Application of the Diffusion Standard Deviation Map for Detection of White Matter Reorganization after Stroke

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Introduction:

Neurorestorative treatment of stroke promotes white matter remodeling and functional recovery [1]. MRI has shown promise in monitoring white matter recovery [2]. Fractional Anisotropy (FA) maps derived from diffusion tensor imaging (DTI) can be used for distinguishing isotropic and anisotropic brain tissue during stroke recovery [2]. DTI anisotropy maps are based on the assumption that diffusion in nerve tissue follows a Gaussian model. This assumption is not always true and these methods fail to identify anisotropic regions in voxels encompassing areas with multiple orientation fibers [3]. In such cases, anisotropy maps will show low image intensities in these areas. We previously reported a new anisotropy map based on calculating the standard deviation (SD) of diffusion, termed the SD map [4]. In that animal study we showed that a high SD value indicated high axonal density even in white matter regions with crossing fibers. In this study, we applied this method in the investigation of white matter recovery in stroke patients. We show the first demonstration of white matter reorganization with fiber crossing in stroke patients. Compared to FA, SD was superior in identifying white matter reorganization during stroke recovery.

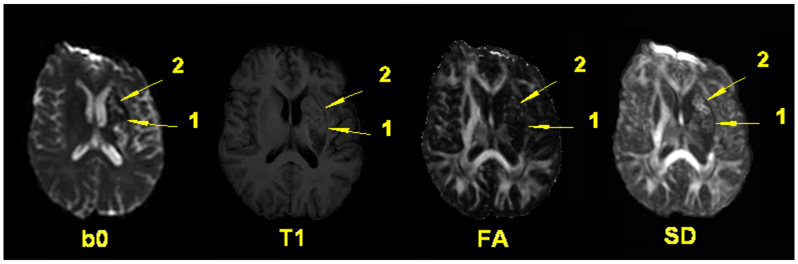

Figure 1. The b0, T1, FA and SD maps of the same slice of the brain acquired from a stroke patient. The arrows on these maps show two locations within the ischemic area which appear as normal tissue. The SD map shows white matter reorganization in these regions but FA map fails to identify them.

Materials and Methods

MR q-ball measurements were performed using a GE 3.0-T whole-body magnet using dual spin echo diffusion-weighted 2D echo-planar imaging with FOV 24 cm, 96 X 96 imaging matrix, 2.6 mm slice thickness, 29 slices, TR = 8s, TE 94ms, 55 diffusion gradients directions, b = 1500 s/mm2, and six baseline b = 0 images for each slice. The total acquisition time was approximately 8 min. The images were acquired from a stroke patient, 41 days after stroke onset. The SD map is created based on calculating the deviation of diffusivity from a sphere for each voxel in the image. For this calculation all 55 measurements are used. If the voxel falls in an ideal isotropic medium, diffusion will also be isotropic in all directions. In such a case, the diffusion vectors will form a sphere and the standard deviation of the length of these vectors will be zero. If for any reason, the envelope of these vectors forms any other shape, the standard deviation will have a non-zero value. Therefore, if diffusion is constrained by tubular structures, the SD of the length of the vectors will possess a non-zero value based on the complexity of the structure.

Results

Figure 1 shows b0, T1, FA, and SD images in the same location of the brain from a stroke patient. This patient presented with a left striatocapsular stroke 41 days prior to MRI evaluation and had good functional recovery. His initial NIH Stroke Score NIHSS) was 20. Follow-up NIHSS at 41 days was 14 with modified Rankin Scale (mRS) 3**.** As can be seen in these images, there are normally appearing tissues within the ischemic region in the b0 and T1 images; however, the FA map shows low intensity in the same regions which can be erroneously interpreted to mean lack of white matter. The FA map fails to detect white matter with crossing fibers confirmed by the q-ball Orientation Distribution Function (ODF) map in Fig 2B. In contrast, the SD map shows a significant increase in intensity in the same regions, consistent with our previous validation study [4]. Compared to FA, the SD map shows significant correlation of white matter reorganization in other regions. Figure 2 shows the result of this processing scheme for a rectangular area overlayed on the SD map. The background of the ODF is the SD map of the same region. The voxels from the two locations marked in Figure 1 show the existence of white matter reorganization with crossing fibers

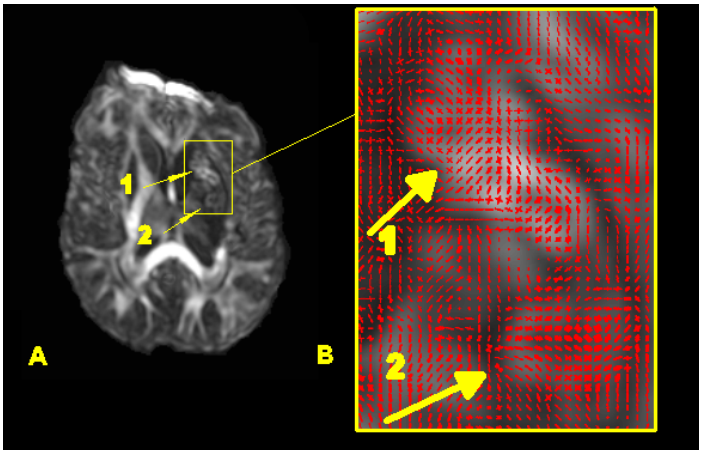

Figure 2. (A) SD map with a rectangular area selected and (B) q-ball ODF icons overlaid on the selected area of the SD map. The two arrows show the corresponding regions. As seen here, the icons show the existence of crossing fibers in these areas. The FA map in Figure 1 fails to detect the fibers in these two areas.

Conclusion

These results show the ability of the SD map to identify white matter reorganization with fiber crossing during stroke recovery. The SD map is correlated with the FA map in regions where the axonal bundle is merged to a single direction; however, FA can lead to error if crossing fibers predominate and the SD map shows to be more reliable in identifying these regions. Characterization of white matter remodeling needs to be investigated further.

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References

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