On the Coregistration of Diffusion Weighted Images

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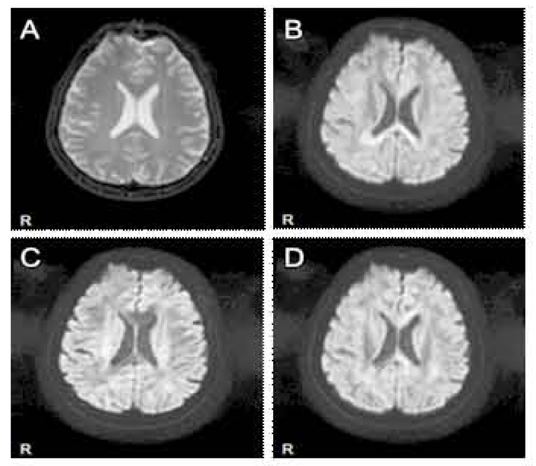
INTRODUCTION

- Spatial coregistration of diffusion weighted images (DWIs) is a critical factor in the correct analysis of diffusion tensor imaging (DTI) data. Voxel-by-voxel correspondence between multiple acquired volumes must be established prior to fitting a tensor model.
- Coregistration (e.g. motion correction) algorithms face particular challenges with DWIs due to the low resolution, low signal-to-noise ratio and inherent spatially dependent image intensity produced by different magnetic field gradients (see sidebar). Additionally, a field of view mismatch can occur (where anatomical features are present in one image but not in another).

Diffusion Induced Contrasts



The minimally weighted (A) and diffusion weighted images (B-D) from the same subject show spatially differing contrast.

OBJECTIVE

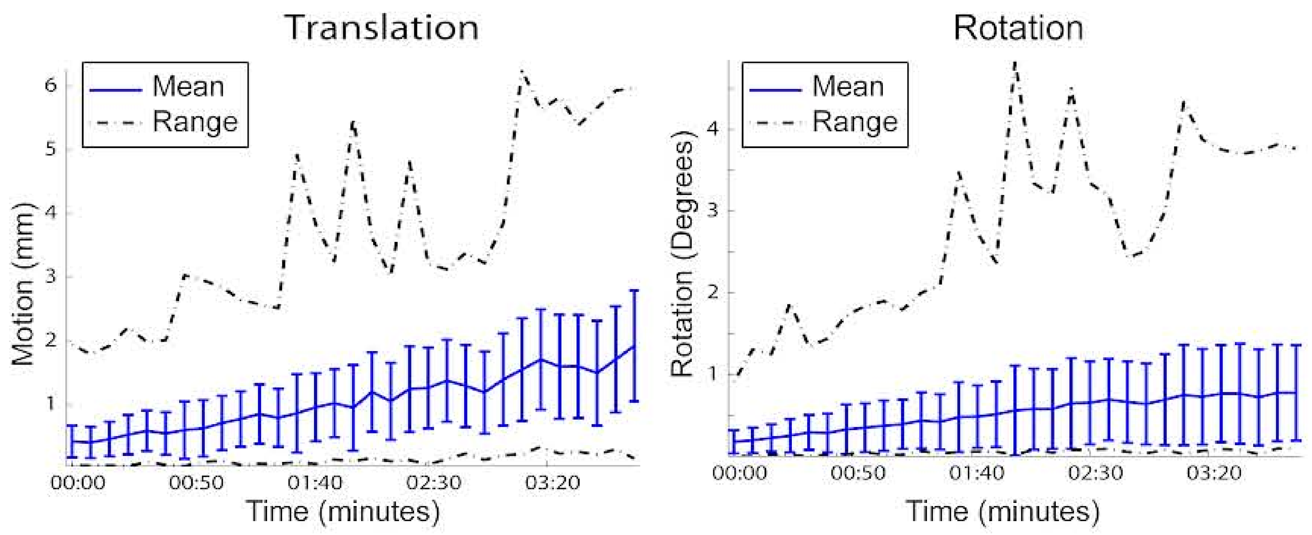
- To experimentally demonstrate that subject motion is a significant concern for diffusion tensor imaging.
- To show that the choice of registration procedure has a significant impact on the derived fractional anisotropy (FA).
- To provide a method for coregistering DWIs that demonstrates improved registration accuracy, reliability, and ease of use relative to direct registration with AIR or FLIRT.

