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Lawrence N. Tanenbaum

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Having more than a year's worth of clinical experience on a first-generation, whole-body, 3-T MR system and approximately 12 months using a second-generation, short-bore, whole-body machine in the community setting, I read Dr. Ross' February 2004 editorial, "The High-Field-Strength Curmudgeon," with great interest and some consternation. Although I assume his "musings" are valid for the (head-only) 3-T system in use at his institution, I am concerned that they do not accurately reflect the strengths and limitations of systems currently being installed and thus may mislead those in the process of assessing the feasibility of higher-field-strength whole-body MR imaging. Those considering acquisition of a higher-field-strength MR system should understand that many of the stated limitations are characteristic of older systems, and through advances in hardware and software, have already been overcome.

Over the past several years, systems operating at higher field strengths have become more prevalent, particularly at research centers. Of late, there has been increasing interest in 3-T MR imaging in the community setting for whole-body imaging purposes. Fueling the shift in interest from 1.5 T to 3 T and from primarily research to clinical practice is the validation of what was once considered to be very high-field-strength MR (3 T) as feasible and indeed now or potentially superior to 1.5-T for clinical indications throughout the body. Reduced concerns over surface coil availability, radio-frequency (RF) deposition limits, higher ambient noise, system homogeneity, increased magnetic susceptibility, chemical shift effects, and reduced tissue contrast as well as demonstration of the incremental benefits of 3-T over 1.5-T imaging with respect to image quality and efficiency is driving this increased penetration of 3-T systems into the clinical setting.

There are a number of fundamental differences in later-generation 3-T devices that impact on clinical feasibility, the most important of which are new system designs that are inherently more SAR (specific absorption ratio) efficient. Because SAR scales with the square of field strength, RF deposition is more limiting at higher field strengths. Older less SAR-efficient system designs were so RF intense that "patient cooling" delays *between* sequences were often required. With today's SAR-efficient modern MR systems and appropriate protocol design, intersystem delays should no longer occur. Limits on the rate of RF energy deposition continue to place minor restrictions on the number of sections that can be acquired per TR period, sacrificing some of the potential efficiency boost afforded by the potentially doubled signal intensity at 3 T. The situation is much less severe with newer systems and section reduction is currently a relatively minor concern. In addition, pending modifications in pulse sequence design from several manufacturers (VERSE, TRAPS, hyperechoes) should, in the very near future, lead to RF limitation and section acquisition efficiency equal to or slightly greater than those *currently* in place at 1.5-T.

Today's short-bore whole-body MR systems do pose certain challenges. To maintain clinically acceptable static field homogeneity more coil windings are required and thus the magnets are much heavier, potentially affecting the site in which they are installed. However, inherent shielding maintains a similar fringe field and footprint to that of a 1.5-T system, and many sites with 1.5-T systems can easily accommodate a swap for a 3-T system. On the other hand, a modern 3-T system does not suffer from the distortion and limited cephalocaudal coverage that Dr. Ross laments. Long z- and off-center field-of-view (FOV) imaging, even with fat suppression, easily matches or surpasses the best of 1.5-T performance (Fig 1).

The broadband acquisition and reconstruction architecture of today's MR systems has an enormous impact on the quality and efficiency of imaging at 3-T. Today's eight channel coils deliver a significant boost in signal-to-noise ratio (SNR) over older designs and are designed for use with parallel imaging (PI) techniques. The use of PI leads to a lower image duty cycle load (proportional to SAR) by reducing the number of phase encoding steps that are performed. The resulting SNR drop on a routine imaging sequence (a factor of 2 is associated with a 40% reduction in SNR and a 50% reduction in imaging time) is better tolerated at higher field strength, particularly with higher SNR coils and thus PI techniques used routinely (Fig 2).

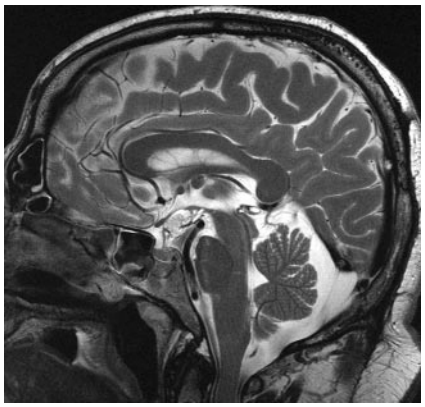


FIG 1. A sagittal T2-weighted image (FOV, 1024 × 384 mm; section thickness, 3-mm) obtained in a patient with a suprasellar dermoid. Note the *z*-axis uniformity of signal intensity from convexity through the foramen magnum on this image obtained with an eight-channel head coil

