Watershed-based Segmentation of the Midsagittal Section of the Corpus Callosum in Diffusion MRI

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Abstract – The corpus callosum (CC) is one of the most important white matter structures of the brain, interconnecting the two cerebral hemispheres. The CC is related to several diseases including dyslexia, autism, multiple sclerosis and lupus, which make its study even more important. We propose here a new approach for fully automatic segmentation of the midsagittal section of CC in magnetic resonance diffusion tensor images, including the automatic determination of the midsagittal slice of the brain. It uses the watershed transform and is performed on the fractional anisotropy map weighted by the projection of the principal eigenvector in the left-right direction. Experiments with real diffusion MRI data showed that the proposed method is able to quickly segment the CC and to the determinate the midsagittal slice without any user intervention. Since it is simple, fast and does not require parameter settings, the proposed method is well suited for clinical applications.

Keywords – Corpus callosum, diffusion tensor imaging, fractional anisotropy, magnetic resonance image, segmentation, watershed transform.

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1. Introduction

The corpus callosum (CC) is by far the largest fiber bundle in the human brain interconnecting the two cerebral hemispheres with more than 300 million fibers [1]. Due to its function, the corpus callosum is related to several different diseases. Proportional increase in the CC cross-sectional area has been observed in individuals with dyslexia [2]. Alterations in white matter tracts have been found in autistic patients, with clusters of reduced fractional anisotropy (FA) values in several structures, including the corpus callosum [3]. Systemic Lupus Erythematosus patients have presented much lower contrast between the CC and its surrounding tissue [4].

Due to the importance of the corpus callosum the number of studies on this topic is increasing and different types of magnetic resonance scans have been used to analyze this structure of the brain. These studies often use the segmentation as a tool in the research development: they are not concerned about the evaluation of the method, but in examining the structure, its shape and properties. Therefore it is essential to have a robust automatic segmentation method that requires minimum user information.

Most of the existent studies are conducted using T1-weighted images. Among them, the majority is based on white matter segmentation, using active contours. After the segmentation, the CC is extracted using connected components analysis with statistical information [2], or atlas-based segmentation [5].

In order to analyze the diffusion parameters within the corpus callosum, it is desirable for the CC segmentation to be performed directly in magnetic resonance diffusion tensor images (MR-DTI), instead of using the T1-weighted images. It would avoid the registration error when the segmentation is made in T1-weighted images, followed by the registration of the result to diffusion images. There are also atlas-based segmentation methods proposed for white matter fiber bundles in DTI [6], but it also includes registration. The cell-competition method [4], despite using the watershed transform, is computationally expensive and does not explore other concepts of mathematical morphology.

In this paper we propose an automatic approach for the segmentation of the midsagittal section of the corpus callosum based on the watershed transform and concepts of mathematical morphology. The method uses diffusion tensor images and the fractional anisotropy (FA) map. It also includes the automatic determination of the midsagittal slice of the brain to be segmented.

The algorithm was developed in Adessowiki [7], a collaborative environment for development and documentation of scientific computing algorithm.

2. Methods

The diffusion data used in our experiments were acquired on a Siemens 3T Trio MR scanner using an 8-channel phased array head coil: diffusion images with $N = 30$ diffusion encoding directions with $b = 1000\ s/mm^2$, $2.0\ mm$ isotropic voxel size, 63 slices, $TE = 95\ ms$, $TR = 8700\ ms$. Two datasets were acquired from each of two healthy volunteers. The diffusion data was first linearly interpolated to 1.0 mm isotropic resolution, before tensor estimation.

The proposed approach is based on two major steps: the automatic determination of the midsagittal slice of the brain (the input image for the following step) and the segmentation of the midsagittal section of the corpus callosum.

This section contains a description of each one of them.

2.1. Automatic determination of the midsagittal slice of the brain

To perform the segmentation of the corpus callosum properly ensuring its repeatability, it is important to have an automatic method for the determination of the central slice of the brain.

One of the landmarks of the central portion of the brain is the interhemispheric fissure, which is mainly composed of cerebrospinal fluid (CSF), except for some white matter structures. The objective of the proposed method is not to identify the interhemispheric fissure, which is a more complex operation, but to find the slice within a dataset that is more aligned with it, here called the midsagittal slice.

