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Extending the Coverage of True Volume Scans by Continuous Movement of the Subject

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Introduction

The spatial coverage achieved in a single MR image acquisition is frequently constrained by hardware. The trend towards shorter magnets is increasingly limiting in this regard. Spatial coverage can be extended by obtaining multiple acquisitions with the subject repositioned between scans. This can result in discontinuities between image sets. We have explored the possibility of synthesising an extended continuous 3D data set by continuously moving the subject during the scan. The techniques described have some similarities with the SLINKY method in MOTSA angiography [1].

Concept

Consider a thick slab encoded using a standard 3D Fourier imaging scheme, with frequency encoding along x and primary phase encoding along y augmented by secondary phase encoding in the slab (slice) direction z. During the scan the subject is progressively moved in the z direction and when full primary and secondary phase encoding is complete the phase encoding sequence is repeated without pausing. (It may be necessary to oversample in the z direction to avoid aliasing.) By acquiring all secondary phase encodes sequentially for each increment of the primary phase encode direction, lines of full z encoded data are obtained with the position of the subject almost constant. This data can then be Fourier transformed (FT) in the frequency (k_x) and secondary phase encode (k_z) directions and realigned in the z direction before performing an FT in the primary phase encode direction k_y (Fig. 1). Alternatively a phase correction can be made to the k-space data to accommodate the z shifts prior to FT in both phase encode directions.

If the subject is translated exactly one slab thickness in the time taken to acquire all primary and secondary phase encodes maximum efficiency is achieved, with all spatial locations being fully Fourier encoded. After realignment each line of primary phase encoded data will be divided into two regions. Where the join occurs close to $k_y = 0$, discontinuities result in overt image artefacts (Fig. 1a). To reduce this problem a slower speed traverse may be employed resulting in some data redundancy, which can be used to average out discontinuities or to avoid transitions close to $k_y = 0$. Moving the subject half a slab width in each full encoding time ensures more equal treatment of all spatial points, e. g. by framewise post-processing and superposition of frames with weighting functions (Fig. 1b).

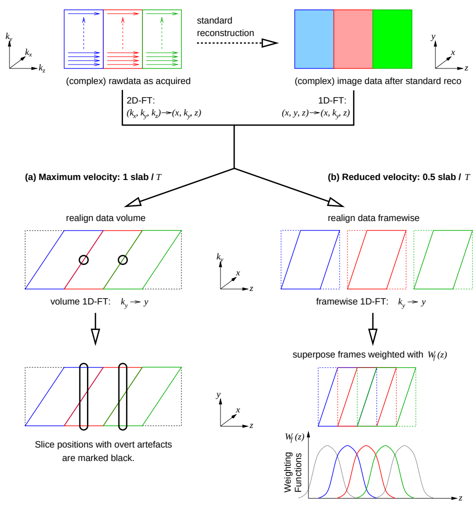

Figure 1: *Post-processing of image data. Either k-space rawdata or complex image data can be used for subsequent image reconstruction (top row). Column (a) shows data realignment at maximum velocity of the imaged subject, column (b) data realignment and superposition with weighting functions $W_f(z)$ at half velocity.*

Methods

This scheme was implemented on a 1.0 T neonatal MR system comprising an ultra short solenoid magnet (Oxford Magnet Technology, Oxford, England; usable imaging range in z direction 5 cm), and a Picker Vista console (Cleveland, Ohio) with patient position adjusted by a stepper motor under computer control. Experiments were performed on phantoms and *in vivo* using an RF spoiled gradient echo sequence ($T_R = 30 \ldots 50$ ms, $T_E = 4$ ms) with slab thickness $2 \ldots 4$ cm, a field of view of 19.2 cm and both primary and secondary phase encoding yielding 1.5 mm resolution. Oversampling of 25 % was employed in the secondary phase encode (slab) direction. All data was processed on a DEC alpha workstation using IDL (Research Systems, Boulder, Colorado).

