MR Imaging at Sub-Millisecond Frame Rates

S. M. Wright[1,2], and M. P. McDougall[1,2]

[1]Electrical and Computer Engineering, Texas A&M University, College Station, TX, United States, [2]Biomedical Engineering, Texas A&M University, College Station, TX, United States

INTRODUCTION: MR Imaging speed has increased steadily since the inception of MRI. High field magnets and RF coil arrays, both providing increased SNR per unit time and high power gradients enable k-space to be traversed more and more rapidly. Parallel imaging is now a common technique to decrease image acquisition time. Several groups have demonstrated the use of RF encoding to completely eliminate at least one gradient spatial encoding phase, an idea suggested early on in the history of MRI [1]. In Single Echo Acquisition (SEA) imaging [2], an array of coils completely reduces the conventional phase encoding step to enable images in, appropriately, a single echo . Lin and Wald [3]. have demonstrated related approaches. Here we report the combination of SEA imaging with an EPI to enable imaging at sub-millisecond image spacing, achieving greater than 1000 frames per second for limited bursts, limited by the data acquisition hardware.

METHODS: A 64 element array of planar pair elements, described elsewhere was used in all experiments [4]. RF preamplifiers, built on Mini-circuits GALI-74 with appropriate protection circuitry were constructed in-house. Isolation between the planar pair elements is sufficient that isolating preamplifiers are not required. An in-house designed and built Two 32 channel data acquisition boards (ICS Ltd. ICS-625) were used for all data acquisition. These acquisition boards are paired with real-time DSP boards, but the data throughput was not found to be sufficient to support real-time DSP in this application. Hence, all data was acquired, stored and digitally demodulated afterwards. Sequences were played from a Varian Unity/Inova console paired with a 4.7T/40 cm magnet. Two pulse sequences were used in our initial tests. Initially a simple gradient echo EPI sequence was used, with echo spacing of 940 milliseconds. 64 echoes were acquired following a 90 degree excitation pulse. The acquisition system was triggered by the Inova console and continuously acquired for 64 milliseconds at 312,500 KHz per channel sampling rate on all 64 channels simultaneously. As described elsewhere, a 1D FFT of the demodulated data from each channel obtained a “strip” of the image directly over each of 64 elements. The 64 strips formed an entire image with each echo. A second pulse sequence was modified from a sequence developed for generating 2D RF pulses. This sequence uses a Cartesian EPI trajectory during the RF pulse generation, with a blipped phase encode, as shown in Figure 1a. RF excitation is only done during one direction of traversal of k-space. The sequence was modified by moving to a fixed point in Kx (x is along the short axis of the array elements), so that an image can be collected during the flyback period. Movement in k-space was done during the ramping of the Kz gradient, approximately 300 microseconds on our system, which has 26 cm shielded gradients installed, capable of something less than 5 G/cm.

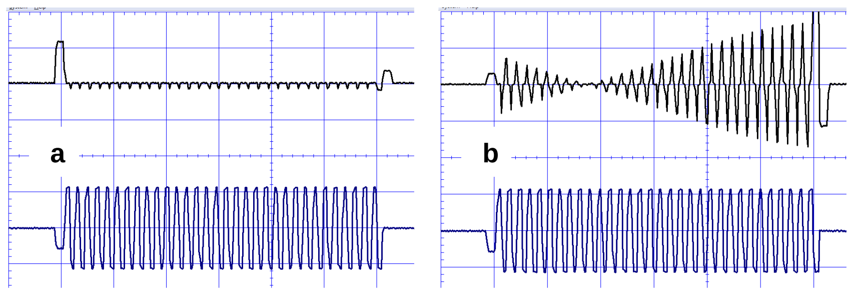

Figure 1. Transverse gradients used for a conventional EPI 2D RF pulse excitation (left) and the same sequence modified to enable acquisition of an image during the flyback of the EPI pulse sequence, in between RF pulses. The blipped gradient is not set to the same scale in the two figures. The sequence allows k-space to be traveled along the optimal line needed to compensate for the RF coil phase during each flyback, and then return to the proper position for the RF pulse generation.