DATA ACQUISITION AND ANALYSIS

- A 33yr old male was studied in 2 sessions of 10 DTI scans (2 weeks apart) at 1.5T (Intera, Philips Medical Systems, Best, The Netherlands) after IRB approval and informed written consent. A total of 20 DTI scans were acquired.
- A multi-slice, single-shot EPI spin-echo (SENSE factor = 2.0) DTI protocol was used with 20 axial slices acquired parallel to the AC-PC line, no slice gap and 2.5 mm isotropic resolution. Diffusion weighting was applied along 30 directions [1] (b = 1000 s/mm^2, G = 19.5 mT/m) with 5 minimally weighted images (TR/TE = 2956/100 ms). Scan time = 2:18 min for each DTI scan.
- For comparison, coregistration of DWIs was performed by direct registration of all acquired data to a single b0 target volume using Automated Image Registration (AIR) [2] and FMRIB's Linear Image Registration Tool (FLIRT) [3]. Both packages provide similar 3D rigid body registration tools that employ different search strategies and comparison criteria. AIR parameters were manually tuned by an experienced user based on visual inspection of the results for one scan. Angular search of FLIRT was limited to 20°. Regions of interest (ROIs) were manually delineated to indicate the corpus callosum and the internal capsule.

Subject Motion in a Clinical Population

- The magnitude of subject motion in 160 DTI scans of 52 subjects from a mixed population of controls and ataxia patients was assessed relative to the first volume acquired (the b0) of each subject's scan.



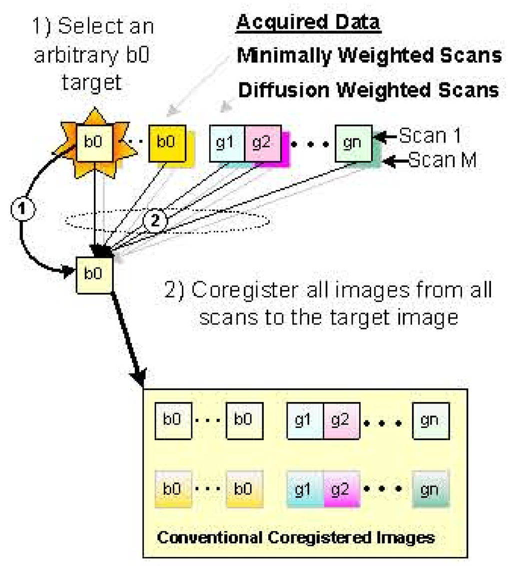
- Subject motion rapidly accumulates over the course of a single scan.
- Without proper coregistration, anatomical structures would be misaligned by approximately a voxel, and gross misalignment would occur for some subjects.
- The inclusion of data from multiple scans in a session would further exacerbate potential misalignment artifacts [4].

Robust Automated DWI Adaptive Registration (RADAR)