Susceptibility effects scale with field strength and are exploited in improving the sensitivity of fast spin-echo (FSE) techniques to the presence of hemorrhage and mineralization at 3 T. Clinical BOLD imaging is also more practical and robust as a result. These same effects have been cited as quality limiting on older 3-T systems with single-shot echo-planar techniques employed for diffusion and perfusion imaging. By reducing effective echo spacing and TE, at the expense of some drop in SNR, PI results in images with artifact severity similar to that seen at 1.5 T. Although susceptibility effects might be expected to be prohibitive and limiting for patients with spine hardware, the combination of efficient coil designs and high bandwidth techniques keeps artifact manageable (Fig 3).

Chemical shift effects also scale with field and have been cited as providing a boost in metabolite peak separation and resolution for spectroscopy at 3 T. Alternatively, an increase in chemical shift artifact at 3 T has been cited a significant limiting factor in routine anatomic imaging. The SNR inherent to 3-T and late-generation multichannel coils are now routinely leveraged via the routine use of higher bandwidths (32–125 KHz) for spin-echo (SE) and FSE imaging, managing susceptibility issues and alleviating concerns over chemical shift artifact (Fig 4).

The longer T1 of background (brain) tissue at 3 T has been exploited to produce superior time-of-flight MR angiography. This same effect leads to somewhat unsatisfactory results with conventional T1-weighted SE imaging in the brain and spine. Fortunately, techniques that are in *wide clinical use* at 1.5 T, such as inversion recovery FSE (T1-weighted fluid-attenuated inversion recovery [FLAIR]) (Figs 2 and 4) and RF-spoiled gradient echo (MP SPGR), produce superior contrast resolution to that provided by T1-weighted SE imaging and are equally well suited to use at 3 T. In addition, in contrast to a situation whereby T1-weighted studies have traditionally been less satisfactory and take longer to perform, a typical T1-weighted FLAIR study of the brain or spine, coupled with the

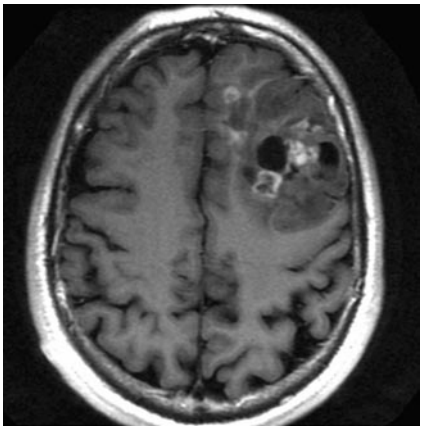


FIG 2. Residual low-grade glioma. Twenty 5-mm-thick sections were obtained with a FOV of 20 mm at 288 × 192, imaging time of 54 seconds, with a parallel imaging acceleration factor of 2.

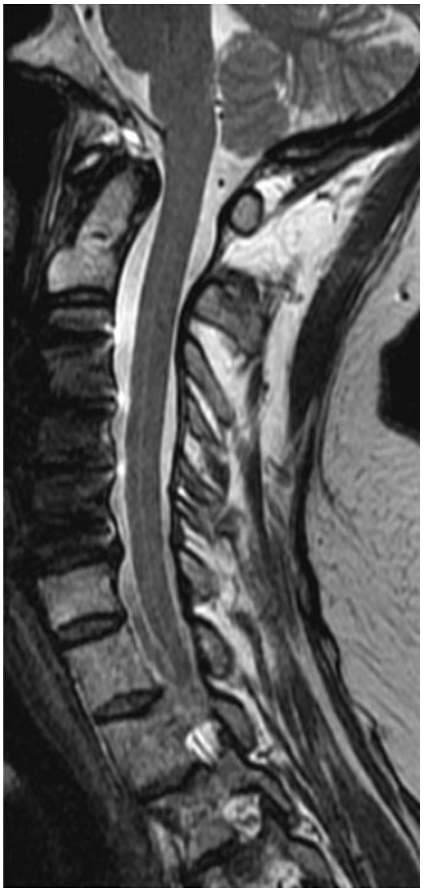


FIG 3. Anterior decompression, fusion, and instrumentation. High-bandwidth techniques are facilitated by the combination of 3-T signal intensity and a high SNR, and an eight-channel spine coil effectively manages susceptibility artifact.

use of PI on a modern 3-T system, allows a higher spatial resolution protocol with a shorter imaging time than at 1.5 T (Fig 2). Although the strength of these novel sequences encourages a shift away from conventional T1-weighted SE imaging, we view this as just another incremental step in progress and quality improvement, like many others that have occurred in the roughly 20 years of clinical MR imaging.

