A novel transceiver wired & wireless array coil assembly for MR guided robot assisted interventions and radiosurgery procedures

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Target Audience: This paper is directed towards engineers and researchers with interest in MR coil design for MR guided neurosurgery system.

Purpose: Over the last decade, surgical robots that can be guided utilizing MRI and are suitable for neurosurgical procedures, biopsies and craniotomies, were introduced.[1-2] The requirements for an optimum system that targets MR guided robotic assisted craniotomies necessitate that any RF coil structure; a) should not interfere or occupy the same space with the designated surgical field and restrict access to a neurosurgeon, b) should not interfere with the sterile field, c) should not restrict the use of navigation systems, d) should generate homogeneous RF field, with great sensitivity and uniformity inside the desired imaging volume, e) and should not inhibit or restrict the placement and positioning of the head skull to a head fixation device (HFD) that keeps the head rigid for the duration of the craniotomy procedure and allow easy access to the patient to attend for any emergency situation during the procedure (Fig 1). In addition, it is highly desired to have an RF coil design that generated a localized transmit RF field because such a field does not interfere with the electronics of the surgical robot and helps controlling the pattern of specific absorption ratio (SAR) deposition on the human head. The aforementioned requirements come in direct conflict with the design of a conventional RF transceiver volumetric coil in terms that the coil structure should be circumferentially uniform in order to generate a uniform B_1 field in the surgical region of interest. In the present abstract, a novel transceiver coil design coupled with a wireless anterior loop array structure that satisfies all the aforementioned requirements of an MR guided surgical robotic craniotomies is introduced.[3] The posterior coil structure has the U shape configuration that is the part of the HFD and is positioned under the surgical drapes. The U shape structure does not interfere with the sterile field and does not inhibit access to the surgical region while the anterior structure incorporates a sterile wireless array loop coil having a center opening large enough to provide access to the surgical theater. It is inductively coupled with the posterior transceiver channels to generate a high uniform B_1 field profile with superior accessibility than previously introduced transceiver coil designated for MR guided robotic assisted craniotomy procedures.[4]

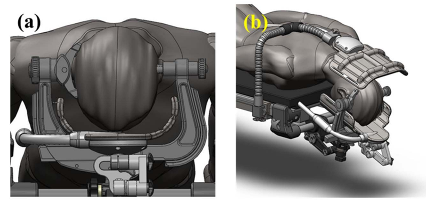

Fig 1. (a) The surface coil covering front head with HFD. (b) the coil assembly covering the whole brain with HFD

Methods: The posterior coil consists of eight rectangular loops each with 90mm width and 250mm length distributed symmetrically on the U shape configuration with 210mm height, 220mm width and 250mm length covering the head and neck area of a 95 percentile adult male. The shape and size of the posterior coil allow us a seamless integration with HFD and the placement of the structure itself under the sterile surgical drapes. The anterior wireless coil has been configured as a transmit/receive coil that inductively couples to the U shape transceiver array. The coupled wireless coil array nesting on the top of the U shape has the square shape (210mm width and 210mm length) with large opening to permit easy access of the surgical field (Fig 2b-c). The wireless coil includes a stacked pair of coil elements.[5] Since the anterior part is sterile, its introduction into the surgical field does not have any adverse event. The eight rectangular loops were wrapped on the U shape and they are driven as the transceiver coil with corresponding phases as shown by Fig 2(a,d). Overlapping is used between adjacent coils and capacitive decoupling is engaged between next-adjacent coils to achieve optimum isolation between coil loops. In order to determine the behavior and quality of B_1 field generated by the interaction between the transceiver wireless coil and the eight channels transceiver posterior coils, electromagnetic (EM) field simulation for these combined coils is implemented by utilizing SEMCAD X (Ver. 14.6.1 Schmid & Partner Engineering AG, Zürich, Switzerland) with a dielectric human model (Duke) (Fig 2b).

