Brain MRI of moving subjects: Snapshot images with Volume Reconstruction (SVR) extended to multi-shot sequences and applied to neonates and adults

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Introduction Motion degrades Magnetic Resonance (MR) examinations and prevents acquisition of self-consistent and high quality volume images. A methodology, Snapshot MRI with Volume Reconstruction SVR has been developed for imaging moving subjects at high resolution and high SNR. The method combines registered 2D slices from sequential dynamic single-shot scans. The SVR approach requires that the anatomy in question is not changing shape or size and is moving at a rate that allows snapshot images to be acquired. After imaging the target volume repeatedly to guarantee sufficient sampling everywhere, a robust slice-to-volume registration method has been implemented that achieves alignment of each slice within 0.3mm in the examples tested. Multi-level scattered interpolation has been used to obtain high-fidelity reconstruction with RMS error that is less than the noise level in the images. Following successful application in fetal brain imaging [1-3], a general application of SVR can allow self consistent volume data to be obtained in other brain studies which would otherwise fail, and from more conventional multi-slice sequences even when the subject drifts in position during data acquisition. Likely applications include pediatric MR scanning (both neonates, who may move during natural sleep or sedation and young children) and those adult patients who have difficulty staying still.

Method Two sequence variations were set up on a 3.0 T Philips Achieva scanner (Best, The Netherlands) using a 8 channel SENSE head coil and SENSE factor 2 as follows: a) for severe motion cases a single shot Turbo Spin Echo (ssTSE) sequence with image matrix of 240×240, field of view of 240 mm (acquired resolution 1mm×1 mm), slice thickness 2 mm with -1mm gap (overlapping slices), TE 160 ms, and TR set as shortest resulting in an acquisition time of ~1s per slice. With 4 complete repeats, whole brain coverage takes 5-7 minutes. b) for almost stationary subjects a multislice TSE sequence was used as a T2 weighted scan or duel echo. The main parameters were similar to (a) with variations in TE according to age of subject and if a duel image or single contrast was prescribed. TSE factor 15 and 2-4 packages were used depending on the total number of slices. The total scanning time for 100 slices is 7.5 minutes.

The ssTSE data was processed as previously [1-3]. The multi-slice data was separated into the separately acquired packages and each package was treated as an independent set of samples of the same rigid body object. These packages of slices were then reconstructed together into a single volume using a scattered data interpolation algorithm based on multilevel b-spline interpolation [4] with control point spacing in the through slice direction set to equal the slice gap in a single package. This results in a mean brain volume image that can be used as a registration target for each package. Following rigid body alignment of packages with the target, a new reconstruction is produced by the same means and the process repeated to achieve convergence to self consistency.

In all cases final reconstruction uses control points spaced at half the acquired resolution both in plane and through slice as this has been found to provide an effective balance of resolution and signal to noise ratio [3].

Results This method has been tested on 4 neonatal subjects acquired with ssTSE sequence and 10 neonatal subjects with multi slice T2 sequence as well as adult data from the IXI cohort of normal volunteers (www.ixi.org.uk) with a duel echo sequence. All resulted in successful reconstructions with very low level of motion artifact. Examples of each sequence type from neonatal subjects imaged at term are shown in Fig 1 and Fig 2. By prescribing the slices as overlapped in their native planes, there is dense sampling even if the subject does not move. Then no registration is needed. However, if the subject does move as displayed in Fig. 1a-c, this method can correct motion for each 2D slice and then achieve 3D coherent imaging with 1mm reconstructed isotropic resolution and almost doubled SNR of the source images. The result (fig 1 d-f) compares well with the conventional multi-shot images acquired before the baby woke up (fig 1 g-i). Correction for the multi-slice variant also works well, making the data consistent as well as preserving close to the original high resolution as shown in Fig. 2(b). Convergence is achieved in 2-3 interactions. If there are slight motion artifacts in a single package, these get suppressed by the reconstruction process which mixes data from adjacent packages, leading to lower levels of artifact in the final images. Since the data is not quite regularly sampled in the slice direction after motion correction, there is a risk of slight under-sampling in this direction particularly in the multi-slice case. However, the precise sample point spacing is known from the registration process, so a map of actual sample density can be produced to reveal any locations of data sparseness. The hierarchical b-spline reconstruction used ensures the final reconstruction only presents at a resolution consistent with the local sampling density.

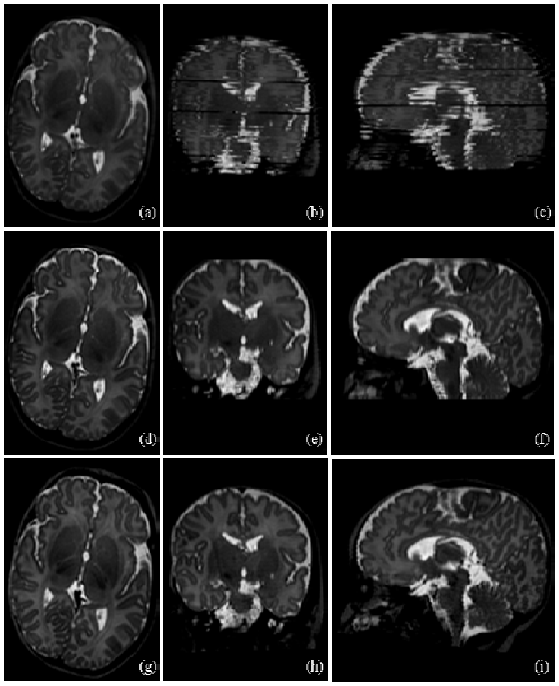

Fig.1 (a-c) is one loop of ssTSE dynamic scan when the neonate (43 w GA) was moving. (d-f) is the reconstruction with 4 loops of ssTSE dynamic scan that achieved both coherent imaging and improved SNR. (g-i) is acquired with TSE sequence when he was still. Although he was sedated, some motion artifacts is still visible.

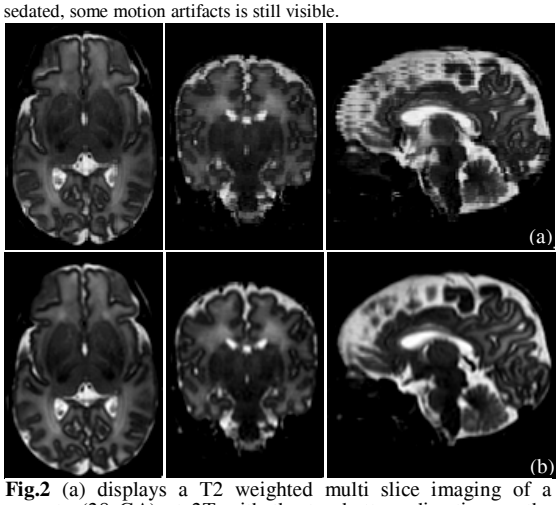

Fig.2 (a) displays a T2 weighted multi slice imaging of a neonate (38 GA) at 3T with the top-bottom direction as the slice select direction; obvious motion occurs while scanning. (b) is corresponding corrected image that show excellent improvement in consistence.

Conclusion The SVR concept allows robust 3D brain imaging in the face of both mild and severe subject motion. The imaging strategy can be chosen to suit the subject and since multi slice sequences are used, there is flexibility in contrast. Further work is under way to evaluate its radiological performance compared to conventional scanning.

Reference [1-3] Jiang et al, ISMRM 2006 p.731 ; ISBI 2006 p.662-665 ; IEEE-TMI, in press [4] Lee et al. IEEE TMI 1997 3(3) 228-243.

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