In utero fetal brain diffusion weighted imaging

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Introduction

Fetal MR brain imaging is proving to be a powerful modality with which to evaluate the developing fetal brain. Advanced imaging strategies, such as diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI) have recently been applied to the human fetus [1,2]. The major difficulty of performing DWI of the fetal brain in utero is the presence of motion, which is especially marked during the second and early third trimester when most clinical fetal MRI is performed. Maternal breathing can also contribute to motion degradation since image acquisition requires the mother to hold her breath. While breath hold single shot acquisitions have been predominantly used for fetal DWI, this technique alone cannot provide the robustness needed against unpredictable fetal motion and motion due to maternal breathing. Therefore, the goal of this study was to devise a DWI technique, capable of obtaining trace ADC maps (D_{av}; averaged ADC), with reduced susceptibility to motion, that could be used to image the fetal brain in the clinical setting. In addition, the possibility of extending the study to acquire DTI was also investigated.

Methods

In our proposed method, the conventional multi-slice single-shot EPI fetal DWI sequence is used but with a shortened TR. By reducing the TR, the scan time can be reduced to a reasonable level where breath holding can be easily performed by the mother. The adverse effect of reducing the TR would be to introduce T_1 weighting in the raw images due to incomplete longitudinal magnetization recovery. By acquiring an additional b=0 image, this can be compensated. Therefore, the timing of acquiring the DWI data set would be b=0 → bx → by → bz → b=0, where each acquisition is separated by the short TR. Any dummy acquisitions prior to the first b=0 image are eliminated to reduce the scan time and enforce T_1 weighting starting with the second image. The signal intensity of each of the acquired images can then be modeled as

$$I(x,y) \rightarrow I(x,y)\cdot w_i(x,y)\cdot(1-e^{-TR/T1(x,y)}) \rightarrow \text{''} \rightarrow \text{''} \rightarrow I(x,y)\cdot(1-e^{-TR/T1(x,y)}).$$

With a 90° excitation assumption, all images after the initial b=0 image are weighted by $(1-e^{-TR/T1(x,y)})$ while the DW images are additionally weighted by $w_i(x,y)$ where i=x,y,or z depending on the particular diffusion direction. From the first and final b=0 images, $T_1(x,y)$ can be calculated which is used to compensate in the intermediate DW images.

Fourteen fetuses that were 22 weeks gestation or older were enrolled in this study (average: 26 ± 4 weeks). No sedating agents were administered. Scans were performed on a 1.5 Tesla GE MR scanner using a torso phased array coil. DWI was acquired with two different protocols. The first was considered a default protocol with relatively long TR: 18 sec 3-dir DWI with breath-hold, TR/TE: 4500/80ms, 8-10 slices, 5mm thickness, 2mm skip, b=600 sec/mm^2. A second DWI data set was collected using our proposed short TR protocol: 13 sec 3-dir DWI with breath-hold, TR/TE: 2500/80ms, 8-10 slices, 5mm thickness, 2mm skip, b=600 sec/mm^2. Images were reconstructed with the algorithm mentioned above to compensate for T_1 effects.

We also extended the protocol to study the feasibility of performing DTI. For this, the sequence was further modified by using a 2.2 sec TR with 6 diffusion directions. The b=0 images were obtained at the 1st and 5th TR, while the 6 diffusion directions were acquired during the 2nd, 3rd, 4th, 6th, 7th, and 8th TR acquisition. This resulted in an 18 sec total scan time. Tensor analysis was performed after processing with the proposed algorithm.

Results

In Fig. 1, in vivo fetal ADC maps acquired from the default protocol and our proposed method are shown. Note that the default protocol was acquired 18 seconds and the proposed protocol was acquired in 13 seconds. A linear regression of the ADC values obtained from the ROIs for these two protocols is plotted on the Figure. The squared correlation coefficient was $R^2 = 0.8619$. The relative SNR resulting from shortened TR for TR=4.5, 2.5, 2.2 was 1, 0.86, and 0.80, respectively. Fig. 2 shows results from the proposed DTI experiment. Various DTI related measurements obtained from a 30 week old fetus with suspected mild ventriculomegaly are given. Slight anisotropy can be identified in the genu and splenium of the corpus callosum.

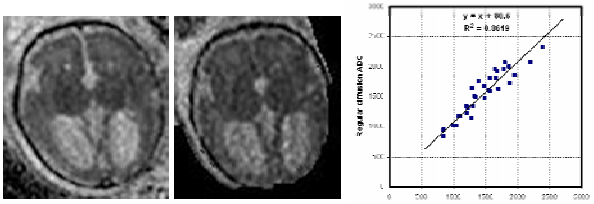

Figure 1: The correlation of the ADC values from the two protocols. ROIs were selected from the two T_2 weighted images and the corresponding ADC values were compared.

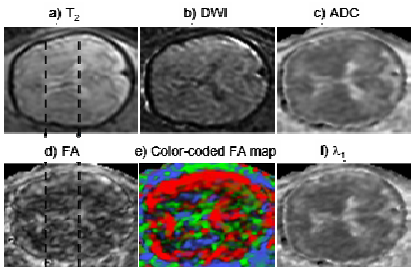

Figure 2: DTI of the fetal brain in vivo

Conclusion

We have developed a clinically feasible DWI protocol for the fetal brain using single shot EPI sequence with short TR and multiple b=0 images. These multiple b=0 images are used to compensate for T_1 weighting due to the shortened TR and also can potentially be used as a motion tracking scheme. The protocol can be useful for obtaining DTI and in imaging mothers who cannot endure a lengthier breath hold.

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References

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