

Combined Effects of Magnetization Transfer and Gadolinium in Cranial MR Imaging and MR Angiography

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Magnetization transfer (MT) imaging is an MR technique in which image contrast is altered by applying RF pulses that saturate a restricted pool of hydrogen protons associated with cell membranes, proteins, and other macromolecules. Protons in this restricted pool, unlike those in tissue-free water, are not visible on MR due to their short T2 relaxation times. However, these restricted protons modulate the observed signal from free water by dipolar and chemical exchange interactions. In MT imaging, specifically tailored RF pulses are applied to saturate selectively the restricted macromolecular pool. This saturation is "transferred" to the free protons, causing their signal amplitude to decrease [1]. Increased signal intensity due to T1 shortening caused by gadolinium administration does not depend upon macromolecular interactions and is not appreciably suppressed by MT pulses (Fig. 1). Consequently, MT pulses act synergistically with gadolinium to increase the visibility of enhancing lesions by preferentially suppressing nonenhancing background tissue [2]. The purpose of this paper is to demonstrate the principles underlying the synergistic effects of MT saturation and paramagnetic contrast agents and to illustrate these effects in clinical MR imaging and MR angiography.

Pulse Sequence

The images illustrating this paper were acquired on a 1.5-T clinical MR unit (Signa, GE Medical Systems, Milwaukee, WI). MT saturation on both T1-weighted spin-echo images and three-dimensional (3D) time-of-flight MR angiograms was produced by modifying the standard chemical-shift selective saturation pulse available on this system [3]. The resultant MT saturation pulse had a frequency offset of 1200 Hz downfield from the water resonance. The relative amount of signal sup-

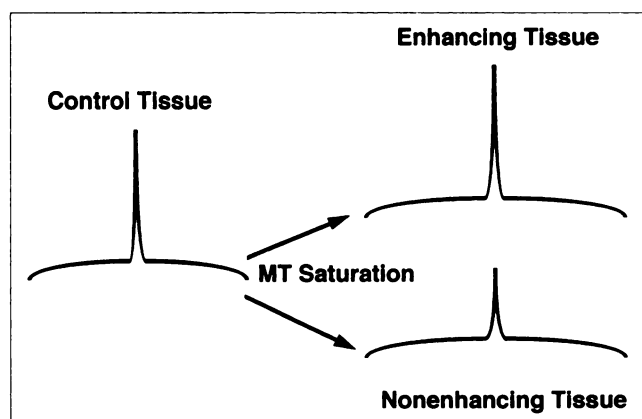


Fig. 1.—When magnetization transfer (MT) saturation is applied to control tissue containing both enhancing and nonenhancing tissue, significant reduction in signal amplitude is seen in nonenhancing tissue but not in areas that enhance with paramagnetic contrast agents.

pression at this frequency offset on a T1-weighted image is approximately 15% for white matter and 7% for gray matter [3]. Because of the narrow bandwidth of this saturation pulse, however, its frequency offset can be reduced to approximately 600 Hz before significant spin-tip effects on water-gadolinium mixtures can be observed (Fig. 2). However, increased imaging time is required to obtain MT saturation. For example, a conventional T1-weighted MR study (20 sec-

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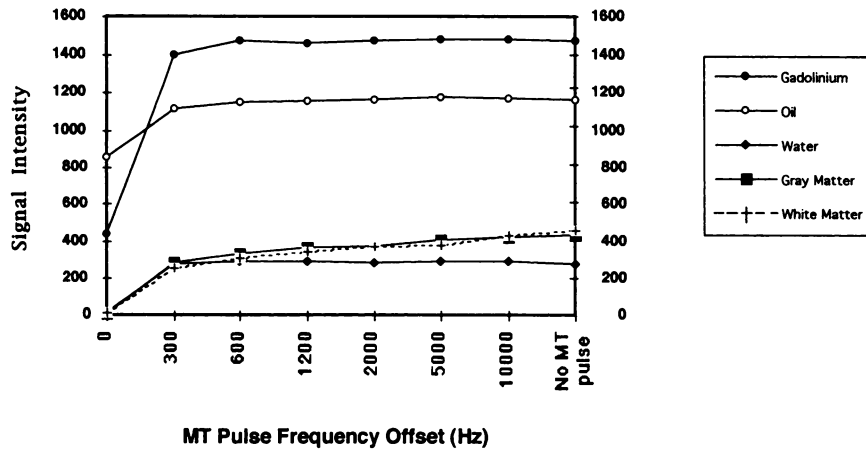


