A simple method for ODF reorientation after deformable imaging registraton

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Background & Objective: High angular resolution diffusion imaging (HARDI) is currently of great interest to characterize complex arrangements of fibers. In particular, Q-ball imaging (QBI) is a popular reconstruction method to obtain the orientation distribution function (ODF) of multiple fiber distributions. QBI provides a model-independent estimation of the fiber orientation probability from the ensemble-average spin displacement [1]. The ability to resolve fiber heterogeneity with the HARDI framework may improve white matter tractography solutions for navigation through fiber intersections in white matter [1-2]. Furthermore statistical quantification of tissue geometry and fiber structure using inter-subject normalization of HARDI data may provide better insights for understanding disease process in the brain white matter. The inter-subject registration problem requires high dimensional registration algorithms to appropriately account for anatomical variability between subjects. The HARDI data is inherently multidimensional and non-Euclidean requiring a complex mathematical framework to reorient the fiber distribution based on the image registration transformation. In this work, we propose a simple and efficient method of ODF reorientation that allows correct estimation of fiber distribution after image transformation.

Methods: A diffusion MR acquisition of the brain for QBI was performed on a healthy volunteer with a Siemens 3T TIM Trio scanner using a 12 channel Matrix head coil and a twice-refocused, balanced-echo EPI sequence. Thirty axial slices with 1.72x1.72x4mm^3 resolution were used. The sequence parameters were TR/TE =4700/114ms, g_{max}=38mT/m, b=3000s/mm^2 and 4 averages. The q-space sampling points were 64 vertices of a regularly tessellated hemisphere. Images were linearly interpolated and resampled to be 2 mm isotropic voxel size. As a proof of concept for this method, a synthetic transform was created by combining a rigid-body rotation by 30° along the z-axis and nonlinear deformation using a landmark based warping algorithm (Fig 1). According to the polar decomposition theorem, a non-singular deformation gradient tensor, $\mathbf{F} = \mathbf{I} + \mathbf{u}\nabla$, where $\mathbf{u}\nabla \equiv \frac{\partial u_j}{\partial x_k}$, can be decomposed into the finite strain parameters of rotation and strain tensors [3]. We used singular value decomposition (SVD) to obtain the rotation tensor component. The cumulative effects from rigid body rotation and local diffeomorphic deformation were represented by multiplication of two successive rotation matrices, $\mathbf{R}^{rigid}$ and $\mathbf{R}^{deform}$. The local diffusion gradient vector was estimated at each voxel using $\mathbf{g}_i = \mathbf{R}_i^{deform} \cdot \mathbf{R}^{rigid} \cdot \mathbf{g}$, where $\mathbf{g}$ denotes uncorrected diffusion gradient vectors and corrected local gradient vectors of $\mathbf{g}_i$. The diffusion wavevectors are then defined as $\mathbf{q}_i = (2\pi)^{-1}\gamma\delta\,\mathbf{g}_i$. The ODF profile was reconstructed using the Funk-Radon transformation (FRT) [2]. To compute the FRT a thin plate spline was used as a radial basis function for spherical regridding of corrected wavevectors $\mathbf{q}_i$. The ODF profile was filtered using truncated spherical harmonic transformation (SHT) reconstruction comprising of parametric boundary fitting with finite spherical harmonic series (l_{max}=8) and elimination of odd harmonic orders [4].

Results: Fiber orientation represented by ODF was incorrectly reconstructed following a nonlinear transformation of the HARDI data without a voxel wise correction of the gradient orientation (Fig 2A). Applying the rotational components of the rigid and non-linear transformations allowed the ODF profile to be correctly recovered along the expected orientation of fiber distribution (Fig 2B).

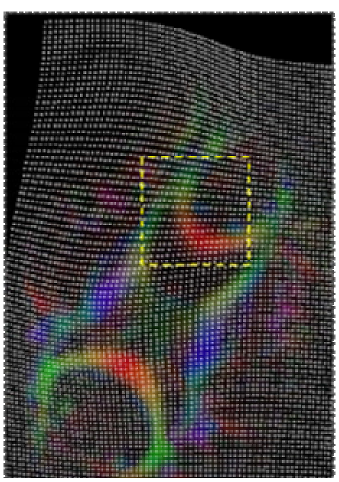

Figure 1. Warped color-encoded principal direction map overlaid with deformation grid.

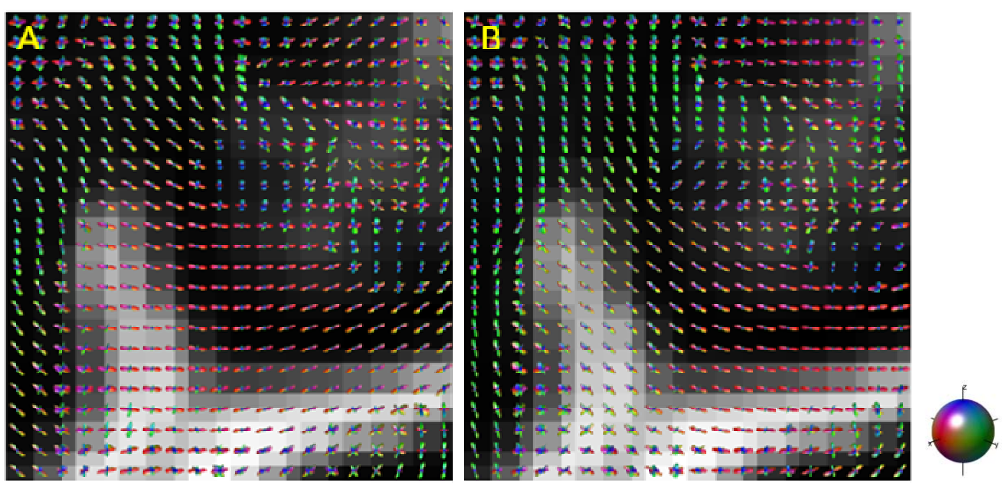

Figure 2. A. Surface map of ODF profile without correction of orientation following rigid body rotation and deformable warping of HARDI (magnified area of the box in Figure 1). **B.** ODF map from the same deformation as A after correction using the locally reoriented wavevector.

Discussion: A new fast and efficient method to reorient the ODF is introduced. This approach is free from rigorous mathematical frameworks or computationally expensive algorithms such as a priori assumption of statistical model or data interpolation on a non-Euclidean space. It is an effective scheme for estimating the correct orientational distributions of white matter tracts following image registration. In addition our method is easily applied to diffusion tensor reorientation without significant modification.

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