Design, Evaluation and Application of a Six-Channel Transceiver Array Tailored for *In Vivo* Human Eye Imaging at 7.0 T

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Target Audience: Engineers, basic MR researchers, experts in MR hardware, clinical scientists and clinicians interested in *in vivo* magnetic resonance imaging (MRI) of the human eye at ultrahigh field (UHF) using a novel six-element transceiver coil array.

Introduction: *In vivo* imaging of the spatial arrangement of eye segments and their masses is an emerging MRI application and ultimately aims at performing MR image-based biometry. Eye MRI requires high spatial resolution over a small field of view (FOV). Realizing this constraint as well as the signal-to-noise ratio (SNR) gain inherent to ultrahigh field MR it is conceptually appealing to pursue *in vivo* MRI of the human eye at 7.0 T. To meet this goal exploration into novel multi-transmit (RF) coil technology tailored to the human eye anatomy are required. Based on these considerations, a six-element transceiver eye coil array (f=298 MHz) which uses loop elements is proposed. The coil design was customized for the human eye and examined in electro-magnetic field (EMF) simulations along with assessment of RF power deposition distribution. A dedicated head- and eye phantom was constructed to validate the EMF simulations in heating experiments using optical temperature measurement. The applicability of the coil for human eye imaging was examined in a volunteer study as a precursor to a broader clinical study.

Materials and Methods: A symmetric design is used to cover each eye with three planar transceiver loop elements (Figure 1a). The three loop elements are angled (element 1 vs. element 2: 151° and element 2 vs. element 3: 161°) to conform to the anterior head as shown in Figure 1b. The width of the rectangular elements was set to 36 mm (elements 1 and 2) and 45 mm (element 3). An element height of 71 mm and a conductor width of 10 mm was used (Figure 1a). Adjacent elements share a common conductor with a trimmer capacitor (Voltronics, MD, USA) for decoupling (Figure 1b). Next neighbor decoupling was achieved using coaxial cables for connection and two trimmer capacitors for decoupling [1]. All other elements were decoupled by distance. The MR experiments were conducted on a 7.0 T scanner (Magnetom, Siemens Healthcare, Erlangen, Germany). Phase adjustment of each channel was accomplished by phase-shifting coaxial cables added to the power splitting network. EMF and specific absorption rate (SAR) simulations were performed using CST Studio Suite 2011 (CST AG, Darmstadt, Germany) in conjunction with the voxel models Ella and Duke from the Virtual Family [2]. The numerical simulations were validated in phantom studies (Figure 1c). For this purpose, two solutions made up of NaCl, glucose and $CuSO_4$ were used to fill a head mock-up (σ = 0.756 S/m, ε = 57.17) and plastic spheres (σ = 1.441 S/m, ε = 54.70). The plastic spheres were placed inside the head phantom to mimic human eyes. Flexible tubes were incorporated into the phantom setup to accommodate fiber-optic probes (Neoptix Inc., Quebec, Canada) for temperature measurement. Eye imaging at 7.0 T was performed on healthy subjects using T_1- and T_2-weighted techniques. Subject preparation to reduce eye motion artifacts was performed [3].

Results: The RF coil is light weight and conforms to a broad range of head geometries. The loop elements showed an average Q_U/Q_L of 4.6. Reflection coefficients of the individual elements averaged over five volunteers were in a range of -22 dB to -28 dB. Element coupling was below -10 dB for all elements and subjects. Noise correlation was below 0.4 for all elements and subjects as illustrated in Figure 1d. The optimized phase setting was found to be 0° for elements 1 and 4, 327.2° for elements 2 and 5, and 248° for elements 3 and 6. The resulting transmit field can be seen in Figure 2a. SAR values derived from the EMF simulations using calculated phase settings optimized for B_1^+ efficiency/uniformity were well below the limits permitted by the IEC guidelines [4] for an average input power of 1 W over 6 minutes as illustrated in Figure 2b. Phantom experiments using T_1- and T_2-weighted imaging sequences tailored for the eye revealed RF-induced heating of less than 0.3 K for a total scan time of 50 minutes measured with fiber-optic thermosensors. *In vivo* imaging demonstrated a rather uniform signal intensity for sagittal and transverse views of the eye as demonstrated in Figure 2 c,d. For parallel imaging, mean geometry factors of g=1.1 (R=2), g=1.9 (R=3) and g=3.4 (R=4) were observed for a ROI covering the eyes and segments of the optical nerve.