Our 3-T system replaced a 1.5-T system and currently works in tandem with a late-generation, gradient-enhanced, broad-

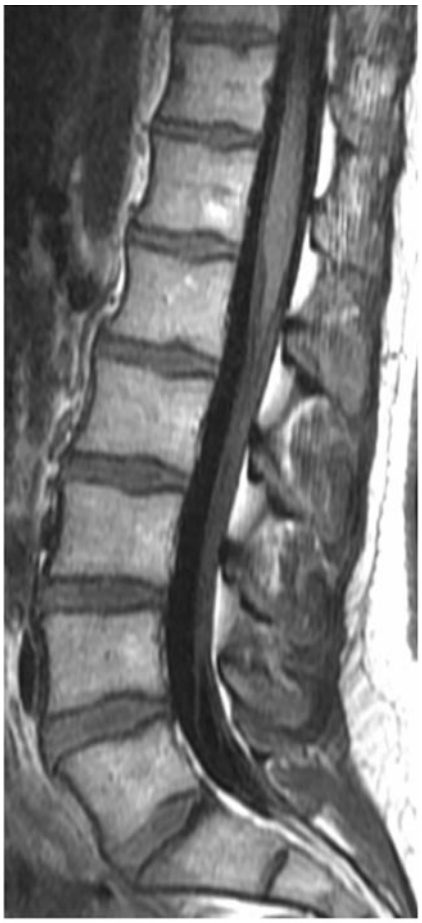


FIG 4. T1-weighted FLAIR study obtained with an eight-channel spine coil. Note the absence of noticeable chemical shift artifact.

band 1.5-T system. The 3-T system looks almost identical to the 1.5-T system with a similar form factor and a similar fringe field. The 3-T system is no more difficult for the technologists (or me) to operate than our lower-field-strength system and in our high-demand, competitive clinical setting the high-field-strength system is our preferred choice for whole-body applications. With a variety of currently available coils of various levels of sophistication ranging from a quadrature extremity coil through an eight-channel spine coi, we *easily* create a recognizably *better* imaging examination in the *same or slightly less time.* As coils match or exceed the capabilities of those available at 1.5 T and current SAR limitations are circumvented, both quality and efficiency will advance.

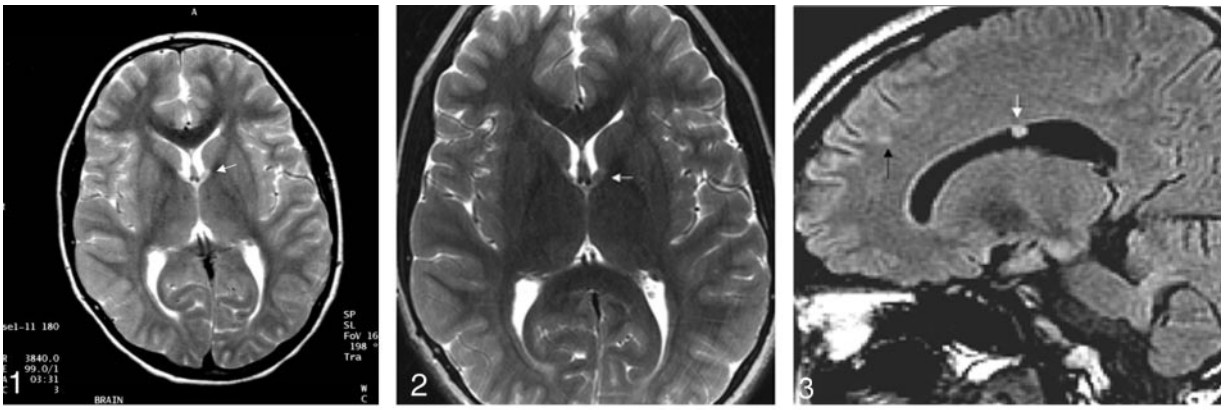
Decisions made about hardware purchases have ramifications for many years, and readers need to know that 3-T is ready to perform "bread and butter" as well as advanced clinical applications *today.* Referring physicians from neurologic and non-neurologic specialties, imaging technologists, and interpreting radiologists are highly enthusiastic about using 3-T systems for applications throughout the body. Only cost considerations will prevent our practice from making 3-T the selection for each of our next high-field-strength systems. Users in a busy, competitive clinical setting should have little difficulty leveraging the power and unique capabilities of higher field strength to generate an incremental boost in demand to justify the higher base cost of a 3-T system.

