A ground truth analysis of the preservation of diffusion tensor information in a population specific atlas.

W. Van Hecke[1,2], A. Leemans[3], S. De Backer[1], E. Vandervliet[2], J. Sijbers[1], and P. M. Parizel[2]

[1]VisionLab, University of Antwerp, Antwerp, Belgium, [2]University Hospital Antwerp, University of Antwerp, Antwerp, Belgium, [3]CUBRIC, University of Cardiff, Cardiff, United Kingdom

Introduction

Voxel based morphometry (VBM) is increasingly being used to detect diffusion tensor (DT) image abnormalities in patients for different pathologies. An important requisite for a robust VBM analysis is the use of a reliable, high-dimensional non-rigid coregistration technique that is able to align both the spatial and the orientational DT information. It has been shown that the use of all DT information during coregistration can improve the image alignment significantly [1]. Consequently, there is a need for an inter-subject DTI atlas as a group specific reference system that also contains this orientational DT information. In order to reduce the image alignment inaccuracies in a VBM setting, it is furthermore important that this atlas is a good representation of the subject group of interest and that the atlas is subject-independent. In this way, the deformation fields of all subjects to the atlas are minimal. In this work, a population based atlas for DT images is developed, using a high dimensional viscous fluid model to coregister the images [2,3]. The coregistration is based on the FA maps as well as on all the DT elements, in order to minimize the orientational alignment inaccuracies. The population based atlas is compared with an atlas that is based on a single subject image as a reference system [4]. In addition, a ground truth methodology is developed to compare the atlases.

