An Implanted 8-channel array coil for high-resolution macaque MRI at 3T

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Introduction: In the last decade diffusion and functional MRI have proven highly valuable tools for studying the anatomy and sensory as well as cognitive processing in awake monkeys. The smaller monkey brain demands higher spatial resolution compared to human imaging in order to reveal equivalent anatomical detail. In turn, increased signal-to-noise (SNR) ratio is needed to support the smaller voxel sizes. Although conventional phased-array coils [1] offer a significant increase in SNR, the arrays never reach their full potential due to the distance between the coil and the monkey brain. Receive coils used for monkey images are inherently further away from brain tissue compared to human imaging due to large lateral yaw muscle and the head fixation post. This distance has previously been reduced by implanting a single coil on top of the skull in anesthetized monkeys [2]. However, single-shot EPI acquisitions used in DTI and fMRI benefit greatly from accelerated image encoding that mitigates geometric distortions. In this study, an 8-channel phased-array coil was implanted for the first time on top of the skull, inside the acrylic head post. This approach, which does not require additional invasive procedures, increases the FOV (up to full-brain coverage) and allows accelerated imaging to reduce distortions. We compared the performance of the array to more conventional external coils available in our laboratory and demonstrated the performance of the implanted array for high-resolution anatomical, diffusion, and functional image acquisitions.

Methods: The coil array consisted of a central loop surrounded by 7 loops and fits tightly around the skull of the monkey (Fig.1a). The 8 elements of the array were formed manually from 16 AWG highly conductive copper wire coated with MW-C35 [1,3]. Except for the copper wire and a female MCX connector, no electrical components were used on the implanted part of the array. The array was implanted on top of the skull of the monkey underneath the required headpost and covered with a layer of polytetrafluoroethylene and dental acrylic to ensure electrical isolation from the surroundings. The external tuning, matching and detuning circuit components were positioned on detachable circuit boards (Fig.1b) containing the matching capacitor (C_1), a tunable capacitor (C_2), a hand-wound inductor L, and a PIN diode (D).

Data were acquired in accordance with SRAC on a 3-T clinical Tim Trio MRI scanner with an AC88 (G_{max}=80 mT/m, SR=800 mT/m/s) insert head gradient (Siemens Healthcare, Erlangen, Germany). The monkey was placed in the sphinx position [4]. In all cases, an external detunable single-loop transmit coil (d = 12 cm) was used for excitation. The SNR performance was compared *in vivo* between the 8-channel implant coil and two external coils: a single-channel horizontal Rx-only coil (d = 10cm) and an external tight-fitting 4-channel coil (element d = 6cm) using the same transmit coil. To estimate the SNR proton density-weighted gradient echo images (TR/TE/α=30 ms/6 ms/30°, slice thickness=1.5 mm, 40 slices, matrix=128×128, field-of-view (FOV)=128×128 mm^2, and BW=200 Hz/pixel) were acquired with transmit on and off. The SNR maps were calculated for a noise-covariance weighted root sum-of-squares (cov-rSoS) combination of the individual channel images [1, 5]. The same coil sensitivity estimates, with a tight FOV around the head, were used for SENSE g-factor calculations. To demonstrate the high-resolution, full-brain imaging capability of the coil, a 200 µm isotropic MPRAGE image volume, a 0.7 mm isotropic DTI data set, and a 0.5 mm isotropic BOLD-weighted GRE-EPI data set were acquired. (MPRAGE: 3D acquisition, TR/TI/TE/α = 2.7 s/850 ms/3.74 ms/9°, matrix = 512×512×240, BW = 180 Hz/pixel, 4 averages; DTI: 2D single-shot twice-refocused DW-SE-EPI, TR/TE= 6960/77 ms, matrix = 148×148, *R*=3, partial Fourier = 6/8, 61 slices, BW = 1408 Hz/pixel, 5 averages of 256 directions at b =1000 s/mm^2, and 50 b = 0 images interspersed every 9 volumes; GRE-EPI images: phase-encoding direction = head-foot, TR/TE/FA = 3000 ms/31 ms/76°, matrix = 150×150, BW=1010 Hz/pixel, R = 2.)

