Effect of registration of Diffusion Weighted Images on Fractional Anisotropy

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Introduction:
Patient motion and eddy current based distortions are a common problem in diffusion weighted imaging. Therefore, for an accurate estimation of diffusion tensors and anisotropy indices like Fractional Anisotropy (FA), it is essential that the diffusion weighted images are spatially aligned. Various groups have shown the registration of diffusion weighted images with non-diffusion weighted image as the reference [1-3]. In this work, we have demonstrated the 3D registration of diffusion weighted images with both non-diffusion weighted and diffusion weighted images as reference, using mutual information [4-5]. The correction of deformations induced by motion and distortion includes translation and shear in three dimensions. FA distribution is plotted to see the influence of use of different reference images.

Methods:
Diffusion weighted images of human brain each with six different directions were obtained from 3 healthy human subjects on a 3T Siemens Allegra (Siemens, Ehrlagen, Germany) imaging system. Each data set consisted of diffusion weighted (B0; b = 1000 s/mm2) and non- weighted (B1, B2, B3, B4, B5 and B6; b=0) images (128 x 128 x 10, FOV = 210 mm^2 and each slice 3.0 mm thick) acquired using a spin echo (number of averages =8, TR = 3900 ms and TE of 81 ms). Registration algorithm and code for calculation of fractional anisotropy was implemented in MATLAB (Mathworks, MA, USA) on a 3 GHz Intel Pentium processor. All diffusion weighted and non-diffusion weighted data sets were used as the reference volume and registered to artificially deformed diffusion weighted and non diffusion weighted volumes from the same subject. The images were deformed randomly such that shear varied from -0.3 to +0.3 along x and y axes and from -0.05 to +0.05 along z axis. The translation varied from – 2 to +2 in x and y axes. The shear and translation of images were implemented in Fourier domain to reduce the interpolation artifacts by exploiting the nature of the MRI k-space data [1]. The corrected deformation consisted of displacement and shear in x, y, and z directions. The corrected deformation is applied to the target volume to obtain an intermediate target volume. The mutual information between this intermediate target and reference volume is found from their histograms. The histogram consists of 256 bins and joint histogram consists of 256 x 256 bins. The initial estimate of the translation parameters is provided by finding the difference between the center of image of the reference and intermediate target volumes. The initial guess of the shear along x, y and z axes is estimated by shearing the target image from -0.3 to 0.3 along x and y axes and -0.1 to 0.1 along z axis in steps of 0.05 and finding the mutual information at each step. The initial guess of the shear parameter were the shear parameters at which maximal normalized mutual information is obtained. The optimal value of the registration parameters is found using the Nelder-Mead simplex algorithm such that the normalized mutual information is maximized. The registration parameters for which maximal mutual information was obtained, were then applied to the target image volume to correct the deformations induced by motion and eddy current. Diffusion tensors were calculated using standard algorithm for the original (un-deformed), deformed and registered (with B0-6 as reference) images. Fractional anisotropy index was calculated for each voxel from eigen-values of the diffusion tensors.

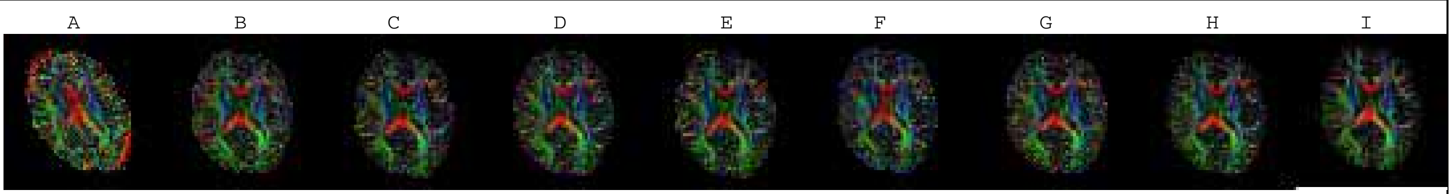

Figure 1 . FA maps of A) unregistered image, B-H) with B0-B6 as reference image and I) original (un-deformed image).

