MR microscopy using uniplanar magnetic field gradients

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Introduction: Ultrafast MR microscopy is largely under developed as a research tool, due in part to limitations on gradient coil performance at very high spatial resolutions. Localized uniplanar gradient designs (1) offer a high gradient strength and fast slew rate and can be exploited to enable high spatiotemporal resolution MR microscopy with high SNR efficiency. In particular, the echo time for the gradient echo and spin echo, and the echo spacing for EPI sequences can be reduced. Here we describe initial experiences using the uniplanar microscopy gradient set to acquire EPI data at an isotropic spatial resolution of approximately 100 microns. Time-resolved 3D gradient echo imaging of dividing frog embryos is also demonstrated using the uniplanar gradient set.

Material and methods: The uniplanar magnetic field gradient set consists of a water-cooled x, y and z uniplanar gradient design (2). The current density for each axis was optimized by balancing current efficiency against uniformity within an elliptical volume of interest. For MR imaging, the prototype gradient set was positioned in a 7T horizontal bore magnet equipped with a Bruker Avance II console. The commercial gradient power supply was used to drive the gradient set. A 1.8-mm-ID solenoid RF coil was used to transmit and receive signal.

Both single-shot and multi-shot gradient echo EPI pulse sequences were tested. Total sequence durations of 7.5 ms and 15.78 ms were obtained respectively at an in-plane resolution of 120um x 120um for a 100um slice thickness. The matrix size was 64 x 32. An echo spacing of 422 us was achieved using a gradient ramp time of 50 us.

The uniplanar gradient set also has advantages for high spatial resolution imaging at shorter echo times. A 3D gradient echo images with 715 us echo time were acquired with 100 um isotropic resolution.

Cell division during embryonic development was chosen as a test application to demonstrate hardware performance, 3D gradient echo images (TE = 10 ms) of developing frog embryos were acquired every 9 minutes for four hours at a spatial resolution of ~50 microns.

Results and Discussion: The current that passed through the gradient set was monitored by an oscilloscope during the EPI sequences. Figure 1 shows a section of the EPI gradient waveform without current preemphasis. Figure 2 shows the acquired single-shot and multi-shot EPI images of a glass tube filled with Ringer's solution used for culturing frog embryos. As expected, geometric distortion due to B0 inhomogeniety is reduced for the four-shot image when compared to the single-shot image. Figure 3 shows a section of 3D gradient echo images (TE = 715 us) of a glass tube filled with Ringer's solution and a spherical frog oocyte. Figure 4 shows a section through the 3D images of dividing frog embryo. The cell nucleus and extracellular space show a brighter signal than cell cytoplasm. During the two cell stage (Fig 3b and c) the two cell nuclei and the extracellular space created during cell division are observable in the image.

In conclusion, the localized uniplanar gradient design allows high spatial and temporal images of millimeter-scale samples. Short echo time and short echo spacing time can be achieved. Initial results are encouraging and suggest that high spatiotemporal resolution imaging of millimeter scale organisms and tissue explants is entirely feasible with this hardware design.

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References: (1) Aksel, B.; Marinelli, L.; Collick, B. D.; Von Morze, C.; Bottomley, P. A.; Hardy, C. J. *Magn Reson Med* 2007, *58*, 134. (2) Demyanenko, A. V.; Tyszka J. M. Proc. Intl. Soc. Mag. Reson. Med. 16 (2008) 1175.

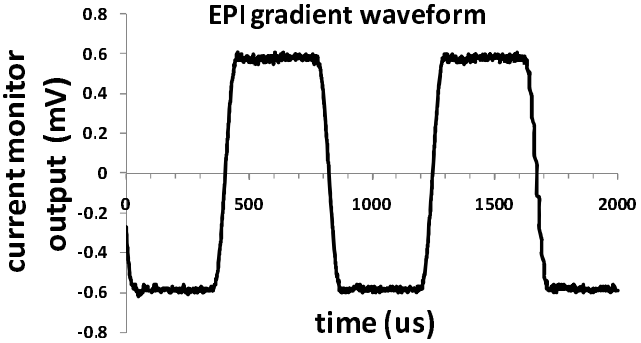

Figure 1 A section of EPI gradient waveform monitored by an oscilloscope. No preemphasis was applied. The ramp time was 50 us and the echo spacing is 422 us.

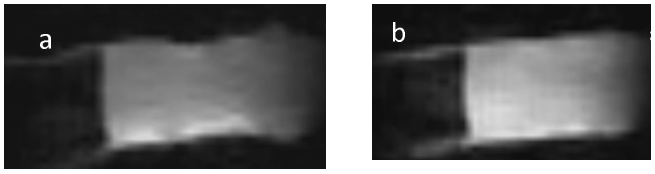

Fig. 2 Single shot EPI and four shot (b) EPI images of a tube with Ringer's solution at 7T.

Fig. 3 A slice of 3D gradient echo images (TE = 715 us) of a water tube with a spherical frog oocyte. The dark sphere is the oocyte and the dark object on the left is a plastic rod to restrain the oocyte.

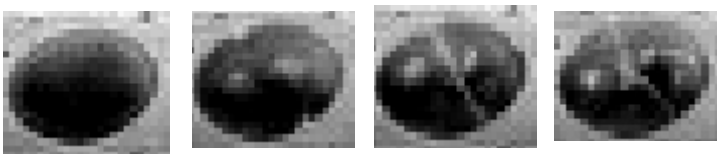

Figure 4 A slice of 3D gradient echo images of a dividing frog embryo at different time points. (a) single cell stage; (b) and (c) two cell stage and (d) four cell stage.