Fig. 2.—Signal intensity of various substances as function of magnetization transfer (MT) pulse frequency offset. Signal intensities of brain, gadolinium solution (5 mmol/liter), corn oil, and water were measured on T1-weighted images (600/15 [TR/TE]) obtained with different frequency offsets. Image contrast between gadolinium and brain can be improved by decreasing MT pulse frequency offset, resulting in greater suppression of brain signal intensity than of gadolinium signal intensity. There is little suppression of gadolinium signal intensity but brain signal decreases linearly as offsets decrease to 300 Hz.

tions) can be acquired in 2 min while a T1-weighted MR study with MT saturation (20 sections) takes 4 min to acquire.

MR Angiography

Both MT saturation and gadolinium administration have independently been shown to improve visualization of intracranial vessels on 3D time-of-flight MR angiography. Recently, the combined effects of MT saturation and gadolinium on the visualiza-

tion of intracranial vessels with 3D time-of-flight MR angiography was quantitated in 35 subjects (Mathews VP, presented at the American Society of Neuroradiology meeting, May 1994). Although visualization of cerebral vessels is improved when either MT or gadolinium is used in MR angiography, their combined use produces a synergistic effect significantly greater than the cumulative benefit of each alone (Fig. 3). Future MR angiographic studies need to address the ability of this technique to detect small vessel abnormalities in various disease states.

