EPI microscopy with uniplanar magnetic field gradient coils

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Introduction Small localized gradient designs generate negligible eddy currents and offer specific advantages for EPI microscopy in small and thin samples. Here, we present initial results for echo planar imaging acquired with a uniplanar gradient design at 7T. The acquired images are geometrically distorted due to the gradient nonlinearity associated with uniplanar gradient design; this image distortion can be corrected using Bz field models for each gradient axis.

Materials and Methods The uniplanar magnetic field gradient set consists of a water-cooled x, y and z planar gradient coils supported within a horizontal stage detailed in (1). The gradient set was mounted in a 7T horizontal bore magnet equipped with a Bruker Avance II console. Preemphasis was determined to be unnecessary due to the large gradient to cold surface distance. RF excitation and reception was provided by a uniplanar RF coil placed approximately 3mm above the gradient assembly. For *ex vivo* histology imaging, mouse embryos were collected from C57BL/6 pregnant mice according to a IACUC-approved protocol. Embryos were immersion fixed in 4% paraformaldehyde and enhanced in a 5mM gadoteridol solution for 7 hours. FLASH images at two different echo times (TE = 5/6ms) were acquired to generate a B0 field map. Single-shot gradient echo EPI images were acquired with the following parameters: TE/TR = 25.09/4000 ms, matrix size: 160 x 160; nominal slice-thickness: 150 μm; slices: 15; echo spacing: 640 μs; averages: 32; total acquisition time: 2min 8s. For *in vivo* imaging an AJM/CYA1 mouse was anesthetized and placed supine on the planar gradient set. Single-shot EPI coronal images of the mouse brain were acquired: matrix size: 128 x 128, nominal slice-thickness: 150 μm, echo spacing: 845 μs, number of slices: 47, number of averages: 8, total acquisition time: 1mins 4 seconds. Gradient nonlinearity was corrected based on Bz field models of the three gradient coils. Distortion correction due to magnetic susceptibility effects was achieved using an independent field map. The acquired EPI images were initially corrected for main field inhomogeneities then for gradient non-linearities using the Bz field models for each axis. The image intensity was also corrected for voxel volume variations using the local Jacobian determinant of the nonuniformity correction transform (1).

Results and Discussion Images acquired from a fixed mouse embryo with a conventional and uniplanar gradient are shown in Fig. 1. Figure 2 shows a representative axial slice of the reconstructed EPI images of the mouse brain acquired with the uniplanar gradient set (in this case with only gradient non-uniformity corrections applied). Omitting the Jacobian determinant intensity correction (Fig 2a) allows the intrinsic fall-off of the surface coil sensitivity to be partially compensated by the increase in effective voxel-size with distance from the gradient coil plane. The uniplanar gradient-RF coil design employed here allows high-resolution imaging of dorsal cortex and sufficient penetration to visualize most of the thalamus and caudoputamen in an adult mouse.

Conclusions a uniplanar gradient design is well suited for single-shot echo planar microscopy in both fixed and living samples. Because the planar gradient design generates a spatially-varying gradient, the image resolution varies in the image plane and the slice-thickness varies with slice position. Although the intrinsic spatial resolution varies with distance from the gradient set, both gradient non-linearity and main field inhomogeneity distortion in echo-planar images can be corrected retrospectively, greatly increasing the utility of this gradient design for high temporal resolution imaging for MR microscopy.

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References: (1) A uniplanar three-axis gradient set for *in vivo* magnetic resonance microscopy. JMR 2009, 200, 38-48.

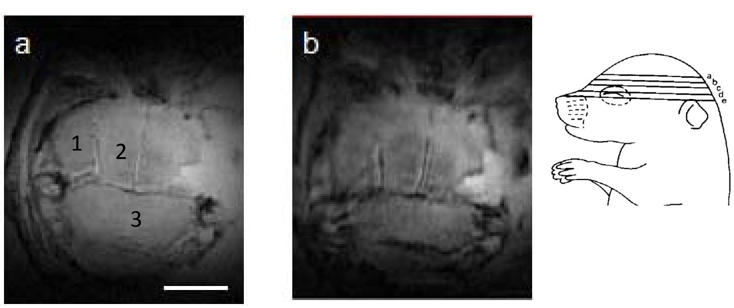

Figure 1 (a) a representative slice of FLASH images of the fixed brain of an E18.5 mouse embryo acquired with the conventional cylindrical linear gradient. resolution: 55 μm x 55 μm, slice thickness: 200 μs. (b) a representative slice of unwarped single shot EPI images of the fixed mouse embryo brain acquired with the uniplanar gradient. Scale bar = 2mm. Image (a) and (b) is approximately the slice e in the schematic of the mouse embryo shown above. 1 – temporal lobe, 2 -- thalamus, 3 – pons.

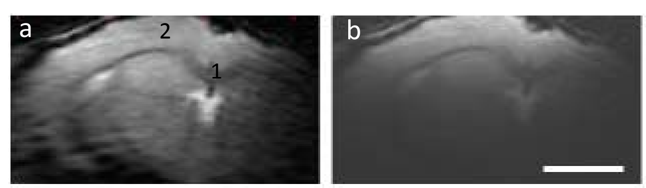

Figure 2 a representative axial slice of reconstructed EPI images acquired from the mouse brain at 7T. (a) No Jacobian correction was applied and (b) Jacobian correction was applied to correct the image intensity variation with effective voxel size. Scale bar = 3 mm. 1: corpus callosum; 2: dorsal cerebral cortex