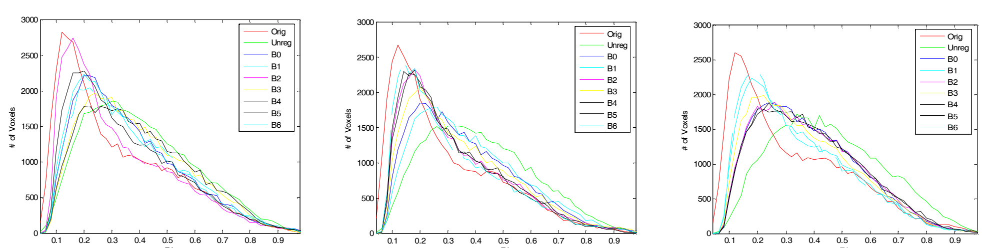

Figure 2. FA distributions of original, unregistered, and registered images for Subjects 1, 2, and 3, respectively.

Table 1. Kurtosis of FA distributions of original, unregistered, and registered (with B0-6 as reference) images.

KURTOSIS	Sub1	Sub2	Sub3
Original	5.13	6.33	5.20
Unregistered	3.43	3.80	3.06
B0	4.23	4.77	3.73
B1	4.29	4.48	4.37
B2	5.25	5.70	3.73
B3	3.68	5.17	4.03
B4	4.52	5.59	3.70
B5	3.65	5.64	3.71
B6	4.04	6.07	4.63

Results and Discussion: Figure 1 shows the FA maps of unregistered, registered and original (undistorted) images. As can be seen in the figure 1A, the FA map of unregistered image is blurry and noisy and do not correlate to the underlying anatomical structure. Whereas the FA maps of registered images (figure 1B-1H) are similar to the FA map (figure 1I) of the original image. However, the registered FA maps are smoothened because of registration and interpolation errors. Figure 2 shows the distribution of FA values for original, unregistered, and registered images. As can be seen in the figure 2, for unregistered images the distribution of FA values is comparatively broad and covers values greater than 0.2 in large amount. Whereas, for original image, the histogram has values less than 0.3 is greater proportion. Histograms of FA values of images after registration are not similar to the histogram of FA values of original image. This difference could be attributed to the registration and interpolation errors. Two-way ANOVA showed that the kurtosis values (Table 1) of FA distributions of original, unregistered and registered images were significantly different ($p<0.05$). Kurtosis was used to see how much the FA distribution deviated from the normal distribution. As can be seen in the table 1, the kurtosis of FA distribution of unregistered image is consistently lower than the kurtosis of FA distributions of original images for all the three subjects. The mean $\pm$ std. deviation of kurtosis of registered images (with B1-B6 as reference) were 4.24$\pm$0.6, 5.44$\pm$0.6, and 4.03$\pm$0.4 for subject 1, 2 and 3, respectively. These are consistently higher than the kurtosis values of FA distribution of unregistered images for all the three subjects but still are lower than the kurtosis values of FA distribution of original image. Thus, in this work, we have demonstrated the use of diffusion-weighted images as a reference for the registration of diffusion weighted images with a mutual information based algorithm, using Fourier transformation to implement translation and shear deformations. However, the results suggests that care must be taken (regardless of the reference image used for registration) while correcting for the motion artifacts and distortions in DWI images because FA estimates are altered and are different from the FA estimates of original image.

Reference:
[1] Mistry NM et al. MRM 2006; 56:310-316. [2] Rhode GK et al. MRM 2003;51:103-114. [3] Mangin JF et al. Med Image Anal 2002;6:191-198. [4] Maes FA et al. Proceedings of IEEE 2003;91:1699-1722. [5] Viola WM et al. Med Image Anal 1996;1:35-51.