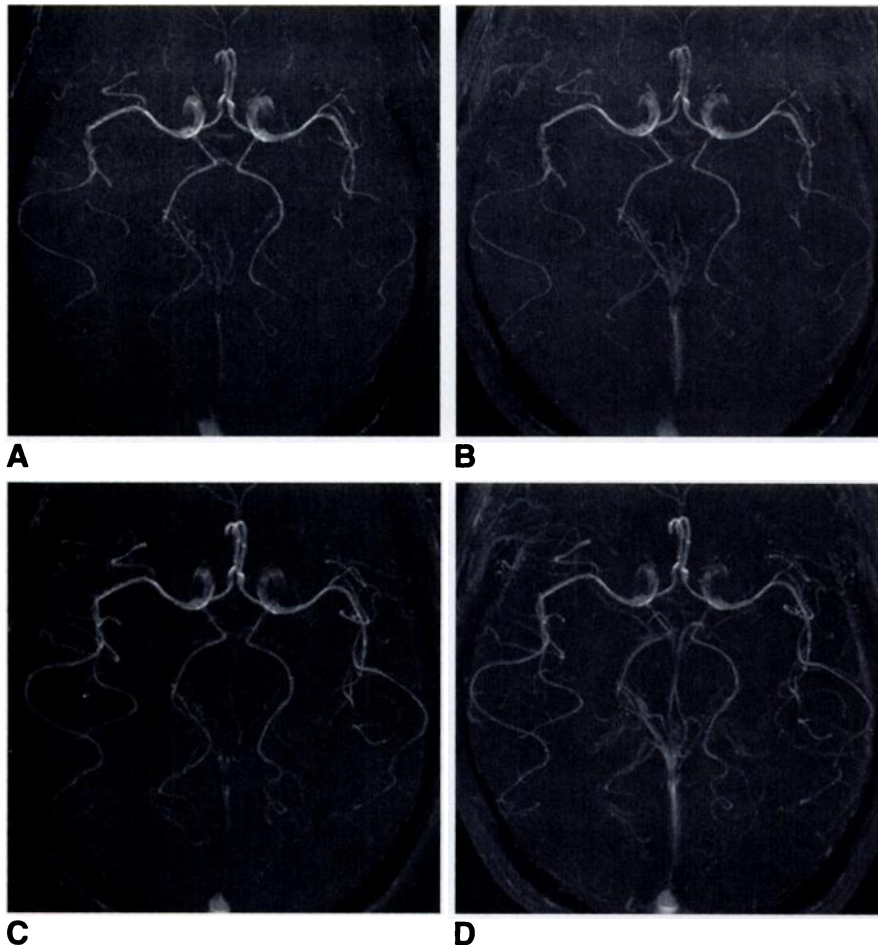


Fig. 3.—A–D, Three-dimensional time-of-flight MR angiography performed on 35-year-old volunteer without magnetization transfer (MT) or gadolinium (A), with gadolinium only (B), with MT only (C), and with both MT and gadolinium (D). While either gadolinium alone or MT alone can improve visualization of small intracranial vessels, MR angiography with both MT and gadolinium demonstrates these vessels best.

MR Imaging

MT saturation significantly reduces signal intensity from all normal cranial tissues except cerebrospinal fluid and fat. Since white matter is suppressed more than gray matter, some normal gray matter structures appear relatively bright on T1-weighted images. MT saturation also increases the visibility of normally enhancing structures such as the choroid plexus, the dural sinuses, veins, and the pineal and pituitary glands [3] (Fig. 4).

When abnormally enhancing lesions are present after administration of standard-dose (0.1 mmol/kg) contrast, MT saturation increases contrast-to-noise ratios by more than 100%, which is at least equivalent to the reported gains from using triple-dose contrast and conventional T1-weighted imaging [4]. In cerebral infarction the degree of enhancement with standard-dose contrast and MT saturation is equivalent to that obtained immediately after administration of triple-dose contrast. Even further gains in lesion conspicuity can be achieved when MT saturation is used with triple-dose contrast [5] (Fig. 5).

MT imaging with contrast improves visualization of lesions in patients with stroke [4, 5], primary brain tumor [2, 4, 6], brain metastases [4, 6] (Fig. 6), demyelinating disease (Fig. 7), and other inflammatory and infectious conditions [4, 7]. MT imaging may reveal lesion enhancement when no enhancement has been seen on conventional T1-weighted sequences [4, 5]. Further studies must address how this additional information affects patient management. For example, how is parenchymal enhancement in acute stroke related to tissue viability? Can MT imaging accurately define tumor margins in cases of infiltrating neoplasms where conventional imaging has been shown to be deficient? Can MT imaging with contrast add to our knowledge of disease activity in patients with multiple sclerosis? Will MT imaging with standard-dose contrast eliminate the need for triple-dose contrast in patients with solitary brain metastasis? We have evaluated several patients with brain infections in whom MT imaging demonstrated enhancement patterns that allowed us to be more specific in our diagnosis (Fig. 8), and we believe that this technique will become a routine part of contrast-enhanced MR imaging.

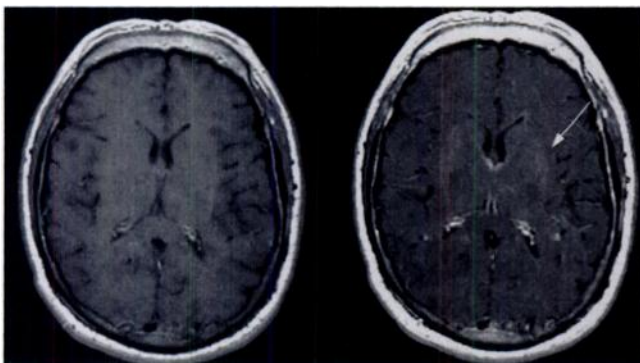


Fig. 4.—Comparison of standard T1-weighted image (left) to T1-weighted image with magnetization transfer (MT) suppression (right) shows greater signal intensity of deep gray matter structures (i.e., putamen, arrow) than of white matter on MT image. Normally enhancing structures such as choroid plexus and vessels are also more conspicuous.