RESULTS: Figure 1 shows three successive frames, 940 microseconds apart, from a 6 cm container of distilled water. Note that the array spans 14 cm, so that only about half of the coils were covered by the phantom, an inefficient use of the array motivated by other experiments. Figure 3 shows simple (approximately) rectangular 2D pulse excitation within the 6 cm cylindrical phantom excited with the conventional EPI excitation sequence (Figure 1, left) and the one generated with the 2D pulse excitation modified for SEA imaging (Fig. 1, right). There was no difference observed in the resultant pulses due to the modification. The resolution is poor due to gradient strength limitation and the relatively short time available to move to the SEA k-space position and back before and after the flyback period. Tuning this sequence so that signal is obtained at the end of the data acquisition period (when the transverse magnetization is formed) is still in progress.

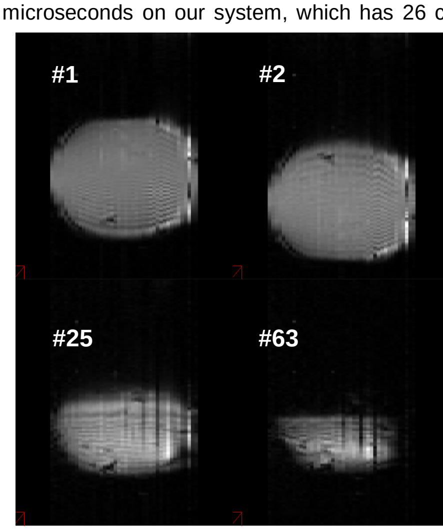

FIgure 2. (right) Four frames from a series of 64 images taken 940 microseconds apart. The four frames are #1, #2, #25 and #63. Even frames are reversed due to acquisition during the flyback period.

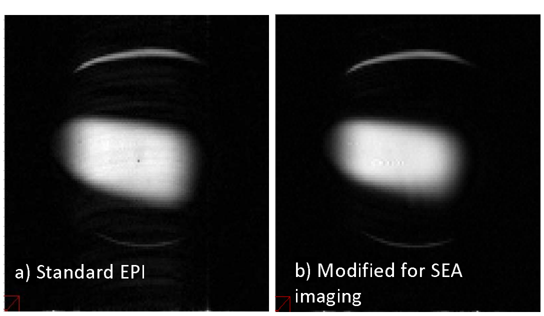

Figure 3. (left) Images of a circular phantom with an inner volume selected using a 2D RF pulse from standard blipped EPI approace (Fig 1a) and with a pulse sequence modified to enable SEA imaging during the flyback period (Fig 1b).

CONCLUSION: Combining EPI sequences with RF encoded imaging has the potential to provide MR imaging over the surface of an array sensor at extremely high frame rates, exceeding 1000 frames/second as demonstrated here. This could prove useful in applications such as monitoring fast flow, monitoring ablation or temperature changes in thermal surgery, destructive events, and even RF pulse optimization.

REFERENCES: [1] Hutchinson and Raff, *Magn Reson Med*, vol. 6, pp. 87-91, 1988. **[2]** Wright, McDougall, and Brown, *Proc. 2002 IEEE Eng. Med. and Biology 24th Annl. Conf.*, vol. 2, pp. 1181-1182, 2002. **[3]** Lin, Wald, Ahlfors, Hamalainen, Kwong, and Belliveau, *Magn Reson Med*, vol. 56, pp. p787-802, 2006. **[4]** McDougall and Wright, ," *Magn Reson Med*, vol. 54, pp. 386-92, 2005.

ACKNOWLEDGEMENT: The authors gratefully acknowledge support from the National Institutes of Health (1R21EB005695 and 1R01NS058576).