Brain imaging with a Dedicated Asymmetric Head-only Gradient Coil without Peripheral Nerve Stimulation at 500 T/m/s

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Target audience: Researchers and clinicians interested in high performance neuroimaging gradient coils.

Introduction: Asymmetric head-only gradient coils with their bore size optimized for neuroimaging [1-3] have been proposed as a solution to achieve high gradient efficiency and slew rate in brain MRI and overcome the low peripheral nerve stimulation (PNS) thresholds encountered with whole body gradient coils [4]. While previous head-only gradient coils demonstrated the feasibility of asymmetric designs that are torque-balanced [2], and with imaging field-of-view (FOV) shifted towards the coil edge [3], their performance was often limited by a relatively small FOV and challenging thermal management [5], as design compromises. We have recently constructed a head-only gradient coil [6] with a 42-cm inner diameter and a distortion-correctible FOV of 26 cm. These dimensions were chosen to operate in a dedicated, high-performance, and small-footprint 3T head scanner that is under development. We report here the first *in-vivo* human images obtained by this gradient coil. Our results demonstrate that PNS-free brain imaging at gradient performance of 80 mT/m and 500 T/m/s is possible with a dedicated gradient coil.

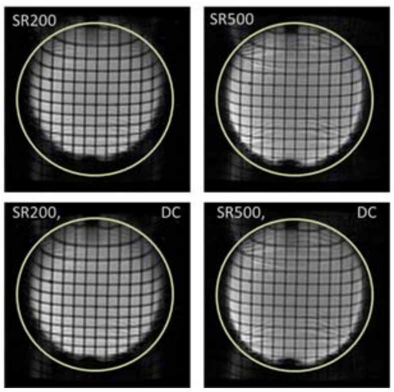

Figure 1. EPI at different SR in the presence of susceptibility induced δB_0. DC: distortion correction using non-linear registration. The circle shows the phantom's actual location from a reference (spin-echo) scan.

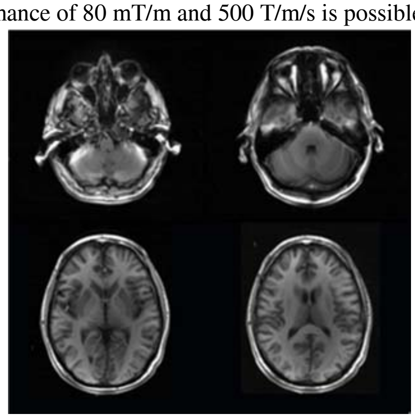

Figure 2. Axial brain images (without gradient nonlinearity correction) obtained with the asymmetric head-only gradient coil at 500 T/m/s slew rate and 80 mT/m maximum gradient amplitude.

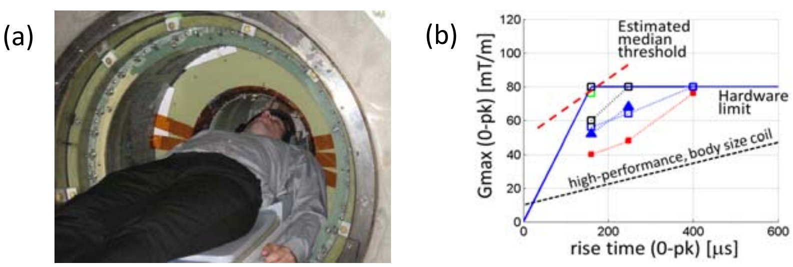

Figure 3. (a) PNS test setup. (b) PNS threshold data for the *x* (left-right) gradient coil. Not all volunteers reported sensation. Markers: Experimental data. Each set of connected data points is from a single volunteer. Solid blue line: hardware limit. Dashed black line: PNS limit in [8].

Methods: The asymmetric head gradient coil was mounted inside a whole-body 3T scanner (MR750w, GE Healthcare, Waukesha, WI) and was interfaced with the scanner's standard systems electronics. A 37-cm inner-diameter birdcage T/R coil and a 32-channel receiver array were custom-built for use with the gradient coil.