Conclusions

MT imaging with standard-dose gadolinium provides visualization of enhancing brain lesions approximately equal to routine

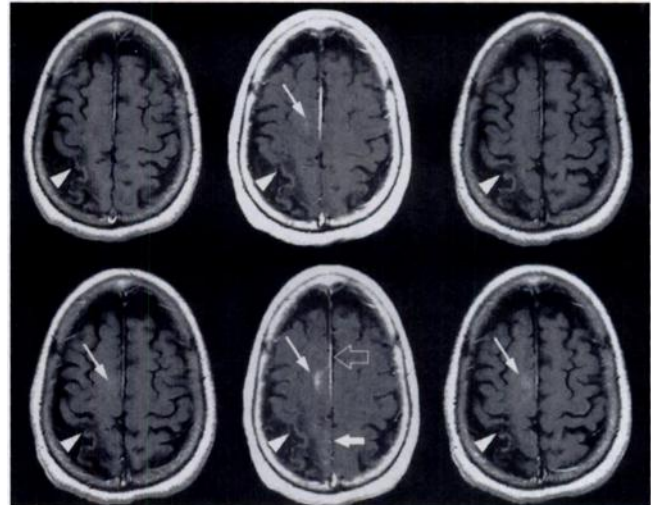


Fig. 5.—T1-weighted images of 63-year-old woman with 4-day history of left-side weakness were obtained with standard-dose gadolinium (0.1 mmol/kg) immediately after injection (top left), with magnetization transfer (MT) saturation (top center) and 15 min after injection (top right), and with triple-dose gadolinium (additional 0.2 mmol/kg) immediately after injection (bottom left), with MT saturation (bottom center) and 15 min after injection (bottom right). Encephalomalacia (arrowhead) due to remote infarct is present. On standard-dose MT image (top center), subtle area of parenchymal enhancement is seen in new infarct (narrow arrow) that is not evident on other standard-dose images (top left and top right). On high-dose studies, parenchymal enhancement is seen best on images with MT suppression (bottom center). Also noted best with MT are meningeal (open arrow) and intravascular (broad arrow) enhancement.

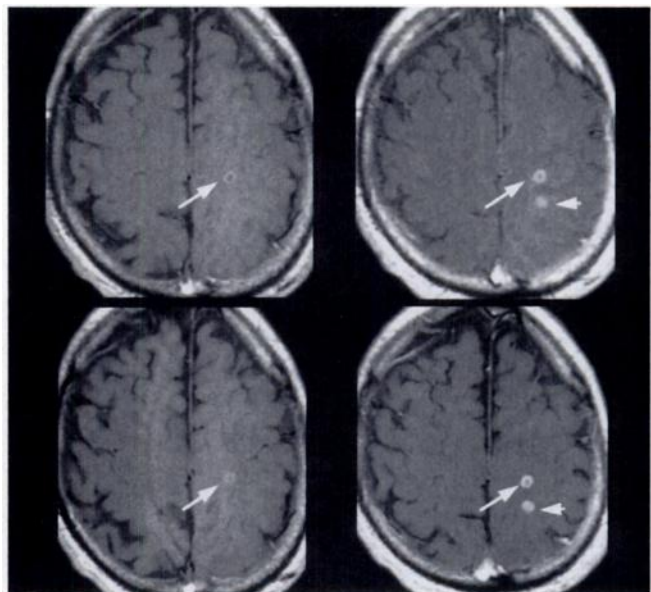


Fig. 6.—50-year-old man with metastatic lung cancer. With MR imaging, one lesion (long arrow) is noted on initial (upper left) and 15-min-delayed (lower left) T1-weighted images after standard-dose contrast. Standard-dose image with magnetization transfer (MT) suppression (upper right) and triple-dose T1-weighted image (lower right) show second lesion (short arrow).