Lawrence N. Tanenbaum
Edison Imaging Associates and JFK Medical Center
New Jersey Neuroscience Institute
Edison, New Jersey

The Time for 3T Clinical Imaging Is Now

We read Dr. Ross's editorial "The-High-Field-Strength Curmudgeon" (1) with great interest, particularly because we have had a very different—in fact, almost opposite—experience with brain imaging with our most-recent 3T system. Our group just completed its first year of 3T brain imaging and have also had 9 months of experience with imaging other parts of the body, including spine, head and neck, abdomen, pelvis, and all orthopedic applications. We are currently examining more than 25 patients a day with our new 3T MR imaging system. Approximately 65% of these examinations are of the brain.

Compared with the results obtained on current 1.5T systems with the strongest gradients, 3T has improved the quality of brain MR imaging at our institution (Figs 1 and 2). We have, however, taken a somewhat different approach to clinical imaging of the brain at 3T than that described by Dr. Ross. We did not seek to duplicate the same quality of images at 1.5T with increased throughput. Instead, we chose to pursue better spatial resolution at the increased field strength by using thinner sections (1–3 mm) with high matrices (256 × 256, and often higher). We perform multiple pulse sequences (T1-weighted, fluid-attenuated inversion recovery [FLAIR], T2-weighted, diffusion-weighted, and echo planar T2-weighted) and reformat the volume acquisitions in multiple planes both before (T1 and FLAIR) and after (T1 only) contrast enhancement. Our examination time is 30 minutes, which includes pre-imaging time. We have circumvented the problem of prolonged T1 relaxation at 3T (obscuring gray matter–white matter differentiation on spin-echo [SE] images) by using, as Dr. Ross alluded to, 3D T1-weighted spoiled gradient echo sequences (FSPGR/



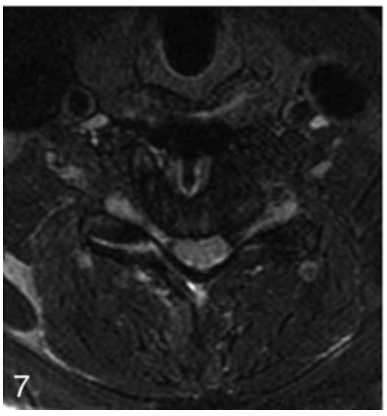


FIG 1. 5 mm Axial T2 TSE obtained on 1.5T in a patient with tuberous scvlerosis showing equivocal lesion (arrow tip) adjacent to left foramen of Monro.

FIG 2. 4 mm Axial T2 FSE, 512 × 384, obtained on 3T 12 weeks later in same patient as Figure 1 with arrow tip on more obvious lesin adjacent to left foramen of Monro. Note increased flow artifacts in phase direction which are exacerbated by 3T. These will be significantly diminished with multidirectional flow comp or with a 3D T2FSE acquisition.

FIG 3. 1 mm Direct Sagittal FLAIR FSE, 256 × 256, demonstrating the only lesions (3mm subependymal nodule [white arrow] and a 2mm subcortical tuber [black arrow]) in another patient with tuberous sclerosis.

FIG 4. 1 mm Reformatted Coronal T1 FSPGR from same patient as Figure 3 obtained in the axial plane with 1mm isotropic voxels, 256 × 256, revealing the subependymal nodule (black arrow) in the superolateral aspect of the left lateral ventricle.

FIG 5. 2 mm Sagittal T1 FSE obtained on 3T showing adequate cord visualization (in patient with a previous anterior fusion) by varying 5 parameters (increasing bandwidth and echo train length [ETL], decreasing slice thickness and TE, and orienting frequency encoding gradient parallel to long axis of metal).

FIG 6. 2 mm Sagittal T2 FSE at 3T from same patient as Figure 5 demonstrating good visualization of the spinal cord by using the aforementionted techniques.

FIG 7. 3 mm T2 Axial T2 FSE with fat sat through the C6-7 foramina, demonstrates adequate visualization of cord and nerve roots (except proximal left C7). If this acquisition had been obtained with 2 mm slice thickness as well as maximum bandwidth and ETL and the lowest TE, the left C7 root may have been seen in its entirety.

MPRAGE) obtained with 1-mm isotropic voxels with 256 × 256 matrices. The signal intensity disparity between gray and white matter is significantly greater by using this pulse sequence than the SE sequence at any field strength (Fig 3).