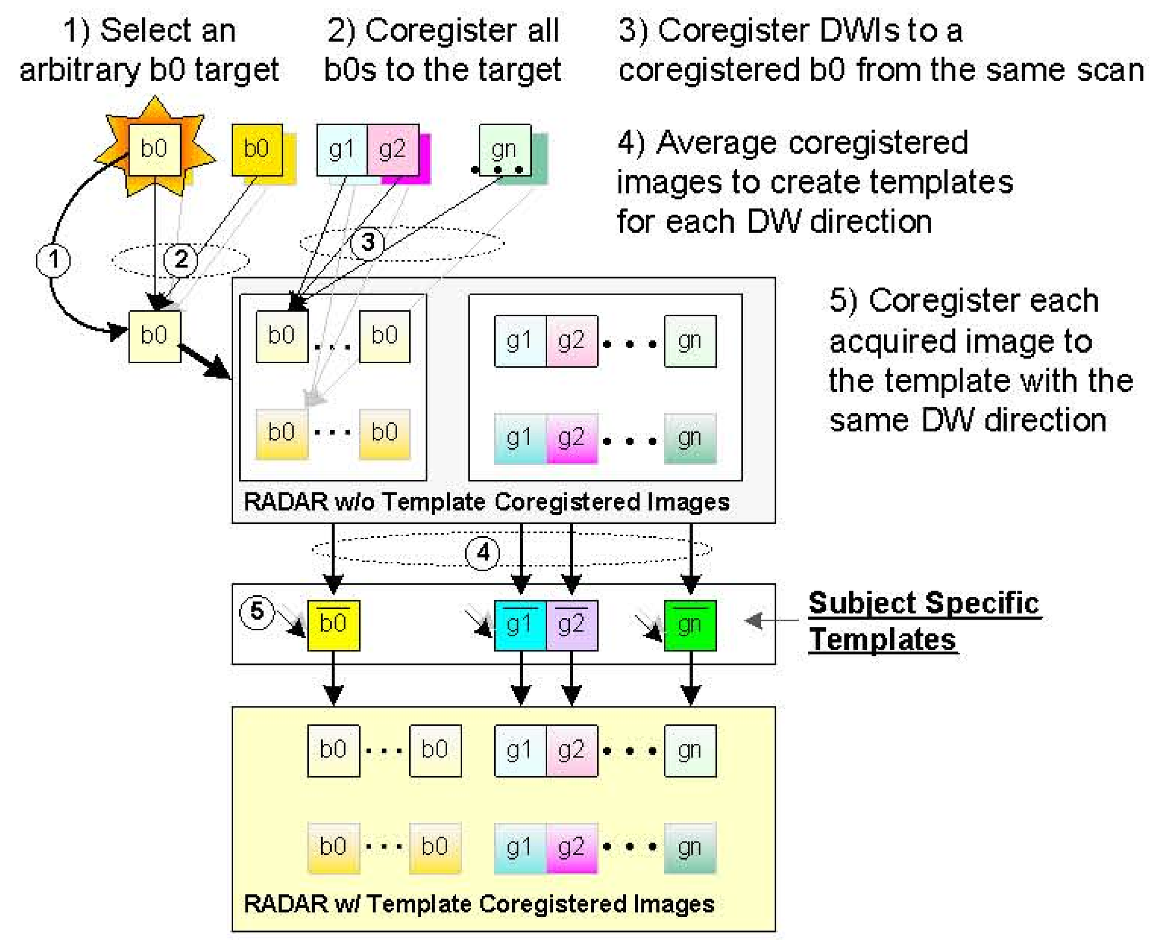
The premise of RADAR is to use existing coregistration programs in a manner so that each registration step operates on images that are as similar as possible in terms of spatial contrast and field of view.

- RADAR system performs two passes: First, all images are registered to create a subject-specific diffusion weighted (DW) template. Second, all images are registered to the template (see flowchart).
- Either the complete registration may be used (e.g., RADAR w/ Template) or the first step may be used alone (e.g., RADAR w/o Template).
- RADAR uses FLIRT registration due to empirically observed performance, but the concepts could be straight forwardly extended to work with AIR or other registration procedures.

