Towards a Diffusion Standard Ruler: Rigid Diffusion Phantom

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INTRODUCTION

Diffusion tensor imaging (DTI) is becoming a popular imaging modality for various types of clinical researches. However, it is often not straightforward to setup an imaging protocol because of an unusually high number of image parameters and its sensitivity to many sources of instrumental variability such as eddy current and SNR. These are especially problematic for multi-center studies, in which scanner calibration is of central issue. Development of anisotropy phantoms is, therefore, an important research endeavor [1]. In the past, biological samples (celery, spinal cord, and muscle tissue) and filament-based phantoms have been postulated, but low anisotropy, difficulty in quality control and maintenance, low stability, and complexity of mass production have been unsolved issues. In this paper, we examined the feasibility of using water-filled arrays of channeled silicon plates to construct a DTI phantom. Various channel sizes were tested to optimize the diffusion and anisotropy properties. We succeeded in producing a phantom with high anisotropy (FA = 0.8).

METHODS

Phantom construction: Six phantoms were constructed using arrays of channeled silicon plates (Fig. 1(a) and Fig. 2(a) and (b)) which were integrated by a layer of equal depth of channels. The channel was constructed on a silicon plate (thickness; 380μm) by chemical etching (SF_6-C_4F_8 gas, ICP-RIE system, Alcatel, Paris, France). Silicon plates were manufactured and supplied by LIGHTM Ltd. [2] (Iwate, Japan). Each array consists of 20 plates and 500 external surface channels. The plates were integrated and also were pressed each other by polyvinylchloride based rubber (Fig.1(c)). The laminate structure of this phantom allows for simple and precise assemblage of macro arrays formed by stacking individual plates into a larger laminate structure. Six phantoms have different channel depth; 50, 100, 150, 200, 250, and 300μm, respectively. The channel width and between the distance of channel was designed to 10μm. Dimensions of the arrays were measured using a JEOL low vacuum scanning electron microscope (Tokyo, Japan). Our phantoms meant for testing on a conventional clinical scanner, was assembled from a water-filled cylindrical 500 ml polyethylene container (Fig. 2(c)). The individual phantoms were immovable by poly vinyl chloride based rubber support.

DWI Acquisition: Experiments were performed on six phantoms using a MAGNETOM, Sonata, 1.5 Tesla MRI scanner (SIEMENS, Erlangen, Germany) with four channel head coil. As the imaging sequence spin-echo EPI was optimized. Parameters are selected: TE=70ms, TR=3000ms, voxel size of 1.0mm×1.0mm×3.3mm, Flip Angle=90deg, average=32, acquisition matrix of 192×192, iPAT(GRAP), and motion probe gradient in six directions(b=0,400 s/mm^2).

Data processing: The fractional anisotropy (FA) and mean apparent diffusion coefficient (ADC) were calculated by DitStudio [3]. Each value was obtained by average of five times measurements of phantom. Averaged FA and ADC values were obtained

RESULTS AND DISCUSSION

Figure 3 shows the results of DTI acquisition of the channel depth 300μm phantom (FA and eigen values maps). These figures clearly show differences in the three eigenvalues. The horizontal diffusivity (λ3, 10 μm) was extremely small (0.02 x 10^{-3} mm^3/s), while the front to rear direction (λ3, 300μm) and vertical directions (λ1, 50mm) have much higher diffusivity (1.31 and 3.25 x 10^{-3} mm^3/s, respectively). Interestingly, the λ1 is about 50% higher than free diffusion constant in the surrounding media (2.25 x 10^{-3} mm^3/s).

Figure 4 and Figure 5 show the results of FA and ADC (mm^2/s) values as a function of the channel depth (front-rear direction). FA values remain high (0.6-0.8) for the range of 50-200 μm and decrease for 250 μm and deeper. On the other hand, ADC values increase steadily as the channel depth increases. These results clearly confirm that FA and ADC can be controlled by changing the depth. The high variability in FA for the 100-150 μm depth could be related to the assembling of the phantom.

CONCLUSION

This study demonstrates the feasibility of using water-filled arrays of channeled silicon plates to construct a DTI phantom. The channel depth of 150-200μm seems optimum for FA and ADC values. We are currently investigating the source of the variability found in the 100 and 150μm plates.The high axial diffusivity (λ1) is an unexpected result, which needs further investigation.

ACKNOWLWDGEMENT

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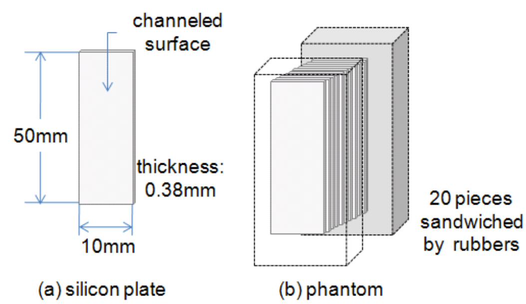
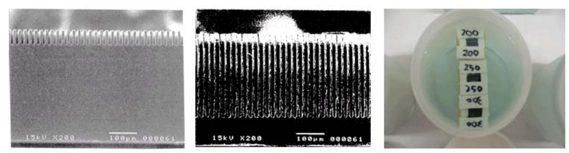


Figure 1 Size of the silicon plate and construction of phantom



(a) channel depth 50μm (b) channel depth 300μm (c) phantom

Figure 2 Channel shape and phantom setting

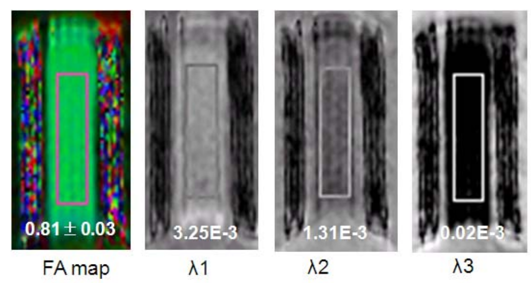


Figure 3 Results of DWI analysis (channel depth; 300μm)

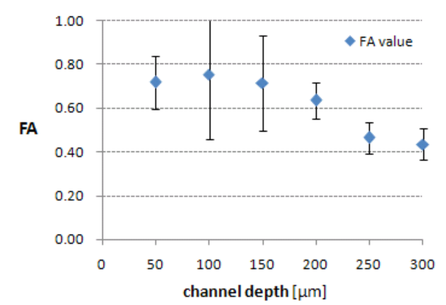


Figure 4 Effect of channel depth to FA value

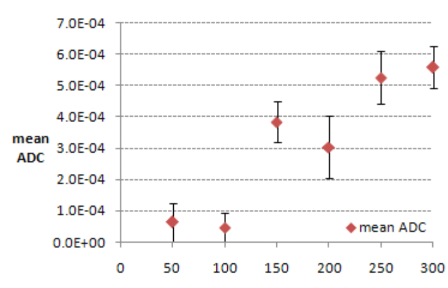


Figure 5 Effect of channel depth to ADC value