Editorial

Novel spinal cord imaging

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Conventional cervical spine imaging techniques such as standard T1- and T2-weighted MR imaging and CT myelography provide limited sensitivity to the microstructure of the spinal cord. Although not routinely used in clinical practice, diffusion tensor (DT) imaging has shown significant sensitivity to structural changes in the human spinal cord and holds promise as an important biomarker for assessing structural damage as well as predicting functional deficits. For example, DT imaging has been used to detect changes in the spinal cord in cases of multiple sclerosis, 2, 25 acute spinal cord injury, 19 and chronic spinal cord injury, 7 suggesting it may be a valuable clinical biomarker for spinal cord health. Additionally, studies have shown that measurements of diffusivity taken in the transverse plane (radially), perpendicular to the orientation of the spinal cord, reflect the degree of myelination. 20, 21 Furthermore, there is evidence to suggest that measurements taken in the longitudinal orientation (axially), parallel to the spinal cord, may reflect the functional integrity of the axon tracts. 1, 5

Is 3DAC Imaging Better Than DT Imaging?

The notion that “three dimensional” anisotropy contrast (3DAC), as defined by color coding the 3 isotropic diffusion directions (x, y, and z) often measured for clinical “trace” diffusion-weighted images, can offer more insight into spinal cord integrity or higher image quality than the full diffusion tensor is not well founded. A fundamental limitation to this claim is accurate alignment of the spinal cord with the MR imaging coordinate system, which is absolutely necessary for consistent color patterns from patient to patient and necessary for higher image quality due to lack of partial volume blurring. Although Tu et al. 23 have suggested that a full tensor is not necessary for transverse and longitudinal diffusion measurements if adequate alignment of the spinal cord is obtained, DT imaging studies in the brain have clearly demonstrated improved image quality, tensor estimation, tractography accuracy, and overall information about the structural integrity of the spinal cord with increasing number of diffusion directions 8 and higher-order DT information such as q-space imaging or HARDI (high-angular-resolution diffusion imaging). 6, 9 Additionally, the color coordinate system used by Urakawa et al. 24 is identical to the color schemes used in routine DT imaging color maps; 10, 11 however, without using the full tensor information, unfortunately, it may be limited in clinical applicability, as it is prone to alignment and thus interpretation error.

Technical Limitations

Despite the promising initial results, many technical issues limit routine clinical implementation of diffusion imaging in the spinal cord. 25 For example, the small size and the motion of the spinal cord make it particularly challenging to obtain high-quality images. Additionally, magnetic susceptibility differences among the spinal cord, CSF, and spinal column can result in significant geometrical distortions. 39 To overcome these issues, investigators have employed sophisticated techniques including reduced field of view (Zoomed echo-planar imaging [EPI]) echo-planar acquisition, 26 dedicated phased array spine coils, 18 respiratory or cardiac gating during acquisition, 22 real-time phase navigation using navigator echoes, 16 post hoc correction of phase errors in k-space, 17 self-navigated radial 14 or spiral acquisition, 6 line scan diffusion imaging, 12 and many more. Despite these rather exotic sequences, single-shot diffusion-weighted spin echo EPI is the easiest sequence to implement on clinical MR scanners and has the fastest scan time; however, image quality is only marginal 8 and it is highly sensitive to magnetic susceptibility differences, making implementation of single-shot echo-planar DT imaging particularly challenging at higher field strengths at which susceptibility errors are often exaggerated.

In their study, Urakawa et al. 24 utilize single-shot spin echo echo-planar DT imaging to assess ascending spinal tract degeneration in cervical spondylotic myelopathy (CSM). Although the current study addresses an important pathological condition of the spinal cord, there are questions of whether the modality employs all of the necessary technical advancements needed for high-quality clinical DT imaging of the spinal cord. For example, images were acquired using a 64 × 32 imaging matrix, which was zero padded to 256 × 128 and later interpolated to 512 × 256. The result of this process is significant blurring of the images and the appearance of higher resolution than is actually acquired. Interestingly, the image quality presented by Urakawa et al. appears to be of higher quality than has been demonstrated with single-shot spin echo echo-planar DT images acquired with a larger matrix size. 32, 38 Although outer volume suppression was used, which allowed for a lower field of view to be imple-
mented without the penalty of image aliasing and other artifacts, this study had higher than expected quality images even compared with focal excitation and reduced field-of-view (Zoomed) echo-planar techniques.26 Outer volume suppression techniques can provide high-quality images of the spinal cord in vivo,27 but not with such a long echo time, low in-plane resolution, and no mention of sequence optimization. It would have been helpful to include some source images, as well as some views of the spinal cord with surrounding osseous and soft-tissue elements. As presented, it will be difficult for other institutions to reproduce the same excellent radiological results.