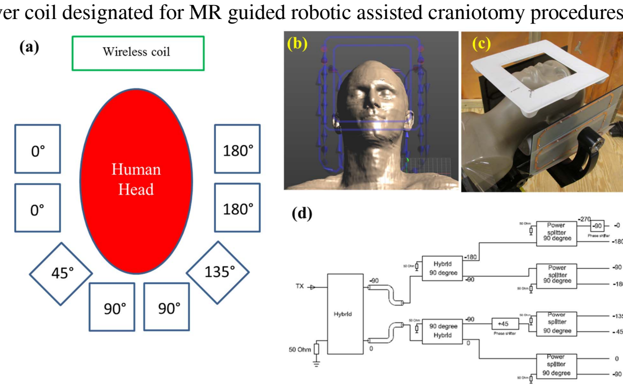

Fig 2. (a) Array coil arrangement for 8 channels transceiver array and the wireless coil. (b) Simulation study setup for the coil assembly on a human model. (c) The prototype of the array coil and setup with a human model. (d) The RF power splitter for the transceiver array coil

Results: A prototype of the eight channel posterior transceiver array that is inductively coupled with an anterior wireless transceiver loop array was constructed. For the posterior part of the coils, all loops were tuned to 123.2 MHz, where per loop the measured ratio of the Q_L/Q_U=8.5. The posterior loops were matched to 50 Ohm and geometrically decoupled from each other achieving greater than -15dB isolation between neighboring and next nearest neighboring coils. As Fig 3(a) indicated, with the posterior only transceiver array present, there is a great B_1 sensitivity drop towards the front end of the head model. However, as Fig 3(b) depicts, the presence of the inductively coupled transceiver wireless loop array placed on the anterior part of the head yields B_1 field sensitivity increment as much as 8.0dB over that region. The behavior of B_1 field on the simulated head model is significantly more uniform over the entire head (Fig 3(b)) when compared with the one without the wireless transceiver coil (Fig 3(a)). The presence of the wireless posterior transceiver loop array does not significantly contribute to the elevation of either the local or average SAR levels of on the human head. The maximum SAR (1.29W/Kg) deposited by the eight channels transceiver wireless array combination was on the Cerebrospinal fluid (CSF) located on the Occipital lobe, while the mean value was 0.052W/Kg.

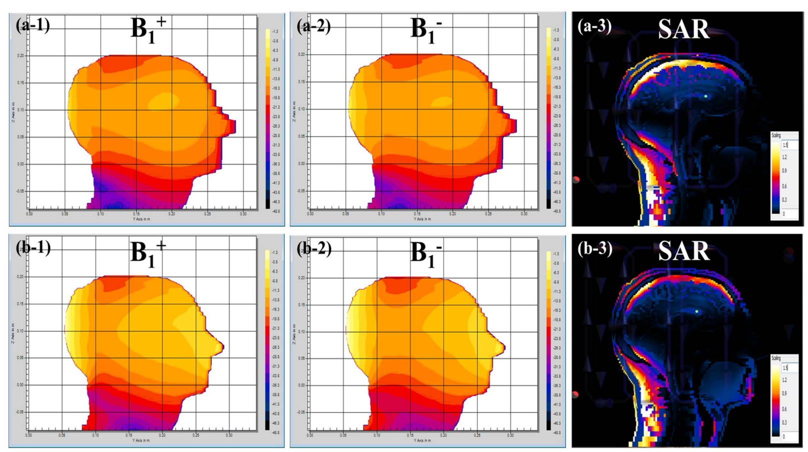

Fig 3. (a) The B_1 field and SAR generated from eight transceiver array. (b) The B_1 field and SAR produced by the transceiver array and the wireless coil. The scales of B_1 field are dB scales normalized by 1.0×10^{-6} (T). The scale unit of SAR deposited on the dielectric head model is (W/Kg)

Discussion & Conclusion: The novel RF coil assembly for robot assisted MR guided interventions and radiosurgery procedures was presented. The coil assembly consisted of the posterior unit comprising of eight channel transceiver loop array pattern and the anterior wireless transceiver loop array inductively coupled to the posterior part. The coil assembly generated a high uniform and sensitive B_1 profile over the entire area without inhibiting valuable surgical space and compromising the sterile field. SAR calculations indicate that the presence of the anterior wireless transceiver loop array does not alter or enhance the SAR pattern behavior inside the human head.

References: 1. Chinzei K and Miller K. Towards MRI guided surgical manipulator. *Med Sci Monit.* 2001;7(1):153-63. 2. Chinzei K, *et al.* MR Compatible Surgical Assist Robot: System Integration and Preliminary Feasibility Study. *Medical Image Computing and Computer-Assisted Intervention* – MICCAI 2000; 1935: 921-930. 3. Ha S, *et al.* Multi channels array coil for MR guided radiation therapy system. 2014; *US Patent Application, Patent Pending.* 3. Ha S, *et al.* An 8 channel Transceiver phased array coil combined with a Surgical Robot for an MR assisted Robotic surgery. *Proc. Intl. Soc. Mag. Reson. Med.* 2014:1311.5. Zhu H, *et al*. Stacked coil for magnetic resonance imaging. 2011; US 20130113485.