The Minimum Detectable Change in Water Diffusion Across DTI Sessions

R. W-M. Lau[1], B. G. Goodyear[2]

[1]Medical Sciences, University of Calgary, Calgary, AB, Canada, [2]Radiology and Clinical Neurosciences, University of Calgary, Calgary, AB, Canada

Introduction

A decrease in the fractional anisotropy (FA) of water diffusion in the presence of Multiple Sclerosis,[1-3] as measured by diffusion tensor imaging (DTI), is thought to result from increased cross-fibre water diffusion as myelin and axons are destroyed during the progression of the disease[4]. Most FA studies of MS to date have been of a cross-sectional design; however, to become a useful clinical tool to track disease progression and/or assess treatment, there is a need to measure FA during the progression of MS in individual patients. In this study, we examine the between-session and within-session variance to determine the *minimum detectable change* in FA, mean diffusion (MD), and transverse diffusion (TD) across imaging sessions. As a result, this will determine the clinical usage and precision of FA, MD, and TD to monitor the progression of white matter disease.

Methods

Eight healthy volunteers were scanned during three sessions on separate days. A 3 Tesla scanner (Signa Excite, GE Healthcare, Waukesha, WI) and a standard quadrature head coil were used to collect all images. Each session included a 3-plane localiser to prescribe slices, a 3D T_1-weighted high-resolution volume for anatomical registration, and six DTI data sets (twice-refocused spin-echo EPI: 11 directions, b=850, TR/TE = 10000/72.8 ms, FOV = 24x24 cm, matrix size = 96x96, slice thickness=4 mm, 32 slices, scan time=130 s). Using scanner software (Functool2; GE Healthcare, Waukesha, WI), DTI images were co-registered and FA maps were calculated. The three eigenvalues (λ_1, λ_2, λ_3) were also outputted to calculate MD ($\lambda_{1,2,3\ avg}$) and TD ($\lambda_{2,3\ avg}$). BET (Brain Extraction Tool; FMRIB, Oxford University) and FLIRT (FMRIB's Linear Image Registration Tool; FMRIB, Oxford University) were used to register the DTI dataset to the within-session 3D anatomical volume and then to the 3D anatomical volume of the first day. An ROI (106.4 mm^3) was positioned within each of the genu of the corpus callosum (GCC), the splenium of the corpus callosum (SCC), the corticospinal tract (CST), the optic radiation (OptRad), ventricular cerebrospinal fluid (CSF), and the putamen (PUTA). A two-factor repeated measures analysis of variance (ANOVA) was performed on each ROI/(FA,MD,TD) combination to obtain mean squares for estimates of variance components due to N_p people being scanned ($\hat{\sigma}_p^2$), due to N_d scan sessions ($\hat{\sigma}_d^2$), due to the interaction between the scan session and the people being scanned ($\hat{\sigma}_{pd}^2$), and due to the within-session variability ($\hat{\sigma}_e^2$) of N_s scans, according to Eliasziw *et al*[5]:

$$\hat{\sigma}_p^2 = (MS_p - MS_{pd})/(N_p N_s), \quad \hat{\sigma}_d^2 = (MS_d - MS_{pd})/(N_d N_s), \quad \hat{\sigma}_{pd}^2 = (MS_{pd} - MS_e)/N_d, \quad \hat{\sigma}_e^2 = MS_e .$$

The within-session and between-session standard errors of measurement (SEM) were calculated as $SEM_{within} = \hat{\sigma}_e$ and $SEM_{between} = \sqrt{\hat{\sigma}_d^2 + \hat{\sigma}_{pd}^2 + \hat{\sigma}_e^2 / N_s}$, respectively. The minimum detectable change (MDC) across sessions was also calculated for different numbers of within-session averages as $MDC_{between} = Z_{\alpha=0.05}\sqrt{2}SEM_{between}$.

Results and Discussion

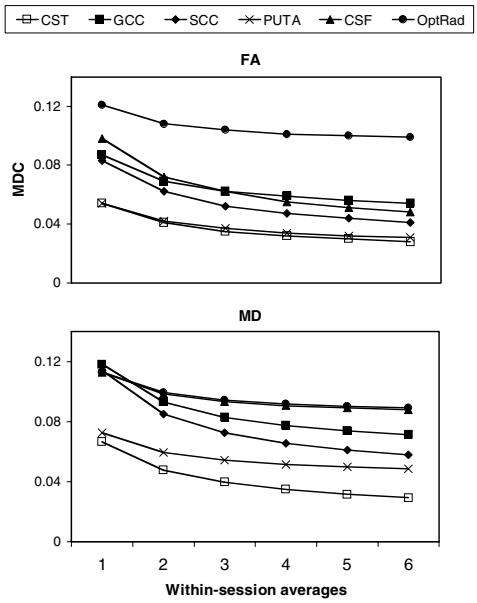

Figure: The minimum detectable change (MDC) in FA and MD across imaging sessions expressed as a fractional change.

An average FA of 0.76 in the genu and 0.84 in the splenium was in good agreement with previous studies[1]. Except for the optic radiations, MDC was below 0.1 for all ROIs and diffusion measurements (see Figure for FA and MD). No significant improvement was seen beyond 3 within-session averages. The within-session variability ($\hat{\sigma}_e^2$) was greater than the between-session variability, suggesting that longitudinal studies may benefit mostly from the reduction of within-session variability by image averaging and/or cardiac or respiratory gating rather than reducing between-session variability.

No significant time trends were found, and no measurements within any scan session significantly differed from any other scan session. As a result, we now have a method to detect 5-10% changes in DTI measurements over longitudinal scans with as few as 3 scans per session. This has important implications in the design of an efficient clinical scanning session in the study of the progression of MS in individual patients.

References

1. Ge Y, et al. *J Magn Reson Imaging*. 2004; 20: 1-7.
2. Tievsky AL, et al. *AJNR Am J Neuroradiol*. 1999; 20: 1491-9.
3. Cicarelli O, et al. *Neurology*. 2001; 56: 926-33.
4. Oh J, et al. *J Neurol Neurosurg Psychiatry*. 2004; 75: 1281-6.
5. Eliasziw M, et al. *Phys Ther*. 1994; 74: 777-88.