Discussion: Our results demonstrate that the proposed six-channel coil array supports the acquisition of high spatial resolution images of the human eye at 7.0 T within clinically acceptable scan times. Our preliminary results indicate that the use of multiple surface coil transceiver loop elements yields an excellent SNR for a ROI encompassing the eye, affords uniform signal intensity across the eyes, and facilitates the depiction of anatomical details of the eye. Further improvements in image quality/contrast can be achieved by tailoring pulse sequences established for eye imaging at 1.5 T/3.0 T for 7.0 T. The open RF coil design provides space for an eye-tracking system to monitor eye position during data acquisition. This approach would be beneficial to correct for artifacts induced by eye motion.

References: [1]. Lopez, M. A. et al. Magnetic Resonance Engineering. 37, 2010, PP. 226-236. [2]. Christ et al. Physics in Medicine and Biology. 55, 2010, Bde. N23-N38. [3]. Richdale et al. Journal of Magnetic Resonance Imaging. 30, 2009, PP. 924-932. [4]. IEC Guidelines Edition: 3.0. PP. 36 - 40, 2010.

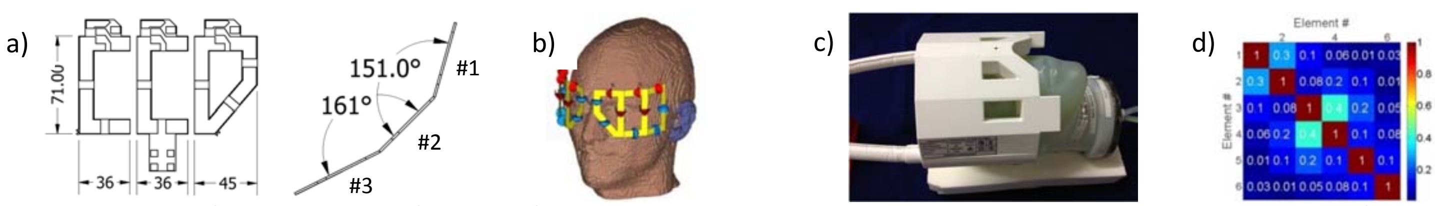

Fig. 1: a) Dimensions of the conductor layout, front view **(left)** and top view **(right)**. **b)** Basic coil design and positioning on the voxel model "Duke" used for EMF simulations. **c)** Phantom setup with the RF coil placed on the head phantom. **d)** 6x6 noise correlation matrix averaged over five volunteers.

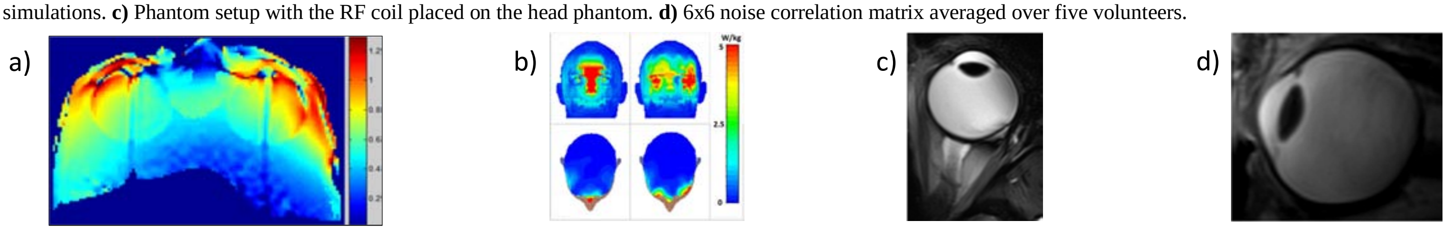

Fig. 2: a) B_1^+-map of the phantom using the calculated phase setting (a.u.). **b)** SAR distribution derived from simulations for a coronal **(top)** and transverse **(bottom)** slice through the eye with all phases 0° **(left)** and with phase setting **(right)**. **c)** Transverse and **d)** sagittal *in vivo* image of a human eye, voxel size (0.5x0.5x3.0) mm^3.