Phantom scans. A 24-cm diameter disc phantom containing a square grid was imaged with a GRE-EPI protocol (without parallel imaging) to demonstrate the reduction of susceptibility-induced EPI pixel shift with a shorter echo spacing (ESP), enabled by the high slew rate (SR) of the gradient coil. The shortest ESP was 356 µs at SR = 500 T/m/s, compared to 564 µs at SR = 200 T/m/s.

In-vivo scans. Healthy volunteers were scanned under an IRB-approved protocol with a 2D IR-prep Fast GRE sequence over several axial scan locations. The scan parameters were: TI = 600 ms, TE = 3.2 ms, flip = 60°, FOV = 26 cm, matrix = 256 X 256, bandwidth = +/–32 kHz. The in-plane (x, y) gradients were operated at 80 mT/m and 500 T/m/s (simultaneously).

PNS tests. Ten healthy volunteers were recruited under an IRB-approved protocol for PNS threshold measurements with the transverse gradient coils. The volunteers were instructed to report the onset of any sensation as the gradient amplitude was incremented with a fixed rise time of a trapezoidal pulse train [7], while inside the magnet. Three rise times were applied in random order. The tests proceeded with each axis pulsed one at a time.

Results and Discussion: Figure 1 illustrates the advantage of high slew rates in EPI image quality. Pixel shift artifacts at 500 T/m/s were significantly reduced compared to imaging at 200 T/m/s. Conventionally, post-processing is used to correct the geometric distortion artifacts but it can come at a cost of increased blurring. Furthermore, distortion correction cannot recover lost signals as seen on the left-right edges of the phantom. Figure 2 shows high-resolution brain images at full gradient performance of 80 mT/m and 500 T/m/s. The images demonstrate good coverage in the superior-inferior direction with the asymmetric transverse gradients. Figure 3(a) shows the patient position with respect to the gradient coil during imaging and PNS tests. Seven out of ten subjects reported minor PNS with the x-gradient. Figure 3(b) shows the PNS thresholds that were significantly higher than in a state-of-the-art, body-sized neuro gradient coil [8]. Only one of the ten subjects reported minor sensation with the y-gradient, even at the peak operation of 80 mT/m and 500 T/m/s. All reported sensations were on the facial area, including teeth, nose and forehead. As compared to FDA guidelines, the subjects in this study were asked to report *any* sensation at all (considered as indicative of positive PNS). Therefore, in clinical practice, it is likely that the threshold for reporting PNS will be higher.

Conclusion: We have successfully demonstrated that a dedicated head-only gradient coil can achieve high performance levels that are much less restricted by PNS compared to whole-body gradient coils. Our initial imaging experience also showed that our proposed design is able to achieve large (24-26 cm) FOVs with minimal spatial distortion. Substantially reduced pixel shift as a result of the 500 T/m/s slew rate in EPI scans presents a potential for acquiring high spatial resolution fMRI and DW-EPI images without having to resort to multi-shot EPI approaches that can substantially increase scan time and sensitivity to motion. A torque-balanced, force-balanced, and well-managed eddy current gradient coil provides an ideal platform for advanced imaging of the brain and brain function.

Acknowledgment: This work was supported in part by the NIH grant 5R01EB010065. **References:** [1] Roemer, US Patent 5177442 (1993) [2] Alsop et al., MRM 35:875-886 (1996) [3] Chronik et al., MRM 44:955-963 (2000) [4] Zhang et al., MRM 50:50-58 (2003) [5] Green et al., ISMRM 16 (2008), 346 [6] Mathieu et al., ISMRM 21 (2013), 2708 [7] Feldman et al., MRM 62:763-770 (2009) [8] Setsompop et al., NeuroImage 80:220-233 (2013)