We perform this sequence in the axial plane except when we are imaging pituitary glands or patients with seizures whom we image in the coronal or off-coronal (angled perpendicular to the hippocampus) plane. The enhanced conspicuity of gadolinium at 3T over 1.5T obviates the old, but still controversial, argument that only SE is adequate for detecting disease on postcontrast images. We have also had two separate manufacturers create 3D FLAIR fast SE (FSE) sequences with 1-mm isotropic voxels using 256 × 256 matrices that we acquire in the sagittal plane (Fig 4) and reformat in the axial and coronal planes. For seizure patients, we acquire this pulse sequence in the off-coronal plane angled perpendicular to the hippocampus. An added benefit we observed in obtaining FLAIR as a volume acquisition is the dampening of increased CSF flow artifacts one invariably sees with 2D FLAIR pulse sequences at 3T. As Dr. Ross commented in his editorial, high-spatial-resolution FSE T2-weighted images are a strength at 3T. We currently are using a T2-weighted FSE sequence with 512 × 384 matrices and 3–4-mm section thicknesses (Fig 2) and are awaiting the completion of a 3D T2-weighted FSE sequences with 1-mm isotropic voxels (256 × 256 matrices), which we requested from the manufacturer. With the advent of fast FLAIR imaging, we have not used balanced imaging in the brain in for nearly 5 years.

Radiologists seeking to push the envelope with 3T should not despair. In reference to specific absorption rate (SAR), the new whole-body 3T MR imaging system that we have been using for 4 months has not had a single SAR error with brain imaging, and there have been very few power deposition problems while imaging other parts of the body. The increase in chemical shift artifact at 3T has not had a deleterious effect on our ability to evaluate disease if adequate band widths are used, and although magnetic susceptibility artifacts are exacerbated at 3T (2), they can be mitigated by increasing band width and echo train length, decreasing TE and section thickness, and aligning the frequency encoding direction parallel to the long axis of any metal (Figs 5, 6, and 7). When a relatively new technique for multishot SE with radial orientation of *k* space becomes available for 3T, this problem will be further diminished (3). We are in agreement with Dr. Ross's and others' (4) opinions that MR angiograms are better at the higher field strength. The added signal-to-noise benefit at 3T has significantly improved our diffusion-weighted and apparent diffusion coefficient images, and that factor plus the advantage of increased magnetic susceptibility effects at 3T, has also made our perfusion studies better. Similar to Dr. Ross, our initial impression with 3D spectroscopy is that we have not yet seen a significant benefit over 1.5T.

Our experience with 3T MR brain imaging during the past 4 months in over 1000 patients has benefited from our new, second generation whole-body MR imaging system. By using the pulse sequences 3D T1-weighted FSPGR without and those with contrast medium administration and 3D FLAIR (both obtained with 1-mm isotropic voxels, 256 × 256 and 220 matrices), T2-weighted FSE with 3-mm section thickness, 512 × 384 matrices, as well as diffusion and echo planar T2-weighted images, we are able to perform brain imaging in 30 minutes with quality we judge tobe superior to that obtained with current 1.5T systems.

Marc D. Shapiro
Tom Magee,
David Williams,
Rick Ramnath
Neuroskeletal Imaging Institute of Winter Park

References

1. Ross J. **The high-field-strength curmudgeon**. *AJNR Am J Neuroradiol* 2004;25:168–169
2. Lin W, An H, Chen Y, et al. **Practical consideration for 3T imaging.** *Mag Reson Imaging Clin N Am* 2003;2:624–627
3. Jellison BJ, Wu Y, Field AS, et al. **Propeller-MR for diffusion-weighted imaging in regions of magnetic field inhomogeneity: brain and cervical spinal cord.** Presented at the 41st annual meeting of the American Society of Neuroradiology, Washington, DC, April 27–May 2, 2003.
4. Gibb GF, Huston III J, Bernstein MA. **Improved image quality of intracranial aneurysms: 3.0T versus 1.5T time-of-flight MR angiography** *AJNR Am J Neuroradiol* 2004;25:8487

Reply

I thank Drs. Shapiro, Magee, Williams, Ramnath, and Tannenbaum for their interest in my editorial and for their detailed responses regarding their usage patterns, sequences, and experience at 3T. The rapid pace of technological advancement at 3T makes purchase decisions even more difficult, compounded by the usual differences in manufacturers, imaging hardware, software, and postprocessing capabilities. Their letter further demonstrates the point—which I tried to make—that moving from 1.5T to 3T is not trivial. These sophisticated users have shown that good image quality can be obtained at 3T, but the old adage remains true now more than ever—caveat emptor. To this I would add caveat vendor, let the seller beware. The responsibility of quality image production is not a one-way street, and considerable burden is placed upon the manufacturers not to bring systems to a general clinical use market before real-life imaging demands can be met.

JEFFREY S. ROSS
Cleveland Clinic Foundation
Cleveland, OH