Subdividing the Corpus Callosum Based on Morphometry and Diffusion Anisotropy

P. Yu[1], D. H. Salat[2,3], P. Golland[4], D. S. Tuch[2], H. Rosas[2,5], B. Fischl[2,3]

[1]Health Science and Technology, MIT, Cambridge, MA, United States, [2]Athinoula A. Martinos Center for Biomedical Imaging, MGH/MIT/HMS, Charlestown, MA, United States, [3]Radiology, MGH, Charlestown, MA, United States, [4]AI Lab, MIT, Cambridge, MA, United States, [5]Neurology, MGH, Charlestown, MA, United States

INTRODUCTION

The corpus callosum is the largest commissural fiber bundle in the brain and plays an essential role in the communication between the two cerebral hemispheres. The corpus callosum is organized with commissural fiber bundles projecting to different areas of the brain topographically organized along its medial axis. Prior studies show that different regions of the corpus callosum are altered due to aging and disease-related pathology, likely related to the differential lobar degeneration in these conditions. Thus, an intensive amount of work has been conducted to measure the extent and location of structural changes in corpus callosa through *in vivo* MRI methods. However, inconsistencies exist with regard to the localization of specific regions that undergo changes due to disease, and how to precisely parcellate subregions of the callosum. To address this problem, we designed a computational scheme to automatically compute medial axis of the corpus callosum and to extract local thickness and intensity information. Thickness and intensity data calculated at each skeleton point were used to examine variability in callosal structure across individuals across multiple imaging modalities. This variability was used to subdivide the corpus callosum into anatomically distinct regions based on biologically relevant parameters.

METHODS

The medial axis of a 2D region is defined as the locus of the centre of all the maximal inscribed circles within the object. Therefore, the radius of the inscribed circle at each skeleton point provides an accurate measurement of the local thickness of the object studied (1). The algorithm employed in this work extracts the medial axis and measures the thickness or intensity in three steps. First, the middle sagittal plane is identified for a given MRI volume by applying spatial normalization to the image to maximally orient the interhemispheric fissue superior/inferiorly and localizing the midsagittal slice in the image. In that plane, the corpus callosum is segmented as the biggest connected area of white matter. In the second step, the skeleton of the corpus callosum in the mid-sagittal plane is extracted with a topology preserving method since the global topology of the callosum should not change. This method provides a robust medial axis computation since it is not sensitive to the boundary noise and allows no branching during the skeleton estimation process by representing the skeleton with an undirected graph. The construction of the medial axis is accomplished with an iterative snake-like algorithm using the distance map (2). Lastly, the thickness and fractional anisotropy, a measure of white matter microstructure obtained from diffusion tensor images, are measured in 100 equally spaced segments along the medial axis for further analysis.

RESULTS

MRI data were acquired on 35 participants (35 T1 MPRAGE scans; Siemens, Erlangen Germany, TR = 7.3, TE = 3.2 or 3.0, flip angle = 7°, slice thickness = 1.3 mm, 128 slices, FOV = 256x256 mm) and 28 diffusion tensor scans; 1.5 Tesla Sonata System; TR = 14.4s, TE = 81ms, slice thickness = 2 mm isotropic, 60 slices total, acquisition matrix 128x128 mm (FOV = 256x256 mm), 5/8 partial Fourier, 6 averages, 6 noncolinear directions with b value = 700 s/mm2, and 1 image, the T2 weighted 'lowb' image, with b value = 0 s/mm2). The correspondence between the thickness and FA value measured at equally sampled skeleton points along the medial axis allows us to compare them directly among different individuals and imaging modalities. Figure 1a gives an example of the medial axis extracted from T1-weighted MRI. The average thickness measured for 35 subjects in 100 equally sampled segments showed a specific characteristic pattern as shown in Fig. 2 (where thickness is defined as the radius of the inscribed circle centered at the medial axis and tangent to the border of the callosum). Further examination of the individual thickness plots showed that all participants had distinct peaks in the anterior and posterior regions (the genu and splenium of the callosum), yet variability existed with only 19 participants showing a single peak in the body part. In contrast, the fractional anisotropy value measured for a subgroup of 28 subjects showed a more consistent pattern. Specifically, 20 subjects showed one distinct peak in each of the anterior, posterior and body parts (Fig. 1c), while the rest had an extra peak in the body. This consistent result provided an anatomically meaningful way to identify biological landmarks for partitioning the corpus callosum into subregions. As shown in Fig 1b, the peaks and valleys were first identified as zero-crossings in the derivative of smoothed plots, which were acquired by convolving the original plots with a Gaussian filter (σ=5.6). The middle points between adjacent peaks and valleys, which are similar to the zero-crossings of the 2nd derivative, were used to delimit distinct subregions. Fig 1c gives an example of the parcellation generated for a T1-weighed MR image based on landmarks calculated form the FA map of the same subject. Future work includes studying the subjects with multiple peaks in the body part and incorporating them into this parcellation scheme.

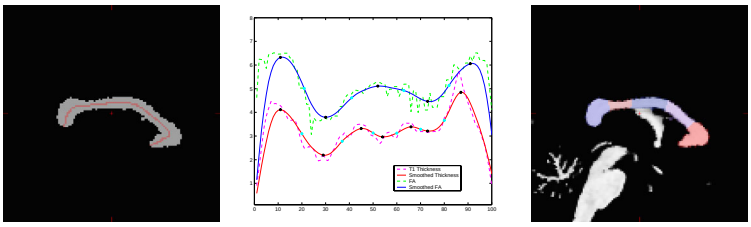

FIG. 1. Medial axis computation and parcellation result for one young healthy subject. **a:** Medial axis. **b:** Comparison of thickness and FA measurements along the medial axis with peaks and valleys (marked in black) identified on the smoothed plots. FA plot is scaled up by a factor of 8 for the purpose of demonstration. The middle points (marked in magenta) between adjacent peaks and valleys are used for parcellation. **c:** Parcellation using the middle points found in **b.**

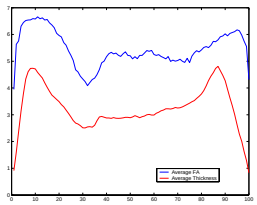

FIG. 2. Comparison of the average thickness and average FA (scaled up by a factor of 8) in 100 segments along the medial axis of corpus callosum computed for 28 young healthy subjects.

DISSCUSSION

In this work we introduced an automated algorithm for robustly extracting the medial axis and local information along the medial axis of corpus callosum. This provides us a convenient tool for studying and comparing corpus callosa among different subjects using various imaging modalities at corresponding points on the medial axis. We have examined and compared the thickness and FA variation among young healthy participants based on T1-weighted MRI and FA map respectively. A preliminary subdivision scheme has been designed to parcellate corpus callosa in the T1-weighted MR image based on the landmarks found on corresponding FA maps. Future work will focus on finding robust characteristic landmarks for further classification and partitioning of the callosum based on thickness measurement and other MR parameters. Such methods will be essential for mapping age and disease related alterations of the corpus callosum.

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