Conventional Registration FLIRT or AIR

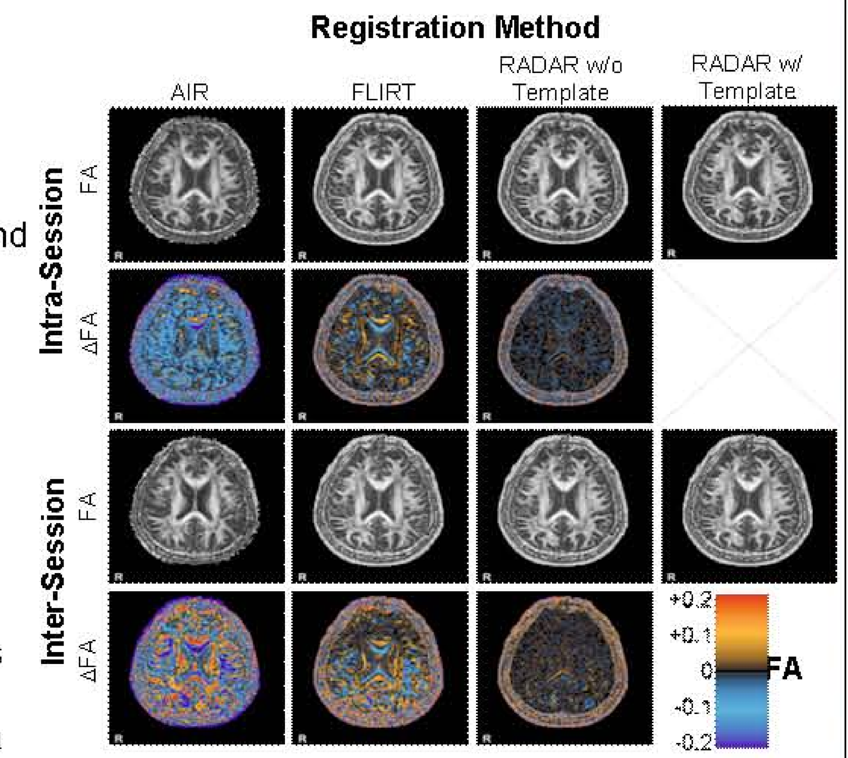


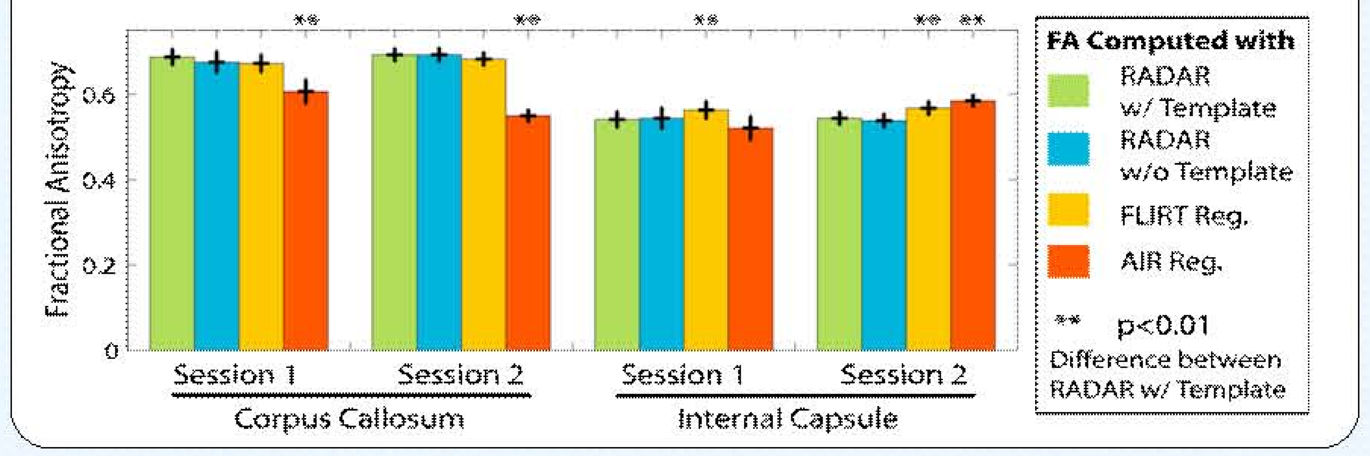
RADAR Flowchart



Registration Impact on Fractional Anisotropy (FA)

- Mean FA was computed with the results of each registration method.
- Spatial differences in FA between either AIR or FLIRT and that from RADAR w/ Template exceed ±0.1 FA units in both white and gray matter regions.
- The observed changes in the computed FA were larger between scan sessions (inter-session effects exceed intra-session effects)
- The degree of FA mismatch is in agreement with the relative registration precision shown via mean squared error (MSE).



