An Optimised Diffusion MRI Technique To Study Neuron Microstructure

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INTRODUCTION

- Water diffusion anisotropy in neurons is an indirect measure of microstructural properties that can provide information about structural changes caused by injury or disease
- Fractional anisotropy (FA) is a diffusion MRI (dMRI) metric of anisotropy; however, it is sensitive to crossing neuron fibers, reducing its specificity to structural changes [1]
- Microscopic fractional anisotropy (μFA) is an alternative method to measure diffusion anisotropy without sensitivity to neuron fiber orientation. μFA imaging techniques can be classified into:
  1. Constrained fitting techniques that have been shown to *yield biased measurements* [2]
  2. The *computationally-intensive* diffusional variance decomposition (DIVIDE) technique [3]
  3. Double diffusion encoding (DDE) techniques that utilize asymmetric pulse sequences that may be *prone to concomitant field artefacts* [4]

AIM

- The objective of this study was to develop a clinically-viable μFA imaging protocol with <5 min scan time

METHODS

- We developed a technique to estimate μFA based on the difference between linear (unidirectional) and isotropic (omnidirectional) diffusion-encoded MRI images [5]
- Four volunteers were recruited and full-brain images were acquired at b-values between 0 and 3000 s/mm^2 with increments of 500 s/mm^2; 6 linear and 6 isotropic images were acquired at each b-value
- The SNR of μFA was derived using first principles and signal from white matter regions and was used to determine the optimal ratio of isotropic to linear scans and the optimal b-value to maximize image quality
- A protocol was developed using the optimal parameters and the same four volunteers were imaged in a preliminary trial; the total scan time was 4 minutes per full-brain acquisition at a 2x2x2 mm^3 resolution

RESULTS

- SNR analysis of mean signal in white matter regions (*Fig.1.*) revealed that the optimal b-value is 2000 s/mm2 and that the optimal ratio of isotropic to linear scans was a function of v-value (~1.6 at b=2000 s/mm^2)

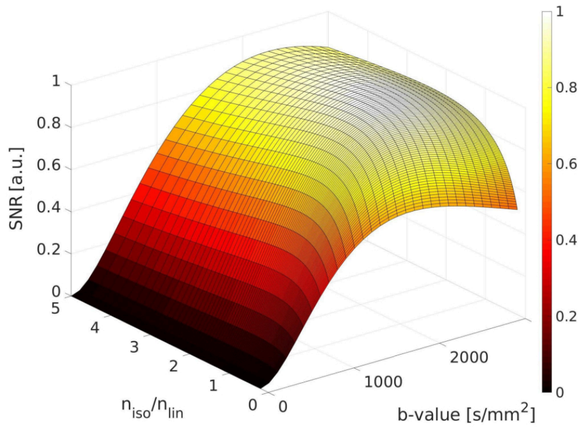

Figure 1. SNR of μFA as a function of b-value and the ratio of isotropic to linear scans (n_{iso}/n_{lin}). The highest SNR occurs when b-value is approximately 2000 s/mm2 and when n_{iso}/n_{lin} = 1.6

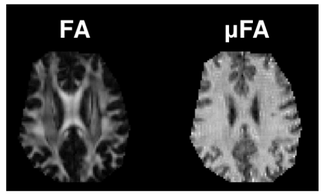

Figure 2. Sample FA and μFA images from one of the volunteers. Note that μFA is relatively homogeneous in white matter brain regions, whereas FA varies due to crossing fiber effects

- White matter regions with known crossing neuron fibers do not appear hypointense as they do in FA images (*Fig. 2.*).
- Images acquired using an optimised protocol (*Fig.3.*) showed high contrast between regions with different water diffusion anisotropy properties and high SNR

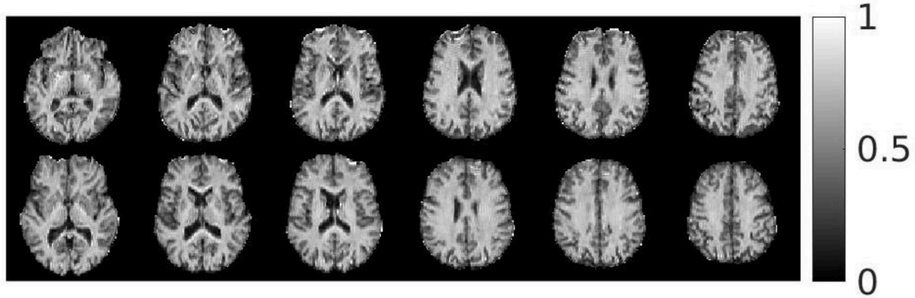

Figure 3. Sample μFA images from the volunteers acquired using an optimised protocol

CONCLUSIONS

- SNR analysis revealed the optimal parameters, which can be used to maximize image quality without increasing scan time; note that both the b-value and the ratio of isotropic to linear scans can be tuned prior to imaging
- Images acquired using the optimised protocol had high quality and depicted strong contrast between brain regions with highly anisotropic water diffusion (white matter), moderately anisotropic regions (grey matter), and isotropic regions (cerebrospinal fluid)
- The next step will be to compare our μFA protocol with either DDE or DIVIDE to determine if measurements are biased
- In the future, we will use the optimised protocol to study neuron microstructure in patients with neurodegenerative diseases such as multiple sclerosis

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