Development of a Dedicated Asymmetric Head-only Gradient Coil for High-Performance Brain Imaging with a High PNS Threshold

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Target audience: MR scientists and clinicians interested in neuroimaging with high-performance gradient coil technology.

Introduction: A compact, asymmetric head-only gradient coil holds promise as a potential solution to achieve simultaneous high gradient amplitude and slew rate, while minimizing peripheral nerve stimulation (PNS) [1-3]. Following successful proof-of-concept demonstration of an asymmetric head-only design [3], we have constructed a new coil (Fig. 1) with maximum gradient amplitude and slew rate of 85 mT/m and 700 T/m/s, respectively, when driven by a standard 1 MVA-per-axis gradient driver. Its generous head-insert bore diameter (42 cm) allows imaging with a dedicated T/R birdcage coil and a variety of multi-channel receiver arrays for high SNR. The tapered and stepped profile at the patient opening, and a distortion-correctable field of view of 26 cm near the edge of the coil can accommodate most adult patients for whole-head imaging. The coil's outer diameter (59 cm) allows insertion inside the gradient coil of a conventional whole-body scanner. It is also possible, and is planned, that the new head-only gradient coil be eventually inserted into a dedicated, lightweight 3T head-only scanner that is currently under construction at our institution. In this work we report on initial performance evaluation of the gradient coil operated in a whole-body 3T magnet.

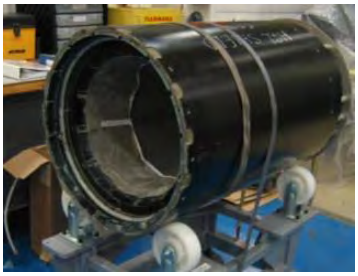

Figure 1. Head-only gradient coil. The outside length of the coil is 92 cm.

Axis	R_{DC} [Ω]	R_{1kHz} [Ω]	L [mH]	F [N]	τ [Nm]	T_{peak} [°C]
X	0.124	0.178	0.234	8	23	64
Y	0.114	0.165	0.204	10	48	75
Z	0.087	0.133	0.186	118	0	73

Table 1. Measured (R, L) and designed (F, τ, T) parameters of the head-only gradient coil. R: resistance, L: inductance, F: force at maximum current, τ: torque at maximum current, T_{peak}: peak temperature at 25 kW.

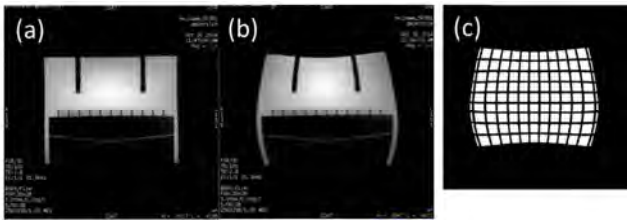

Figure 2. Phantom images in the coronal plane with (a) and without (b) gradient nonlinearity correction. FOV = 29×29 cm^2. (c) Predicted distortion of the phantom from the simulated gradient field maps.

Methods and Results: *Systems integration.* The head-only gradient coil was manufactured in a manner similar to a previous coil described in [4], but with much improved design optimization in terms of gradient efficiency, slew rate, linearity, eddy currents, force/torque balancing, and thermal management. Some of the key physical parameters are summarized in Table 1. After standalone tests of basic performance parameters, the gradient coil was inserted into a whole-body 3T scanner (MR750w, GE Healthcare, Waukesha, WI) and connected to the scanner's standard systems (amplifier and cooling) cabinets. The coil was designed to dissipate 25 kW continuous power with a standard chiller and coolant pump. The coil was lined with an RF shield with a foldable sleeve on the patient end [5]. A custom-built 37-cm inner-diameter birdcage T/R coil was inserted into the gradient coil. Both a standard 8-channel brain array (GE Healthcare) and a 32-channel receiver array (Nova Medical, Wilmington, MA) were used for imaging. During the initial tests reported here, the performance parameters were set to 80 mT/m and 500 T/m/s.

Gradient warping correction. Three-plane images of a head-sized phantom showed that standard gradient nonlinearity correction worked well to produce undistorted images in the FOV when supplemented by additional harmonic terms (up to the 10th order) for unwarping (Fig. 2). Since the correction coefficients were obtained using the simulated gradient field maps, good geometrical accuracy after correction indicated that the coil was manufactured well according to the electromagnetic design.

In-vivo scans. Four healthy volunteers were scanned under an IRB-approved protocol to assess scan coverage in the head region. All volunteers were scanned with a 32-channel Nova coil (Fig. 3c). All volunteers reported acceptable acoustic noise with standard ear plugs, and no volunteer reported significant PNS. A typical acoustic noise spectrum showed a peak at around 2 kHz, which was consistent with the location of gradient vibration peaks as measured by impedance sweeps in the magnet. Anatomical images showed consistent whole brain coverage. For example, in Fig. 3(b) the cerebellum and the cervical spine down to the C3/C4 junction were well visualized with little geometric distortion from gradient nonlinearity.

Discussion: Initial evaluation of the new head-only gradient coil demonstrated the coil's capability for high-speed, high- quality neuroimaging while being much less restricted by PNS compared to a whole-body-sized gradient coil [6]. Our initial imaging experience showed that the new mechanical and electromagnetic design of the coil provides a reasonable whole-head FOV with good spatial distortion correction. We expect that this will lead to high image quality and improved workflow in a clinical setting. Diffusion and EPI image quality at the maximum performance level will be the subject of a future study.

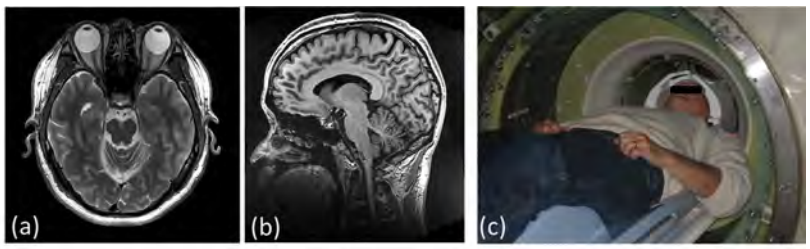

Figure 3. In vivo images. (a) Axial fast spin echo with FOV = 22 22 cm^2, slice = 4 mm, matrix = 256×256, bandwidth = ±25 kHz. (b) Magnetization-prepared 3D fast gradient echo with FOV = 26×26 cm^2, slice = 2 mm, matrix = 512×256, bandwidth = ±31.25 kHz. (c) Volunteer scan setup.

Conclusion: We have designed, built, and tested an asymmetric head-only gradient coil that provides easy patient access and performance efficiency. The coil is expected to provide an ideal platform for advanced neuroimaging research as well as high-quality clinical brain scans.

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References: [1] Roemer, US Patent 5177442 (1993). [2] Chronik et al., MRM 44:955-963 (2000). [3] Lee et al., ISMRM 22 (2014), 310. [4] Mathieu et al., ISMRM 21 (2013), 2708. [5] Chishti et al., ISMRM 22 (2014), 1293. [6] Setsompop et al., NeuroImage 80:220-233 (2013).