From a clinical standpoint, the most salient limitation of this study is the relative paucity of clinical information regarding the patients. We do not know if these patients predominantly presented with motor symptoms referable to upper-extremity function (for example, hand coordination) or lower-extremity function (for example, gait dysfunction). Because motor dysfunction is a hallmark of CSM, and responsible for a substantial proportion of the disability associated with this disorder, the missing information is of significance. The lack of correlation between the 3DAC imaging and Japanese Orthopaedic Association scores, a validated outcome measure for global neurological function in patients with CSM, further accentuates this limitation.

The authors provided information regarding sensory disturbance in the upper and lower extremities. However, this may represent concurrent radiculopathy rather than true CSM, particularly in patients in whom the disturbance was only found unilaterally. That said, it is noteworthy that the 3DAC findings of the fasciculus gracilis showed excellent correlation to the Nurick grade, which is focused on gait function. Thus, the authors were able to show some linkage between a novel imaging modality and an objective assessment tool, a key finding in the early stages of this investigation. Certainly the findings can be used as a foundation for future research, and further study should be undertaken to determine potential application of 3DAC imaging to the clinical management of patients with CSM. The authors should be congratulated on this innovative line of research and the novel findings that they have elucidated.

Disclosure
The authors report no conflict of interest.

References


Response

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I appreciate Drs. Ellingson and Holly’s editorial comments. At the same time, I am surprised to see that there is still a basic misunderstanding of images based on numerical estimation and images based on direct pictorial processing. For old-timers like me, who participated in the early development of water proton nuclear MR imaging, it has been an axiomatic rule that one should never rely on images reconstructed from estimated numbers obtained from given pixel intensities of multiple images. We originally believed that T1 or T2 images (not T1- or T2-weighted images), whose construction was based on numerical estimates of T1 or T2 values of each pixel, would be clinically useful. Subsequently, we realized that the mathematical processes of numerical estimates inherently contribute additional errors. This led to the use of “weighted” images for primary clinical judgment, whereas numerical estimates of T1 or T2 of target tissues were available for potential supplemental information. In current practice, we seldom see anyone use estimated T1 or T2 values of any tissue for clinical judgment, let alone T1 or T2 images themselves. We even encounter the situation in which the terms T1 and T2 images are wrongly used to indicate T1- or T2-weighted images.

For anisotropic analysis of diffusivity, based on the assumption that the system is symmetrical, we estimate 3 eigenvalues based on a minimum of 7 appropriately obtained differential diffusion-weighted (DW) images. This is a much more complex mathematical process than estimating T1 or T2 values. Accordingly, even for numerical analysis, individual eigenvalue analysis in clinical conditions is difficult because of significant variance of estimated eigenvalues. Consequently, the majority of anisotropic analyses are performed using one of the error-reduction indices such as fraction anisotropy. Therefore, it is abundantly clear that one cannot create images based on estimated eigenvalues. Magnetic resonance imaging system vendors misguide clinicians by providing so-called DT color images in which the image quality is artificially improved by using 2D DW images as a base image. The DT color images are colored 2D images created to intuitively understand the fiber tract orientation of 2D DW images. One should not misunderstand that DT color images actually reflect eigenvalues of each pixel, which is 3D in nature. By contrast, 3DAC represents actual 3D fiber orientation images based on pictorial mathematics, derived without the need of performing eigenvalue estimation. As an analogy to the T1 image versus the T1-weighted image, 3DAC can be considered “fiber tract weighted” images.1–3

As a physicist, I can go into a more elaborate discussion. As a clinician, however, I would like to stop this unfruitful discussion at this point because I strongly believe that, as far as patient care is concerned, pure academic arguments regarding the utility of imaging techniques without appropriate data is absurd. Final judgment should be made by the clinicians who take care of actual patients. The vendors of MR imaging systems provide routine software for DT imaging, but not 3DAC imaging. As a result, almost all physicians, including Dr. Holly, have thus far not been given the proper opportunity to judge the clinical utility of 3DAC imaging. I am confident that many clinicians who have doubts about the incredible power of 3DAC imaging, including Dr. Holly, will change their opinion as soon as they start using it routinely, as has been the case at several Japanese academic institutions with which we provided 3DAC capability.

A basic rule for any imaging technique is that the judgment of how a technique impacts everyday clinical practice has to wait until the method, including the system and algorithm, becomes available to the majority of clinicians. Because there is no apparent technical reason for a system to perform 3DAC imaging, it must be a vendor’s executive decision based on financial/social factors for not providing 3DAC capability for any systems including 3.0-T system. I strongly urge clinicians to demand that MR imaging system vendors provide appropriate 3DAC imaging capability, especially for 3.0-T system. Meanwhile, as algorithm developers, we will continue to pursue our research in hopes of developing other techniques useful for patient care.4,5

References

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