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 the widespread use of single shot techniques that can freeze fetal motion for individual slices. The conventional result is a time series of individual images which have uncertain spatial relationships and cannot be reconstructed into a coherent 3D volume representing the full fetal brain. To deal with this, we present a methodology to reconstruct 3D images of *in-utero* fetal brains with isotropic high resolution and high SNR by performing dynamic MR scans and image registration. A related approach has recently been presented, but with discretely acquired blocks of images in three orthogonal planes and a local registration method using normalized mutual information as its cost function [1].

Method Our method relies on the assumption 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. 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, 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 (acquired resolution 1.08mm×1.45 mm) and slice thickness 2.5-2.8 mm. The mother was free breathing during scanning and no sedation was used. Typical scanning time was 4minutes at a rate of 1 image/second. In addition test data was obtained from both neonatal brains and adult volunteers.

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. Neglecting fetal motions, 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.

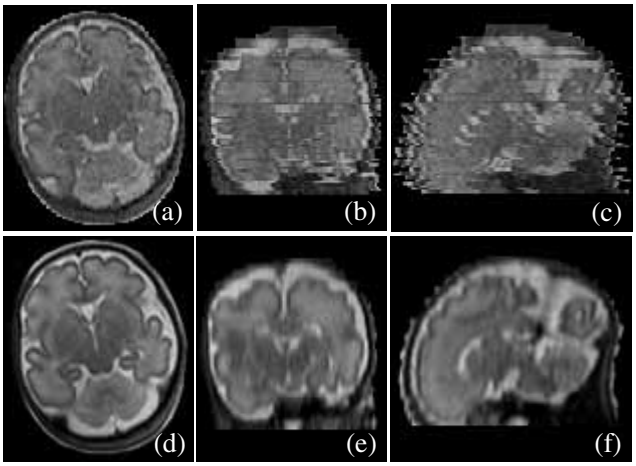

Fig. 1. (a), (b) and (c) are acquired fetal MR transverse data viewed in Transverse, Coronal and Sagittal planes with 1.08mm×1.45mm in plane resolution and 2.8mm slice. (d), (e) and (f) are the corresponding views of reconstructed 0.74mm isotropic high resolution image.

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.

We used a global optimization method [2] 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 0.5 mm in translation and 0.4 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. An example of a fetal dynamic scan is displayed in Fig.1. Although there is high in-plane (transverse) resolution the data is inconsistent. After motion correction, the reconstructed 3D images (Fig. 1 (d-f)) show clearly improved consistency and higher SNR. At the final stage of image registration, all 240 slices were individually registered and used to compose a 0.74mm isotropic 3D self-consistent, high resolution volume that has both improved SNR (287% higher than individual acquired slices) and high contrast between cortical grey matter and white matter. Details of cortical folding and small structures in the cerebella are well displayed in all three planes. This method can also estimate motion of the fetal brain during the scan process as shown in Fig.2.

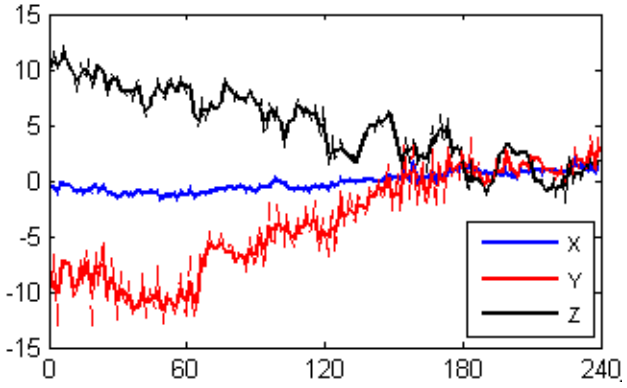

Fig. 2. Fetal motion history: X, Y and Z displacements in millimeter of a representative point in the fetal brain tracked every second.

Conclusion This novel 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.

Reference [1] Studholm et al, MICCAI 2005 p.548-555. [2] Jenkinson et al, Medical Image Analysis 2001, 5(2), 143-156.

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