Results

Results of the *in vivo* experiments are shown in Fig. 2. Without correction, slow subject movement resulted in blurred images with an inhomogeneous distribution of intensity (e. g. intensity loss in slice 5, Fig. 2a). After correction, image resolution was restored without artefacts in most slices. With no data overlap, image quality was clearly reduced in some images centered on the slice where the discontinuity in the primary phase encode data crossed the center of k-space (Fig. 2b). With 10 % data redundancy all images appeared artefact free, but reformatting into planes containing the z axis revealed small discontinuities in the data at isolated single slices. Use of the full overlap scheme eliminated this effect (Fig. 2c, d, e). The FOV in z direction in Fig. 2d and e is about 23 cm and thus almost five times the usable imaging range of our MR system.

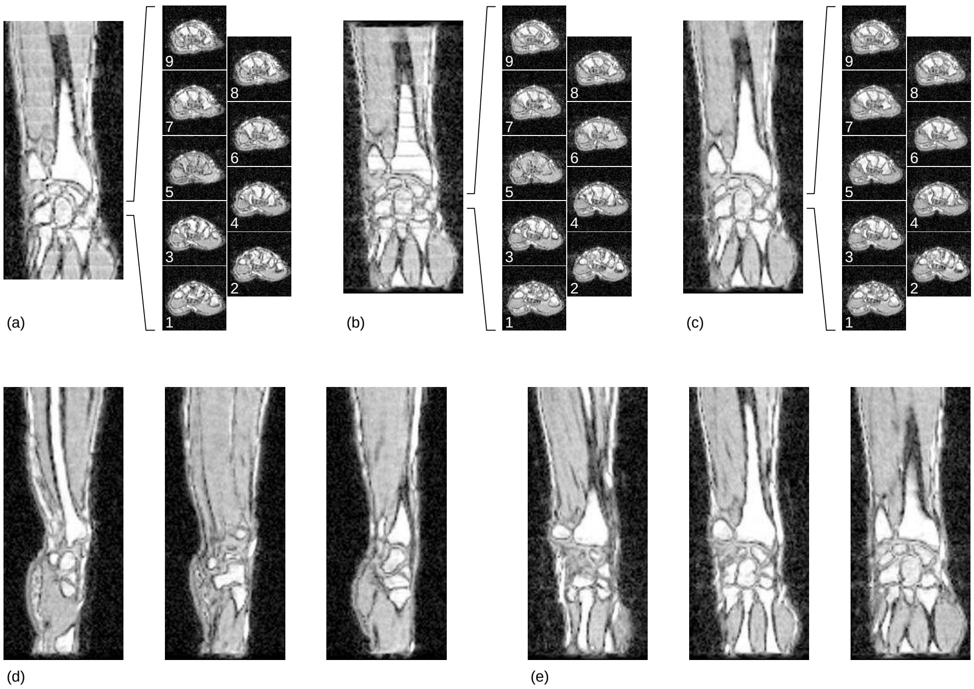

Figure 2: *Results of in vivo experiments with reduced velocity (0.5 slab/T): (a) without correction, (b) with correction but without data overlap as described in Fig. 1a, (c) with correction as described in Fig. 1b, (d) examples for long sagital section, (e) examples for long coronal section.*

Discussion

We have presented a technique for scanning over regions of space that are much longer than supported by limitations in magnet homogeneity. Some sampling overlap was required to produce consistent image quality in all slices. We believe that in our studies this was due to static B_0 and gradient inhomogeneities that destroyed the symmetry between the two edges of the excited slab. Inspection of the data in hybrid form, with only the primary phase encode direction left in the Fourier domain, strongly supported this conjecture. The potential advantage of the proposed method over conventional acquisition of multiple slabs with discrete subject movement is that it provides a controlled way of fusing the data together.

Reference

[1] Liu K, Rutt BK; *J. Magn. Reson. Imaging* **8**: 903–911 (1998)