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A NOVEL APPROACH TO ACCURATE 3D HIGH RESOLUTION AND HIGH SNR FETAL BRAIN IMAGING

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Introduction

▪ Fetal brain imaging by MRI is attracting increasing interest because it offers excellent contrast and anatomical detail.

▪ However, unpredictable fetal motion has led to widespread use of single shot techniques to freeze fetal motion. The conventional result is series of images which have an uncertain spatial relationship and cannot be reconstructed into a coherent 3D volume.

▪We present a novel methodology to reconstruct 3D images of fetal brains *in-utero* with sub-millimeter isotropic resolution and high SNR by performing dynamic MR scans and image registration .

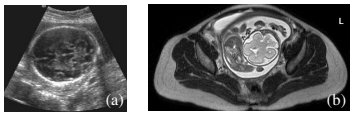

Fig. 1 (a) and (b) are a typical ultra-sound fetal image and a MR T2-W image. MRI can achieve much more anatomic details.

Method

▪Assumption

We assume that the fetal brain can be treated as a rigid body undergoing an unknown motion that is sampled sufficiently frequently to ensure all parts of the brain are represented on at least one acquired image.
This is achieved by performing dynamic scans.

▪ Dynamic Scan

▪A set of parallel contiguous slices is prescribed that covers a region expected to contain the fetal brain, and these slice planes are acquired in a repeated loop with every second complete set of slices offset by half a slice thickness (TH), so that in the absence of motion there would be dense sampling of space. Images are acquired using a 1.5 T scanner (Philips Intera) with a T2 weighted single-shot Fast Spin Echo sequence, image matrix of 352*262, field of view of 380 mm and TH 2.5-2.8 mm. The mother was free breathing during scanning and no sedation was used. Typical scanning time was 4minutes for 4 dynamic loops at a rate of 1 image/second.

▪We have also experimented with adding scans acquired in orthogonal planes to provide more isotropic data. This increased the number of images used so improving SNR as well (Data 2 in Fig. 3).

▪ Motion Correction and Reconstruction Using a Hierarchical Temporal Scale

▪A multi-time scale registration and combination approach was employed. The data was divided into temporally contiguous blocks each consisting of 60 slices that provided full coverage of the volume of space containing the fetal brain. The slice centre to centre separation within these blocks was 1.4mm. These slice blocks were treated as 3D volumes and registered together using rigid body transformations. One such block is chosen as the target for these registrations. If extreme fetal motion has occurred, the stack with least motion is used.

▪Once aligned, the data was combined to form an average data volume. The time scale was then reduced to create smaller packages and these were each registered to the average brain created from the rest of the data using the previously determined transformations. After registering all the sub-packages, the time scale was halved and the process repeated until each slice was treated in isolation.

▪ Registration and Reconstruction Method

▪We used a global optimization method with cross correlation as a cost function to perform the stack-to-volume image registration.

▪The individual 2D slices were finally combined together into a high resolution 3D volume taking account of the 3D point spread function- in plane this is a Sinc and through plane a model of the slice profile consisting of a Gaussian was used.

Results

•The 2D to 3D registration method was tested on adult and neonatal data for which a ground truth could be known and was found to be accurate to 0.2 mm (STD 0.2mm) in translation and 0.2 deg (STD 0.2 deg) in rotation. The use of intermediate volumes consisting of compounded slices as a target for the fetal registration proved to be both robust and allow accurate slice alignment. Two examples of dynamic scanning from fetuses with gestational age (GA) 33 week and 28 week are displayed in Fig.2 and Fig. 3.

•Although there is high in-plane (transverse) resolution the acquired data is inconsistent. After motion correction, the reconstructed 3D images (Fig. 2 and Fig. 3 (g-i)) show clearly improved consistency and higher SNR.

•At the final stage of image registration, Data 1 (Fig. 2) takes 240 slices from 4 transverse dynamic loops and Data2 (Fig. 3) takes 327 slices from 4 transverse, 2 coronal and 2 sagittal dynamic loops, with each slice individually registered to compose a 0.74mm isotropic 3D self-consistent volume that has improved SNR and high contrast between cortical grey and white matter.