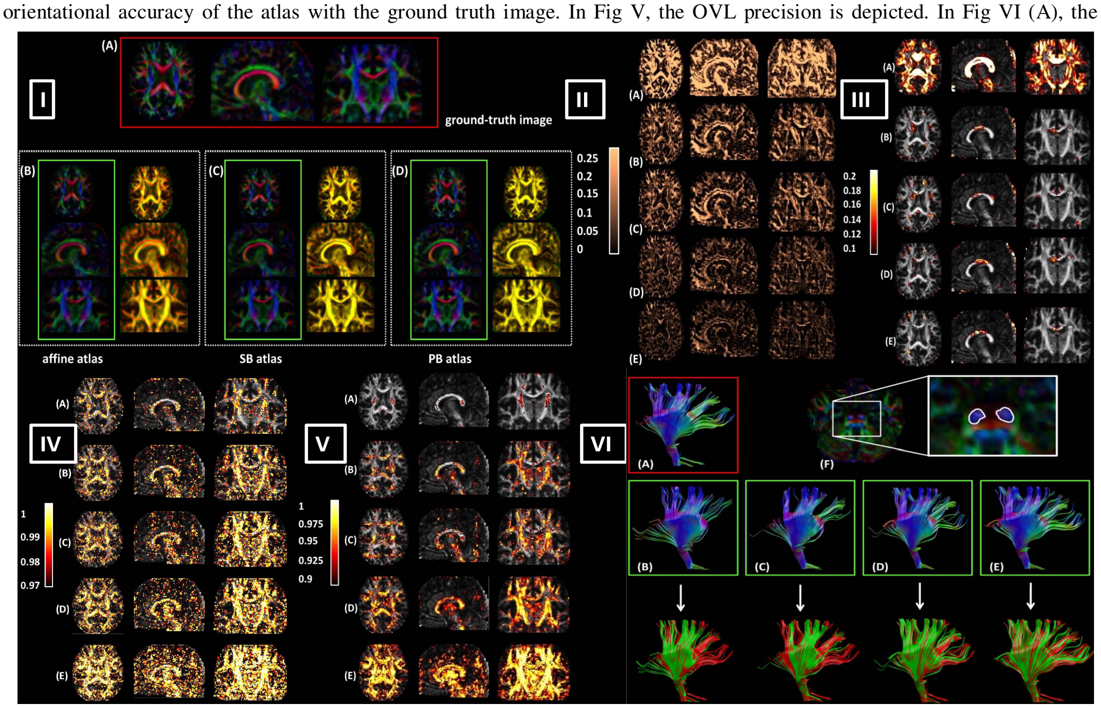
Methods

The main purpose of the proposed DTI atlas is to minimize the effect of an initial reference image during the atlas reconstruction and to optimally include all orientational DT information. To this end, transformations are calculated between all images I_i of the group. Thereafter, the mean deformation field T_i of image I_i to all other images of the group I_j is calculated for each image I_i. Subsequently, this T_i is used to transform image I_i, after which a PPD based tensor reorientation is applied, resulting in image I_i^* [5]. Finally, all images I_i^* are averaged to construct the final population based (PB) atlas. This atlas will be referred to as the PB-DT (DT based coregistration) or PB-FA (FA based coregistration) atlas. The proposed PB DTI atlas methodology is compared with the method of Guimond et al., referred to as the subject based (SB) atlas, in which a single subject image is used as the initial reference system [4].

A general problem in the evaluation of an atlas is the lack of a ground-truth. In this work, a ground-truth for the atlas construction is created based on a single subject DTI data set I. **(1)** First, the diffusion weighted images (DWIs) of this data set are deformed with 10 predefined sinusoidal deformation fields T_i (i=1-10). **(2)** The DTs are calculated from these deformed DWIs and reoriented using the PPD technique [4]. **(3)** The DWIs are recalculated from these reoriented DTs, producing 10 new DT images I_i (i=1-10). **(4)** Next, 10 deformation fields, are calculated as the inverse of the first 10 transformations. **(5)** Analogously to **(2)** and **(3)**, 10 deformed DTI data sets I_j were constructed (j=11-20). As a result, the total vector sum over all deformation fields equals zero in each voxel. Consequently, an atlas construction of these 20 deformed data sets I_i (i=1-20), should result in the original single subject image (=ground-truth), since the total vector sum of all deformation fields is zero in each voxel. All atlases are evaluated both visually and quantitatively. The FA difference between the SB and PB atlases and the ground truth image I are calculated. This comparison will be referred to as the FA accuracy. In addition, it is also important to compute the precision. In this context, the precision of the atlases is calculated as the standard deviation (SD) of the FA over the images that are averaged to compose the final atlas. In addition, the OVL (overlap of eigenvalue-eigenvector pairs) accuracy and precision are calculated, evaluating the preservation of orientational information in the atlases.

Results

In Fig I (A), an axial, sagittal, and coronal directionally-encoded FA slice of the single subject ground truth image is shown. In Fig (B), (C), and (D), the same slices of the affine atlas, the SB-DT atlas, and the PB-DT atlas are depicted, respectively. For all images in Fig II-V, (A) represents the affine atlas result, (B) and (C) the SB-FA and the SB-DT atlas results, and (D) and (E) the PB-FA and the PB-DT atlas results. In Fig II, the FA map of the ground truth image is subtracted from the FA maps of the different atlases. Besides a low FA accuracy (Fig II), a low FA precision can be observed for the affine atlas, as can be seen in Fig III (A). A higher FA precision is obtained in the SB-FA, SB-DT, PB-FA, and PB-DT atlases, as depicted in Fig III (B), (C), (D), and (E), respectively. In order to evaluate the preservation of the orientational information during the atlas construction, the OVL is measured at each voxel between the ground truth image on the one hand and the different atlases on the other hand. The OVL between the ground truth image on the one hand and the atlases on the other hand are shown in Fig IV (A)-(E). A high OVL represents a large tensor correspondence and thus a high orientational accuracy of the atlas with the ground truth image. In Fig V, the OVL precision is depicted. In Fig VI (A), the cortico-spinal tracts of the ground truth image are visualized. The ROIs that were used to obtain these tracts are shown on an axial slice of the ground truth image in Fig VI (F). These ROIs were also used to define the seed points during the tractography algorithm on the atlases. In Fig VI (B), (C), (D), and (E), the cortico-spinal tracts of the SB-FA, SB-DT, PB-FA, and PB-DT atlases are shown, respectively. In order to allow a better visual comparison of the tracts, the cortico-spinal tracts of the ground truth image are given a green color, whereas the cortico-spinal tracts of the different atlases are given a red color.



Conclusion

A population based DT atlas, with a minimal bias towards any individual data set, is constructed and evaluated with a ground truth method. The atlas contains all orientational diffusion information accurately and precisely, due to the use of all DT elements during coregistration and the specific atlas construction methodology.

References

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