Implementation of Single-Shot 3D Imaging Using the SEA Technique

M. P. McDougall[1], S. M. Wright[1]

[1]Electrical Engineering, Texas A&M University, College Station, TX, United States

INTRODUCTION

Parallel imaging techniques commonly enable acceleration times in the clinic up to a factor of two and three, and in the research arena, the acceleration factors routinely exceed this, particularly as the number of receivers available continues to increase [1]. The use of a 64-channel receiver and array coil enabled our group to introduce a completely parallel imaging method in which an image is formed in a single echo [2]. Using the Single Echo Acquisition (SEA) imaging method, slice selection and frequency encoding are performed using standard gradient methods, with the frequency encoding along the long axis of the array elements and slice selection parallel to the plane of the array. No phase encoding is required; instead, the echo from each coil is 1-D Fourier transformed and becomes one column of the final $N_c \times N_f$ (*number of coils x frequency encoding points*) image. By nature of the voxel-sized (in the phase encoding direction) coils required to implement the method, SEA is primarily a surface imaging method – an area of MRI that is most commonly associated with microscopy and 3D techniques in order to obtain not only in-plane but also thru-plane resolution of intricate structures such as the skin and tissue samples [3,4]. Because SEA acquires an image every echo, the method has the potential to facilitate the acquisition of an entire 3D data set in a single shot (a full 3D set acquired in a single TR cycle) using recalled echoes. We are currently in the process of upgrading our 64-channel data acquisition system to allow for collection of long echo trains, enabling the technique [5]. This paper discusses the methodology of implementing 3D-SEA, specifically regarding the need to compensate for the phase across the coils at varying heights from the array, and presents the results – a *64 x 128 x 32* image set acquired in only 32 acquisitions, one for each slice encoding step.

METHODS

SEA imaging requires the use of a "phase compensation gradient" to cancel the phase imparted across each voxel-sized coil [6]. With the optimal gradient strength applied (that which is equal and opposite the phase across the coils), the signal strength of the echo received from each is maximized to form a SEA image. The strength of the optimal compensation gradient, however, is dependent not only on the given coil geometry, but also on slice location. Figure 1 illustrates this phenomenon, presenting modeled signal strength vs. compensation strength (translated to k-space line for the given imaging parameters) for varying slice-offsets (slo) from the coil relevant to the implementation of 3D-SEA described below. Slices closer to the coil require a stronger compensation gradient (higher k-space line) to optimize than slices further from the coil, implying that the top and bottom of the excited slab will have different optimal strengths. Implementing 3D-SEA required the selection of a compromise compensation strength for the entire slab, with the logical optimum at the intersection point of the curves for the top slice and bottom slice (k=43 for parameters described below). A 3D phantom was constructed from a spiraled dish containing 1g/L $CuSO_4$ and coarse and fine thru-plane resolution structures (1-mm thick plates of decreasing size and ¼-mm thick lettering s-e-a-m-r-i). For 3D acquisition, a 4mm slab was excited within an 8mm FOV that was slice encoded with 32 steps. The excited slab extended from a slice offset 1mm off the coil to 5mm off the coil, with 16 slice encoding lines through it, resulting in effective thru-plane resolution of 0.25mm. The k-space line can be pre-selected at the console before true SEA imaging (acquiring only a single echo) is performed; however, for comparison and testing purposes, a fully encoded $64x128x32$ ($N_{pe} \times N_f \times N_s$) 3D data set was acquired from each coil as well as from the volume coil. The 3D-SEA data set *(1x128x32* from each coil*)* was then constructed using the echo acquired from each coil at k-space line =43, the optimal compromise compensation point predicted by the modeling.

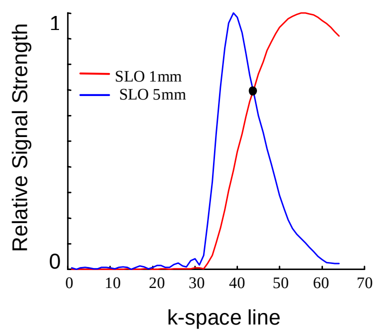

Fig. 1 Signal strength vs. gradient compensation strength (translated to k-space line) for imaging planes at the top and bottom of a 3D slab. Slice offset notation is relative to the coil. The optimal compromise compensation strength occurs at the intersection of the two curves (k=43).

RESULTS & DISCUSSION

Fully encoded and SEA encoded slices from the 3D data set ranging from 1mm off the coil to 5mm off the coil are presented in Fig. 2. The SEA images compare well at slices close to the array but deeper slices further from the array do not compare as favorably due to losses in SNR. All of the SEA images were formed using the k=43 phase compensation value. Using retrospective reconstruction, it can be seen that successful 3D-SEA data sets can be acquired with a single phase compensation pulse. Using recalled echoes, this will allow single shot 3D imaging.

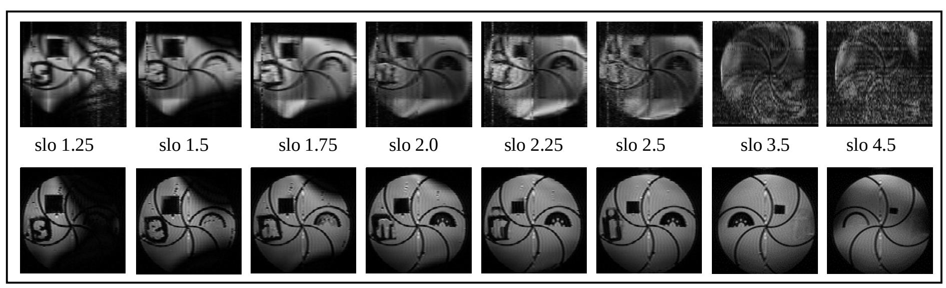

Fig. 2 Top row: Eight frames from 3D-SEA data set with ¼ mm thru-plane resolution acquired in only 32 echoes ($N_{pe} \times N_s$=*1x32)*. Successful SEA images were made throughout the slab from slice offsets (slo) 1mm off the coil to 5mm off the coil with a single compensation value corresponding to k-space line=43 in the fully encoded set. Bottom row: corresponding frames from fully encoded 3D data set from volume coil acquired in 2048 acquisitions ($N_{pe} \times N_s$=*64x32)*.

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ACKNOWLEDGMENTS

Support by the Army (DAMD17-97-2-7016), the NSF (BES-0101059), and the NIH (1R21EB003296-01A1) is gratefully acknowledged. This paper does not necessarily represent the position or policy of the sponsors.