On the Coregistration of Diffusion Weighted Images

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Introduction

The spatial coregistration of diffusion weighted images (DWIs) is a critical factor in the correct analysis of diffusion tensor imaging (DTI) data, as a voxel-by-voxel correspondence between multiple acquired volumes must be established prior to fitting a tensor model. Errors generated in the initial registration step can corrupt subsequent calculations. Conventional registration algorithms face particular challenges with DWIs due to the poor resolution, low signal-to-noise ratio, field of view mismatch (e.g., anatomical features may be present in one image and not another due to patient motion), and inherent spatially dependent image intensity differences produced by the magnetic field gradients used to generate diffusion weighting. We show with experimental data that registration procedures have a significant impact on the calculated fractional anisotropy (FA) both within a scan session and across scanning sessions. We present a novel method, **R**obust **A**utomated **D**WI **A**daptive **R**egistration (RADAR), to address the problem of registering DWIs.

Methods

Imaging: Two sessions of 10 repeated DWI studies were performed on a young male control (33 y/o) two weeks apart. The protocol utilized a single-shot EPI sequence with a SENSE factor of 2.0 on a 1.5T Philips Intera NT (96x96 imaging matrix, 256x256 reconstructed, 240x240 mm FOV, 2.5 mm nominal slice thickness, 100/2956 ms TE/TR). Each DTI study consisted of 20 transverse sections acquired parallel to the anterior commissure-posterior commissure line to cover the corpus callosum and centrum semiovale with 30 DWIs with encoding magnetic field gradients applied along independent directions (based on the Jones30 table [1]) at a b-value of 1000 s/mm^2. Five minimally weighted (b0≈33 s/mm^2) volumes were acquired for each study.

Analysis: RADAR involves a three step process. First (Step 1), the original, unregistered volumes are coregistered using FLIRT [3], such that all b0 volumes are registered to a single, arbitrary, b0 volume; then DWIs are registered to a newly registered, b0 volume from the same study. Second (Step 2), a template is created for the b0 and each DWI by averaging the corresponding registered volumes from Step 1. Third (Step 3), each original volume is registered to the corresponding DW (or minimally weighted) image in the template volume. Note that Step 1 produces a complete registration of all images which may be used without Steps 2 and 3. We refer to the Step 1 results as "RADAR w/o Template", while the end result is referred to as "RADAR w/ Template." Conventionally, coregistration of DWIs is performed by direct registration of all acquired data to a single b0 target volume. For comparison, we performed conventional registration using AIR [2] and FLIRT. AIR parameters were manually tuned for the data set by an experienced user based on visual inspection of the results. The angular search of FLIRT was limited to 20°. All registration methods used a rigid body (6 degrees of freedom) transformation model. To evaluate FA, regions of interest (ROIs) were manually delineated to indicate the corpus callosum and the internal capsule.

Results and Discussion

Within the data from a scan session, little difference was observed for the coregistration of minimally weighted (b0) volumes, however, AIR and FLIRT performed less well than either RADAR method for the coregistration of DWIs (**Table 1, top section**). For inter-session coregistration, the AIR method resulted in a higher mean squared error (MSE) than either the FLIRT or RADAR method for the coregistration of b0 volumes, while the RADAR methods had a lower MSE than either other method for DWIs (**Table 1, bottom section**). Note that MSE is reported relative to the templates created with RADAR. The differences in MSE were not normally distributed as assessed by Q-Q plots (not shown). Inspection of correlation diagrams revealed numerous outliers, where the MSE for a particular method was 2 to 5 times higher for a subset of the volumes while equivalent to that with RADAR w/ Template for the remainder. The outliers often corresponded to visually detectable and erroneous differences in registration. Using each of the coregistration results, we calculate the FA for each study. There were clear spatial differences in mean FA (over voxels in studies by session) derived with each of the registration methods (**Figure 1, bottom row)** relative to the mean FA as found by RADAR w/ Template (**Figure 1, bottom left**). Within the ROIs, the mean FA (across all studies within each session) by method was significantly different ($p<0.01$) from the RADAR w/ Template method in (1) the corpus callosum for the AIR method for both sessions and (2) in the internal capsule for both sessions with FLIRT and for the second session with AIR (**Figure 1, upper row**).

We demonstrate that the choice of registration method has an impact on FA (**Figure 1**), and thus the design of robust registration procedures is a clinically relevant problem. In DTI, varying the DW direction creates stark differences in the spatial position of local contrast, especially on the dark/light boundaries near the ventricles, corpus callosum and internal capsule. The shifts in location of high contrast regions as a function of diffusion weighting direction can create an impetus for registration errors of one DWI relative to a different DWI. An optimal coregistration scheme should have no directional bias. RADAR w/o Template addresses the influence of potential FOV mismatch by minimizing the image differences due to subject motion when registering volumes with different contrasts, while RADAR w/ Template directly addresses the problem by ensuring that volumes being registered have similar contrast. The improvements result in a lower MSE relative to the best estimate of true registration (**Table 1**).

References

[1] Skare et al. JMR (2000) 147:340 [2] Woods et al. JCAT (1998) 22:139. [3] Jenkinson et al. NeuroImage (2002) 17:825

Table 1. Ratio of MSE to RADAR w/ Template MSE		
Intra-Day Coregistration (Session 1 to Session 1)		
Method	**b0**	**DWI**
AIR	1.04±0.100	1.47±0.770
FLIRT	1.03±0.051	1.14±0.201
RADAR w/o Template	1.04±0.065	1.03±0.078
Inter-Day Coregistration (Session 2 to Session 1)		
	b0	**DWI**
AIR	1.54±0.112	2.99±0.684
FLIRT	1.04±0.033	1.53±0.385
RADAR w/o Template	1.02±0.019	1.01±0.023

Figure 1. Differences in Mean FA With Registration Method