MRI of the brain in moving subjects

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MRI of the very young is particularly vulnerable to subject motion. Neonates are generally examined either in natural sleep or with sedation, but they remain prone to motion and many examinations are terminated at the point where the subject gets too restless. The impact of motion can be even more severe for fetal imaging where both maternal and fetal movements are likely to be present. Sedation is used for fetal imaging at some sites, but this is not the dominant approach. Neonatal brain MRI has mostly relied on conventional multi-shot techniques, whereas fetal imaging almost exclusively relies on single shot techniques to freeze motion. Single shot fast spin echo (ssFSE) methods are the mainstay for anatomical imaging[1] although echo planar imaging (EPI) has also been used for both anatomical scanning[2], and more frequently for diffusion imaging[3]. In such studies maternal motion may be controlled by use of breath-hold techniques, but this places sever limits on imaging time. Cine sequences, for example using balanced steady state methods are being used to study fetal motion directly[4]. Particularly in the later stages of pregnancy, the fetus may be quite constrained by the physical containment provided by the womb and this has been taken advantage of in recent diffusion imaging studies for which multiple EPI slices must be combined to calculate diffusion properties[5] and even to allow tractography to be achieved[6].

For brain imaging, data compounding approaches have recently been demonstrated[78] in which images acquired using single shot methods are retrospectively aligned to correct for changes in brain position and the aligned slices are then combined to reconstruct high resolution 3-Dimensional (3D) images of the brain. We call this approach slice to volume reconstruction or SVR. The SVR method can operate with both maternal and fetal movement, and can also find application for neonatal imaging to make scanning more motion tolerant. By operating in the image domain, the method can be focused on fetal motion and can easily accommodate differential motion of mother and fetus. The alignment process converts from the scanner coordinates in which the acquired slices have a neat regular pattern containing inconsistent anatomy, to anatomical coordinates in which the anatomy is self consistent, but the slices are no longer regularly spaced or even parallel to one another. Irregular slice spacing could lead to missing data caused by gaps between slice positions, and this is avoided by imaging the region containing the anatomy of interest multiple times and compounding all the data into the final reconstruction (see Figure 1). A benefit of combining data from multiple slices is an increase in signal to noise ratio in the final reconstruction and this can be put to good use in allowing higher resolution imaging. To achieve isotropic resolution in 3D requires careful choice of slice thickness and in plane resolution[8]. The SVR method has now been extended to diffusion imaging[9] and shows promise for tractography studies.

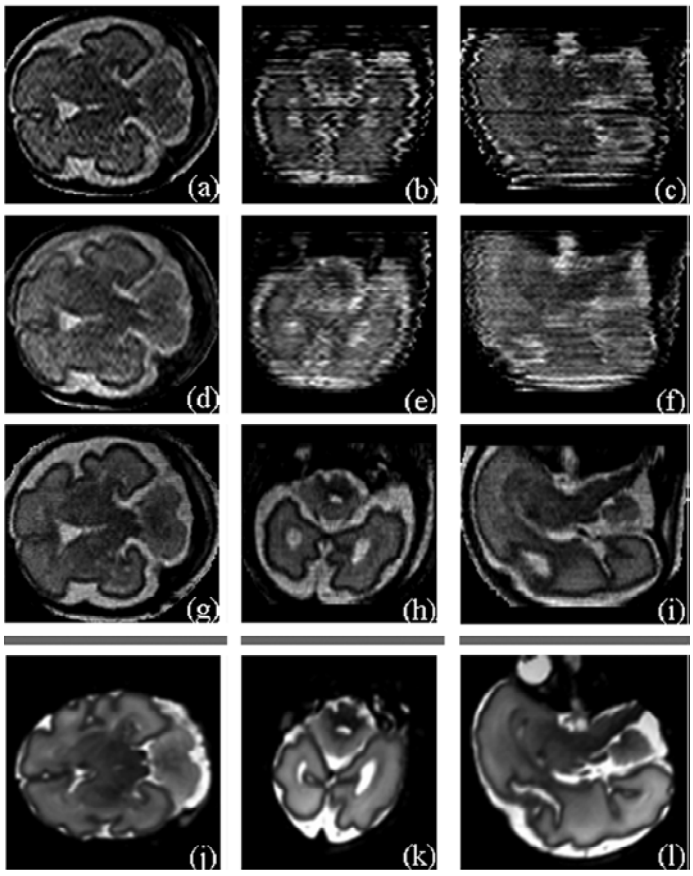

Figure 1: Results for a 28 week fetus imaged *in utero* using the SVR technique. (a)–(c) Images acquired ssFSE images acquired in a nominal transverse plane with 1.08 x 1.45 mm in-plane resolution and 2.5 mm slice thickness, viewed in transverse, coronal, and sagittal planes. (d)–(f) the corresponding views for averaged images from the full dynamic scan before motion correction. Images (g)–(i) are the corresponding views reconstructed to 0.74mm isotropic voxels after registering slices from three orthogonal orientations. For comparison, images (j)–(l) are the corresponding views of a preterm neonate born at 28 weeks and scanned at 30 weeks with 0.98_0.98 mm in-plane resolution and 1 mm slice thickness at 3T (see ref 8).

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