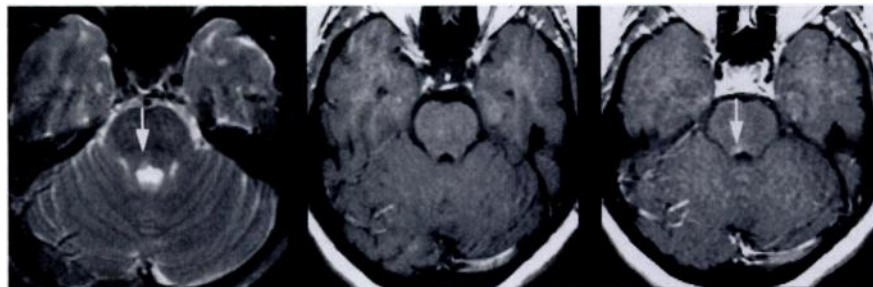


Fig. 7.—43-year-old woman with multiple sclerosis who developed internuclear ophthalmoplegia. T2-weighted image (left) demonstrates hyperintense lesion (arrow) involving medial longitudinal fasciculus. Contrast-enhanced T1-weighted image (center) shows no enhancement. Enhanced T1-weighted image with magnetization transfer suppression (right) shows enhancement (arrow) consistent with acute nature of lesion.

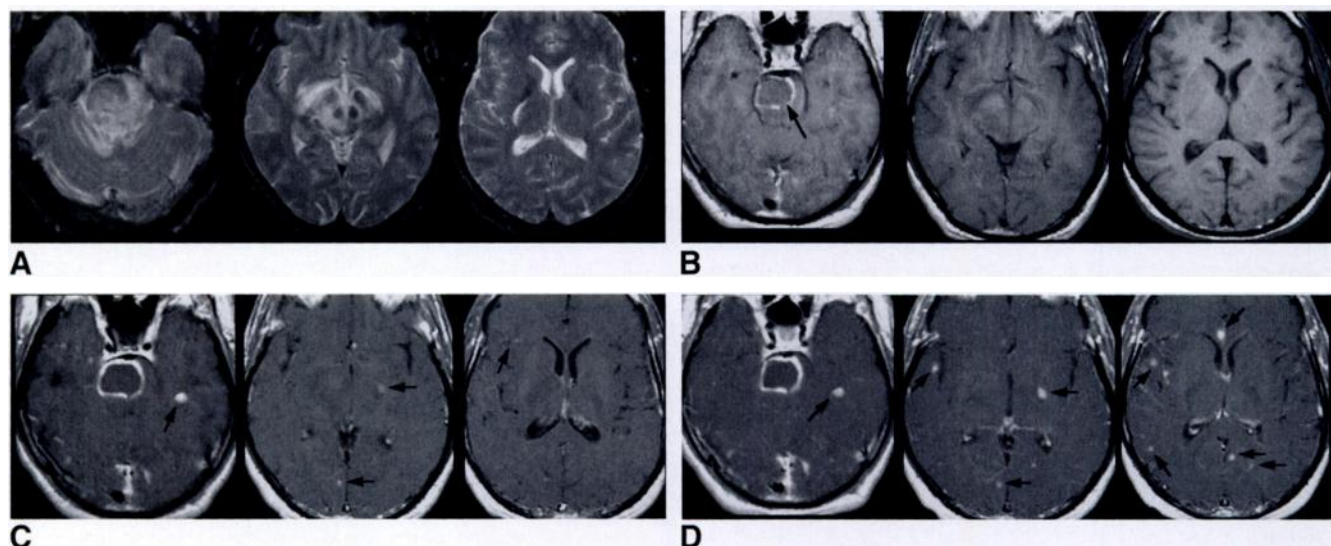


Fig. 8.—A–D, 28-year-old man with gait disturbance. Routine T2-weighted images (A) show brain stem lesion with edema that enhanced on T1-weighted images (long arrow) after standard dose (B). Standard-dose T1-weighted images with magnetization transfer (MT) (C) show additional lesions (short arrows). Triple-dose T1-weighted images with MT (D) exhibit even more lesions (short arrows). Multiple lesions in young male led us to suggest AIDS-related infection, and HIV-positivity was subsequently found. Lesions resolved with anti-*Toxoplasma* therapy.

imaging with triple-dose gadolinium. This has obvious economic ramifications if MT saturation can obviate the need for high-dose studies. Further evaluation of gadolinium and MT saturation must be performed to determine if contrast dosages below the standard dose can be used effectively in clinical practice.

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