The fractional anisotropy (FA) map derived from the MR-DTI reflects the scenario in the midsagittal slice: large areas, corresponding to the CSF, with low FA values and the white matter structures, including the corpus callosum, with high FA values.

Consequently, if the average FA is calculated for each slice, after discarding higher values (above 50% of the maximum), the slice with lowest average will be the midsagittal slice. That is true if not taking into account slices from extremities, with small cross-sectional area of the brain. So, only slices with a cross-sectional area above a certain minimum (in this case, 80% of the maximum) are considered as candidates for midsagittal slice.

For validation purpose, the midsagittal slice was previously assigned in each dataset by medical experts.

2.2. Corpus callosum segmentation in the mid-sagittal slice

Diffusion tensor images, as tensorial images, present a variety of derived scalar maps, each one representing a particular property. Since the watershed transform is usually performed over a gradient image, the choice of a scalar map, or a combination of them, to be used in the segmentation of the corpus callosum section should consider its capacity to enhance the CC borders in the external morphological gradient computation.

To emphasize the CC features in the midsagittal slice (high FA values and preferential diffusion in the left-right direction), the fractional anisotropy map is weighted by the projection of the principal eigenvector in the left-right direction, or the e_{1x}-weighted FA map. This combination is essential to differentiate the corpus callosum from other structures that also present high FA values but different orientation from the fibers at corpus callosum, e.g., cingulum, fornix.

Once the weighted scalar map is computed, the external morphological gradient is calculated to capture the edges of the corpus callosum. The external morphological gradient is chosen over the morphological gradient and the internal morphological gradient due to its efficiency on extracting external boundaries of objects brighter than the background [8].

The external gradient G_e is defined as the difference between the dilated image and the original image f:

$$G_e(f) = f \oplus b - f$$

where $\oplus$ denotes the dilation operation, using a structuring element b. In this case we used the elementary cross as the structuring element.

The obtained external gradient is then used to compute the watershed transform from markers [9]. Since the critical part in the watershed segmentation is the proper choice of markers, a hierarchical approach is considered in order to retain the most significant regions of the image. The extinction values of the local minima based on the volume dynamics are used to build the hierarchy [10]. Local minima with highest extinction values are then used as markers for the watershed segmentation.

The number n of markers to be assigned, and consequently the number n of regions, must be greater than the number of labels in the final result (2 labels, the corpus callosum and the background) to guarantee that the external boundaries of the corpus callosum are detected. Initial experiments have shown that 5 regions are sufficient for the detection of the CC boundaries for all tested datasets, and increasing the number n of segmented regions does not affect the final result.

Finally, after segmenting the midsagittal slice in *n* regions using the watershed transform, it is necessary to group the obtained regions to achieve the final segmentation. The e_{1x}-weighted FA average of each region is an important parameter for distinguishing between the corpus callosum and the background: all regions within the corpus callosum present a high average, while the regions outside the CC present a low average. Few points with high values outside the CC are not sufficient to significantly increase the average of these regions. Therefore, a single threshold is sufficient to classify the regions as CC or as background, based on the e_{1x}-weighted FA average of each region.

3. Results and Discussion

As mentioned in previous section, before segmenting the CC, the midsagittal slice of the brain had to be determined. For all datasets used in the experiment, the correct slice was identified by the method.

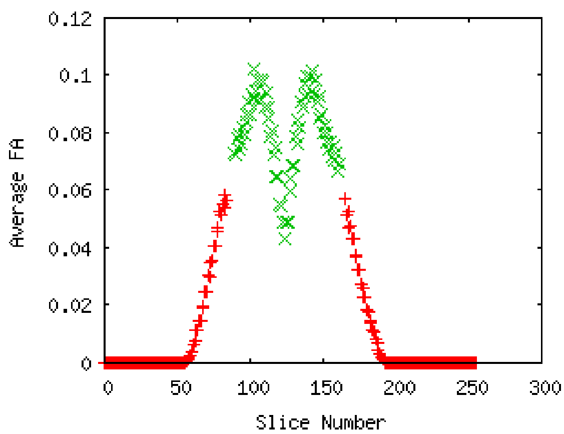

Figure 1. The average FA for each slice of a given volume: the midsagittal is the slice with lowest average between the candidates (green), the discarded slices (red) are not considered.