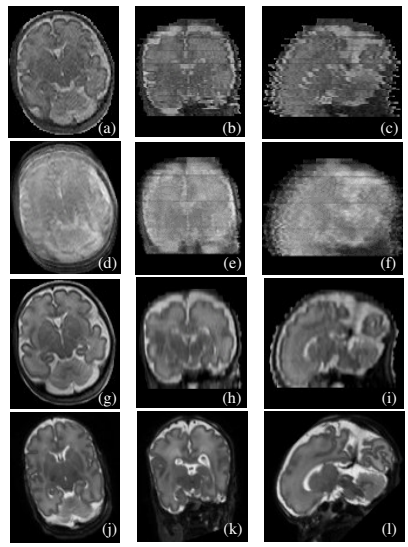

Fig. 2 Results for fetal Data 1 (33 GA). (a)-(c) are acquired fetal MR transverse data viewed in Transverse, Coronal and Sagittal planes with 1.08mm*1.45mm in-plane resolution and 2.8mm TH. (d)- (f) are the corresponding views for averaged images from the full dynamic scan before motion correction. (g)- (i) are the corresponding views reconstructed to 0.74mm isotropic resolution image after registration. (j)- (l) are the corresponding views of a preterm neonate born at 28 week and scanned at 34 week with 0.98*0.98mm in-plane resolution and 1 mm TH.

Details of cortical folding and small structures in the cerebella are well displayed in all three planes. SNR in the reconstructed image is 220% higher than individual acquired slices. Moreover, it is 120% better than that of the in-plane view of three orthogonal conventional clinical scans with much thicker slice thickness of 4mm.

•When compared to preterm born infants scanned at similar gestational age, we see strong correlations in brain anatomy including cortical folding, deep white matter tracts and cerebellar structures (Fig. 2 and Fig. 3 (j-l)) .

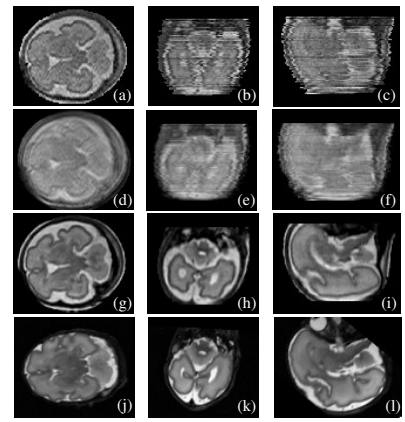

Fig. 3 Results for fetal Data 2 (28 GA). (a)-(c) are acquired fetal MR transverse data viewed in Transverse, Coronal and Sagittal planes with 1.08mm*1.45mm in-plane resolution and 2.5mm TH. (d)- (f) are the corresponding views for averaged images from the full dynamic scan before motion correction. (g)- (i) are the corresponding views reconstructed to 0.74mm isotropic resolution image after registration. (j)- (l) are the corresponding views of a preterm neonate born at 28 week and scanned at 30 week with 0.98*0.98mm in-plane resolution and 1 mm TH.

This method can also estimate motion of the fetal brain during the scan process as shown in Fig.4 for Data 1.

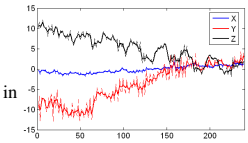

Fig. 4 Fetal motion history: X, Y and Z displacements in mm of a representative point in the fetal brain tracked every second.

Conclusion

This method creates a capability for studying fetal brains *in-utero* at high resolution. It could not only provide improved clinical information in three dimensions, but also permit many volumetric and morphometric studies that may improve understanding of the process of human brain development. This method could also be applied to other brain studies in both children and adults wherever motion is a problem. The compounding of multiple images increases SNR, so that improved resolution can be achieved both in plane and by using thinner slices than would otherwise be possible.

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