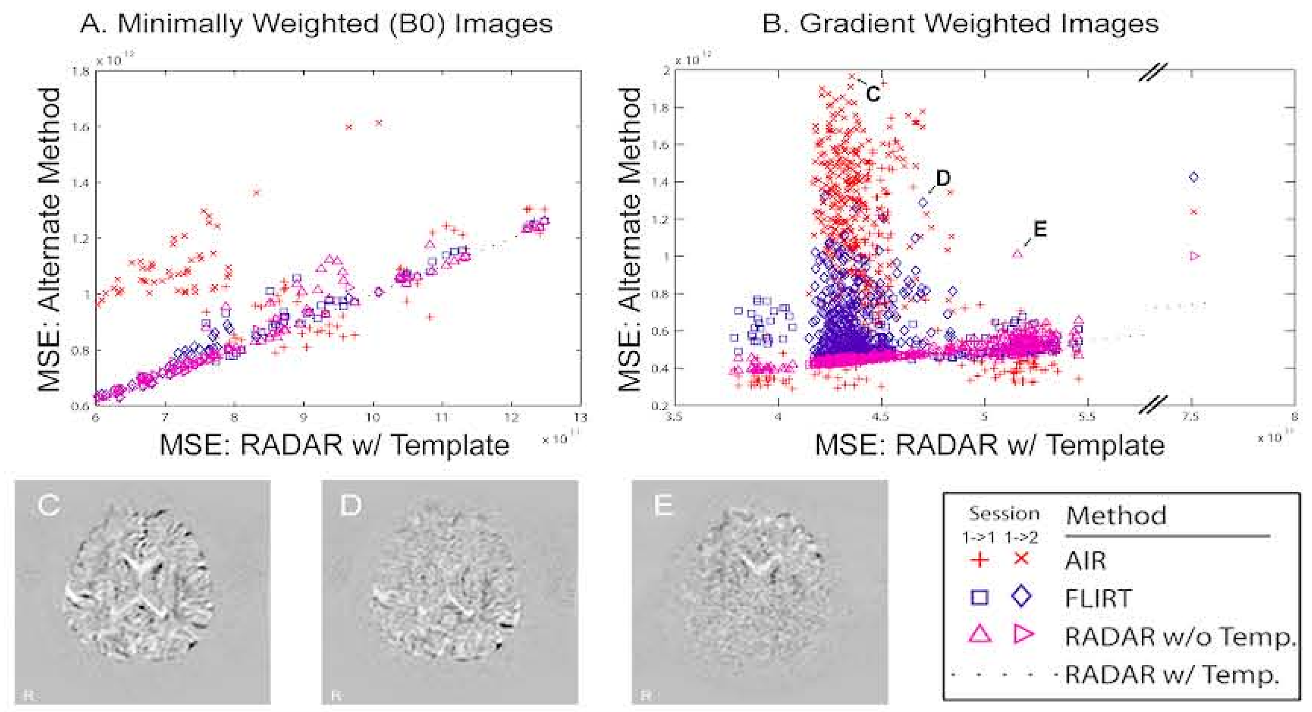


Region of Interest (ROI) Analysis

- The mean FA (across all studies within each session) by method was significantly different from the RADAR w/ Template method in the corpus callosum for the AIR method for both sessions and in the internal capsule for both sessions with FLIRT and for the second session with AIR.
- FLIRT and the RADAR methods show approximately the same variability of the ROI means, while AIR yielded increased variability in session 1.

Registration Fidelity Assessed by Mean Squared Error

- Mean squared error (MSE) was assessed relative to the templates created in the first stage of the RADAR registration process.



- **Types of Errors:** For all methods, the MSE was equivalent for many images (line of data points on the diagonal). However, some images showed large differences. These differences correspond to outliers (indicated by arrows and difference images in Boxes C, D, E).
- **Minimally Weighted** (Box A): All methods performed approximately equally well except for AIR (+54% MSE) with inter-session registration.
- **Diffusion Weighted** (Box B): AIR and FLIRT performed noticeably less well on both intra-session (+47% and +14%) and inter-session (+199% and +53%) registration. RADAR w/o Template performed slightly worse (+4%) than RADAR w/ Template.

CONCLUSIONS

- Subjects from clinical populations are likely to move a significant distance over the course of a single DTI scan. To prevent nonsense tensors computed from signal at different anatomical locations, accurate coregistration is essential.
- Various best effort algorithms for coregistration can produce significant differences in fractional anisotropy.
- RADAR yields consistent improved MSE over the conventional implementation of AIR and FLIRT alone.
- Registration quality can be improved with subject specific templates using RADAR. Additionally, some improvement is also possible when only using the first RADAR step.

REFERENCES

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