Figure 1 presents the average FA for each of the slices of a given image. Once extremity slices are discarded (red), the midsagittal slice can be easily determined by its low average FA.

After the determination of the midsagittal slice, the segmentation of the corpus callosum was performed. Results for each step of the proposed segmentation method can be seen in Figure 2. The e_{1x}-weighted FA map (Fig.2b) allows the corpus callosum to be distinguished from other structures with different fiber orientation, what cannot be done from the FA map (Fig.2a) only. The external morphological gradient (Fig.2c) is calculated from the weighted map and captures the edges of the corpus callosum. The watershed transform (Fig.2d) is then computed from the gradient, for 5 regions (n = 5). The e_{1x}-weighted FA average of each region is calculated and a single threshold is used to classify the regions as CC or as background, obtaining the final result (Fig.2e).

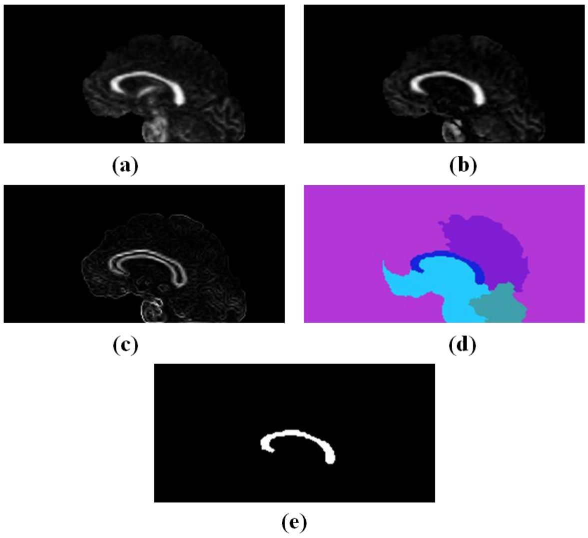

Figure 2. Stages of the proposed method: (a) the FA image, (b) the e_{1x}-weighted FA image, (c) the external gradient, (d) watershed transform and (e) the final result.

The proposed method of segmentation was able to segment correctly the corpus callosum for all datasets. Also, when comparing the final result for two datasets of the same patient acquired in different moments, it is possible to notice that the shape of the CC remains the same, suggesting the repeatability of the proposed method.

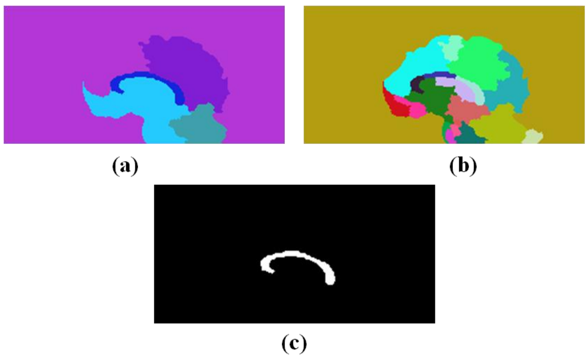

Figure 3. The result of the watershed transform for different number of regions: For both 5 regions (a) and 20 regions (b), the final segmentation result is the same (c).

Figure 3 shows the watershed segmentation for n = 5 and n = 20. Although the obtained segmentation for 20 regions divides the CC in 3 parts, the final result is the same. Even for a bigger number of regions, the average values for the regions within the corpus callosum are significantly higher than the values of the regions in the background, even with some high value voxels outside the CC.

4. Conclusion

In this article we proposed a new approach for segmentation of the midsagittal section of corpus callosum in magnetic resonance diffusion tensor images, using the watershed transform. This approach includes the automatic determination of the midsagittal slice of the brain.

The proposed method has shown promising results, not only for the corpus callosum segmentation but also for the determination of the midsagittal slice of the brain. Experiments with real diffusion MRI data showed that the method is able to quickly segment the CC and to determinate the midsagittal slice without any user intervention. It is simple and does not require parameter settings. All parameters are previously assigned, and their choice is not critical for the performance of the method.

We envision that the proposed method, together with the Adessowiki environment, might be useful for clinical applications. Therefore, further experiments should be conducted in order to analyze the accuracy of the obtained segmentation and the robustness of the proposed method in relation to the parameters choice.

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