BRIEF COMMUNICATION

q-space Imaging (QSI) of the Brain: Comparison of Displacement Parameters by QSI and DWI

Zareen FATIMA^{1*}, Utaroh MOTOSUGI¹, Masaaki HORI¹, Keiichi ISHIGAME¹,
Hiroshi KUMAGAI¹, Satoshi IKENAGA¹, Toshiyuki ONODERA², Kazuo YAGI²,
and Tsutomu ARAKI¹

¹Department of Radiology, University of Yamanashi
1110 Shimokato, Chuo-shi, Yamanashi 409-3898, Japan

²Department of Radiological Sciences, Graduate School of Human Health Sciences, Tokyo Metropolitan University
(Received February 4, 2010; Accepted June 30, 2010)

Keywords: *q-space imaging, diffusion-weighted imaging, displacement parameters*

Introduction

Diffusion-weighted imaging (DWI) is based on the Stejskal-Tanner equation, which assumes existence of a single, isotropic, and unrestricted diffusing component.¹ Analysis of q-space imaging (QSI) translates magnetic resonance (MR) signal attenuation to probability density function (PDF) of the translational displacement of diffusing water molecules via Fourier transformation.^{2,3} Information from QSI about tissue microscopic environment is believed to supplement that from apparent diffusion coefficient (ADC).^{4,5} QSI yields mean displacement (MD), a physical parameter that can provide geometrical details.⁴ QSI utility has been evaluated in spinal cord maturation, degeneration from chronic hypertension, and trauma and in multiple sclerosis.⁵

We present preliminary results of QSI in brains of normal individuals, using a clinical scanner in comparison with conventional DWI.

Materials and Methods

Ten normal subjects (5 men, 5 women; aged 24 to 42 years; 6 volunteers, 4 patients undergoing brain MR imaging for screening) underwent imaging using a 1.5-tesla MR unit (GE Healthcare, Milwaukee, WI, USA). For QSI, we applied diffusion gradients in 3 axes (assuming isotropic diffusion) at b values of 0 to 12000 s/mm² in 12 steps, linearly increasing q values to a maximum of 838 cm⁻¹. Other parameters were: pulse gradient duration (δ),

55.8 ms; time separation between leading edges of gradients (Δ), 62 ms; and repetition time (TR)/echo time (TE), 10000/147.6 ms. Raw data comprised 740 images—20 of 5-mm slice thickness for each axis (b values, 1000 to 12000) and 20 with b value, 0. Imaging took 6.5 min. For DWI, we acquired data using slices 5-mm thick along 3 axes (b=0 and 1000 s/mm²); Δ/δ , 39/32 ms; and TR/TE, 8000/68 ms.

We analyzed raw q-space data using IDL-based diffusion software (QSI Analyzer 2.4, Tokyo Metropolitan University, Japan), which generated PDF maps. We calculated values of full width at half maximum (FWHM) by placing ROIs at approximately the same sites in the centrum semiovale (white matter) and lateral ventricle (CSF) on PDF maps (Fig. 1), then obtained MD_q values using:⁵ MD_q = 0.425 × FWHM. We calculated MD values using ADC (MD_d) by Einstein-Smoluchowski equation: (MD_d)² = 2 × ADC × (effective diffusion time). We calculated effective diffusion time, the expected time for DWI to detect molecular movement, as: (effective diffusion time) = $\Delta - \delta/3$.

Results

Mean values (μ m) ± standard deviations of MD_q were 6.42 ± 0.2 in white matter and 17.14 ± 1.07 in CSF; MD_d (μ m) for the same regions were 6.45 ± 0.16 and 14.24 ± 0.78.

Discussion

We evaluated results based on difference in effective diffusion time, which is longer in QSI than in DWI. For freely diffusing particles, MD is expected

*Corresponding author, Phone: +81-55-273-1111, Fax: +81-55-273-6744, E-mail: drzfatima@gmail.com

Fig. 1. (a) Apparent diffusion coefficient (ADC) map and (b) probability density function (PDF) map with regions of interest (ROIs) placed at approximately the same position in the white matter.

Fig. 2. Graph showing relationship among the mean displacements calculated by q-space imaging (QSI) and diffusion-weighted imaging (DWI) in white matter and cerebrospinal fluid (CSF).

to increase as diffusion time increases (Fig. 2). For CSF, our results showed larger MD_q than MD_d ; the ratios for both MD_q to MD_d and for the square root of effective diffusion time of QSI and DWI were 1.2. Diffusion was assumed isotropic and not restricted in the CSF, which might indicate that MD for CSF is only affected by effective diffusion time and not dependent on methodological difference. For particles with restricted diffusion, such as in white matter, MD_q and MD_d were almost comparable, indicating that molecules can move no further in a restricted environment, even with longer diffusion time. These results agree with previous findings that increasing diffusion time in a restricted environment does not affect MD values.⁶

We obtained reasonable results although we used 3-dimensional gradients, assuming isotropic molecular movements in tissues. Some difference in se-

quence parameters of the 2 methods, including TE, Δ , and δ , also limited our study. Further study is needed to address the essential differences between the 2 methods.

Conclusion

Information from QSI may supplement that from conventional DWI in defining restricted or slowly diffusing component.

References

1. Stejskal EO, Tanner JE. Spin diffusion measurements: spin echoes in the presence of a time-dependent field gradient. *J Chem Phys* 1965; 42:288–292.
2. Callaghan PT, MacGowan D, Packer KJ, Zelaya FO. High resolution q-space imaging in porous materials. *J Magn Reson* 1990; 90:177–182.
3. Cory DG, Garroway AN. Measurement of translational displacement probabilities by NMR: an indicator of compartmentation. *Magn Reson Med* 1990; 14:435–444.
4. Assaf Y, Mayk A, Cohen Y. Displacement imaging of spinal cord using q-space diffusion-weighted MRI. *Magn Reson Med* 2000; 44:713–722.
5. Cohen Y, Assaf Y. High b-value q-space analyzed diffusion-weighted MRS and MRI in neuronal tissues—a technical review. *NMR Biomed* 2002; 15: 516–542.
6. Bar-Shir A, Cohen Y. High b-value q-space diffusion MRS of nerves: structural information and comparison with histological evidence. *NMR Biomed* 2008; 21:165–174.