slab MRA) at 3T improves the non-invasive pre- and postoperative depiction of AVM flow dynamics (14).

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