Piecewise diffusion tensor estimation for fetal imaging application

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Introduction: Recent advances in imaging, particularly diffusion tensor imaging (DTI) are now enabling us to understand brain maturation and the development of myelin both in neonatal and pediatric populations [1, 2]. However, the same has not been extensively used for in-utero applications, largely owing to fetal motion and maternal breathing. Most of the current approaches are limited to research settings and are dependent on obtaining quantifiable data in the quiescent phase of the fetus [3]. However these methods would be a challenge to apply in a clinical setting on a regular basis. As an alternative, we propose a modified acquisition scheme of the conventional DTI sequence available on any commercial scanner. In this feasibility study we employ a piece wise approach of acquiring the volume of interest i.e. – multiple smaller volumes to encompass the whole volume, using a short TR single shot EPI. This approach enables a DTI volume set (12-directions) to be acquired within 10 secs, which greatly reduces the possibility of data corruption due to fetal motion. As a first step towards this, we applied this approach in adults and evaluated the SNR penalty in the reconstructed FA maps.

Purpose: The purpose of this study was to evaluate the feasibility of performing piecewise DTI with small volume acquisitions and to recreate the final volume following the estimation of the tensors in the individual volumes.

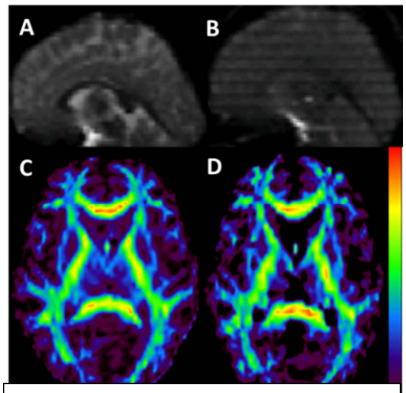

Fig 1: Reformatted Bo image of (A) conventional acquisition (B) Piecewise acquisition. (C), (D) Corresponding FA maps after normalization to the standard space.

Material and Methods: Three healthy adult volunteers were imaged in a Siemens 3.0T Verio system. Whole brain DTI data was acquired using the conventional protocol of multi-slice single shot EPI, with the following parameters; TE – 78 ms: TR – 11400 ms: Resolution- 3x3x3 mm^3; b-value- 1000 s/mm^2 ; volume acquisition – 3 min 4 sec; directions - 12. Piecewise DTI data was acquired using the same sequence using a shorter TR of 600ms. Each piecewise DTI acquisition contained 3 consecutive slices and a total of 9 such data sets so that whole brain coverage is achieved that is similar to the conventional DTI acquisition. Each individual piecewise volume took 10 sec to acquire. The FA (fractional anisotropy) of the whole volume and the individual piecewise DTI volumes were first generated using DTI-studio. Following this they were concatenated and registered using affine registration to a standard space FA template. Based on predefined ROI on the standard space, the FA values from both the acquisitions were noted along the major white matter tracks namely the (a) CC (Corpus callosum: Genu, body splenium) (b) EC (External Capsule: Right, Left) (c) IC (Internal Capsule: Anterior limb, Posterior limb, Retrolenticular limb on both the right and the left). The choice of major white matter bundles were driven by the fact that these develop early in the gestation.

Results: In all the adult volunteers the FA maps from the two volumes were similar. The short TR piecewise acquisitions had low SNR. However they did not affect the estimated FA values. Figure 2 shows the percentage error in the FA values for the three volunteers, plotted for different anatomical regions. The piecewise acquisition scheme generally underestimated the FA in the corpus callosum but was over estimated in the in the external capsule. The FA underestimation was a maximum of 4% in the retrolenticular portion of the right internal capsule, and overestimation was a maximum of 6% in the right external capsule. The median error among the 3 major tracks (11 sub regions) across all three subjects was -0.46% (IQR: -2.1 – 1.2%).

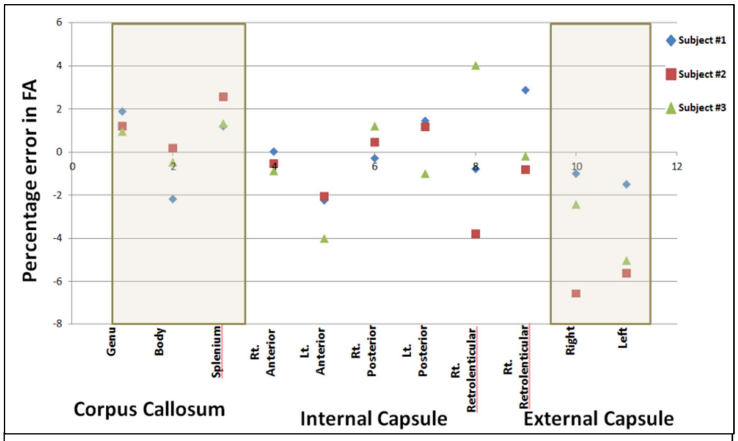

Fig 2: Plot of the error in the FA between the two acquisitions for different tracts

Discussion and Conclusions: The very nature of the diffusion sequences makes it very sensitive to motion. This study proposes a simple piecewise approach to DTI data acquisition that could potentially minimize the probability of data corruption from bulk motion artifacts. The approach could be beneficial in fetal imaging where unpredictable fetal motions often severely affect DTI acquisitions [3]. As seen on the sagittal reformat of the piecewise acquisition, the banding like phenomenon is due to the use of low TR and the result of saturation in the signal. Since this phenomenon was consistent across all the diffusion directions the FA values were not influenced. It may also find application in DTI acquisitions in abdominal organs like kidney. To evaluate its utility in fetal imaging, data was collected at the same system on a single third trimester fetus at different TRs. A 6 element flexible abdominal coil was used. Preliminary analysis of the data shows that initial SNR in fetal DTI acquisitions is very low even with a TR of 6000ms and further reduction of TR would adversely affect the images. This aspect stems primarily from the fact that SNR in fetal MR imaging is low to start with due to large separation between the coil and the fetal head. This problem however is surmountable if coils with higher elements and larger spatial coverage are used. Such coil are now available with the newer MRI systems which also support parallel transmit capabilities.

References: [1] Hermoye, Laurent, et al. Neuroimage 29.2 (2006): 493-504 [2] Huang, Hao, et al. Neuroimage 33.1 (2006): 27-38 [3] Kasprian, Gregor, et al. Neuroimage 43.2 (2008): 213-224.