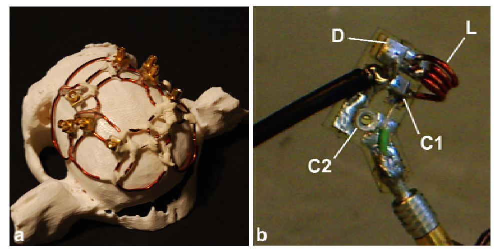

FIG 1: (a) 8CH array coil on a 3D replica of the monkey's skull. (b) The external circuit board.

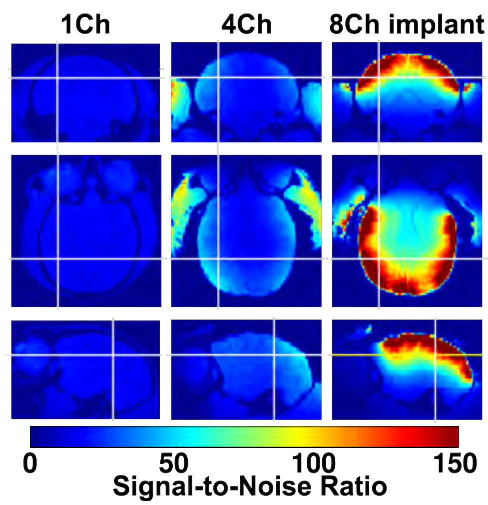

FIG 2: SNR comparison of the external single- and 4-channel coil with the implanted 8-channel array.

Results: The average unloaded/loaded Q factor of the elements of the implanted array was 153/59=2.6, showing that body-noise is dominant. Fig. 2 shows the SNR comparison between the coils. The noise correlation coefficient between channels ranges from 16 to 27% with an average over all channels of 10%, demonstrating good isolation. In an ROI covering the brain periphery the implanted 8-channel coil has a 5.4- and 3.6-fold SNR gain compared to the external single- and 4-channel coil, respectively. G-factor calculations show a significant improvement for 2- and 3-fold acceleration with the implanted 8-channel (slice averaged g-factors: 1.04 and 1.17; max. g-factors: 1.4 and 2.5, respectively for R = 2 and R = 3) compared to the 4-channel coil (slice averaged g-factors: 1.8 and 2.94; max g-factor: 1.5 and 22.3, respectively for R = 2 and R = 3). Fig. 3 shows the high-resolution anatomical, DTI, and GRE-EPI images. These images show that even at these extremely high resolutions the level of SNR in all three images is sufficient to reveal subtle details of the brain that cannot be observed at lower resolutions.

Conclusions: An 8-channel array coil for macaque imaging was constructed and embedded in the acrylic head post of an adult macaque monkey and tested *in vivo*. Significant improvements in SNR and parallel imaging performance were obtained compared to external coils. The use of the implanted coil allowed reaching very high spatial resolution *in vivo* anatomical images (200 µm isotropic) and DTI volumes (0.7 mm isotropic) with full brain coverage and GRE-EPI volumes that are suited for fMRI (0.5 mm isotropic) with near-full brain coverage at 3T.

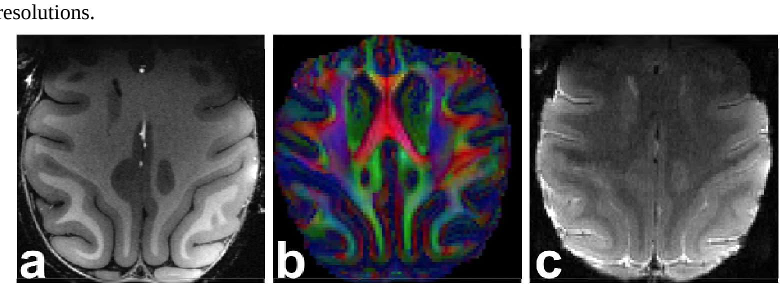

FIG 3: (a) MPRAGE image, T_a (total acq. time) = 92 min, (b) directionally encode color DTI image, T_a = 3 h, and (c) single GRE-EPI image, T_a = 3 s.

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