A Semi-Optimized Phased Array Coil Design for High-Resolution MRI of Cervical Spinal Cord

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INTRODUCTION: Cervical spinal cord (CSC) is a compact and one-dimensional nerve, of which cross-sectional area is about 1 cm^2 at the C2 level. Any injury in the CSC may lead to disability, such as in patients with multiple sclerosis and spinal cord myelopathy. Although the magnetic resonance imaging (MRI) is the most widely used non-invasive tool to evaluate the cervical spinal cord, it generally detects the legion at the late stage. The earlier the pathological change is detected, the more option we have in the treatment. Diffusion tensor MRI (DTI) is known to be more sensitive to the earlier change in the nerve system than other conventional MRI methods, such as T_1 and T_2 weighted imaging. In order to detect the change in the CSC at its early stage, the high resolution imaging is needed using advanced MR imaging method and improved detections, which include the high magnetic field strength and high-sensitivity RF coil. In this work, a CSC-dedicated phased array coil is developed with its layout and the dimension optimized using computer simulation. The performance of phased array coil depends on its shape, size and number of elements. A phased array coil picks up the signal according to the Faraday's law of electromagnetic induction. The sensitivity of a phased array coil depends on the magnetic field of the coil perpendicular to the static magnetic field. The magnitude and direction of the RF magnetic field (B_1) in 3-dimensional space was calculated using the Bio-Savart's law and the shape and size of the surface coil was optimized. An 8-channel phased array coil is constructed in the shape of human neck for CSC imaging with the eight optimized surface coils by placing them in such a way that the mutual induction between any two adjacent coils becomes zero. MRI experiments were performed to confirm the numerical simulation.

Theory: The signal voltage, which is induced on the coil from the voxel of volume V containing the magnetization per unit volume M_0 [1] $V_{signal} = \omega b_{1r} V M_0$ and the noise voltage picked up by received coil is given by- $V_{noise}=\sqrt{4kT\Delta f R}$, where b_{1r} is the transverse component of rotating magnetic field created by the unit current in the coil at the voxel of volume V , R = coil resistance (R_{coil}) + sample resistance (R_{sample})≈ R_{sample} at 3 T and Δf is observational bandwidth in hertz. The Signal-to-Noise Ratio (SNR) is defined as the ratio of the signal voltage and the standard deviation of noise. For a phased array coil consisting of eight elements with the negligible mutual induction among the elements, the expression for the combined SNR can be written as [2]: $SNR^2_{phased} = SNR^2_1+SNR^2_2+ SNR^2_3+SNR^2_4+ SNR^2_5+SNR^2_6+ SNR^2_7+SNR^2_8$

METHODS: **(a) Numerical simulation**: The transverse component of RF field (B_{1r}) and sample resistances have been numerically calculated for circular, square and rectangular coils with different sizes in the planner as well as cylindrical surface using software programmed with Matlab (Mathwotks, Natick, MA). **(b) Experiment**: For the circular, square and rectangular coils with different sizes, the SNR was measured using Gradient Echo (GRE) imaging at Siemens' 3T MRI system (Trio, Siemens Medical Solutions, Erlangen, Germany). Single surface coil was placed on planner surface where as a phased array coil constructed from eight individual coils was in cylindrical surface.

RESULTS: Numerical simulation as well as experimental result [Fig.1 and Fig.2] indicated that at the depth of 6.0 cm from the surface of planner single surface coil, the maximum value of SNR is achieved with a circular coil of diameter 5.4 cm. However, the square coil with 4. 8 ×4.8 cm^2 also has the comparable SNR with the circular coil of diameter 5.4 cm at the depth of 6.0 cm from the coil plane. The simulated value of SNR at the depth of 6 cm from the surface of the 8-channel phased array coil [Fig.3] constructed on the cylindrical surface using the circular coils with diameter 8 cm is also almost comparable with that obtained using a 8-channel phased array coil constructed on the same cylindrical surface using the rectangular coils with dimension 20 ×3 cm^2 [Fig.4]. The image obtained with 8-channel phased array constructed from 8 optimized circular coils has 3.90 times more SNR than the imaged obtain form Siemens' body coil [Fig. 5].

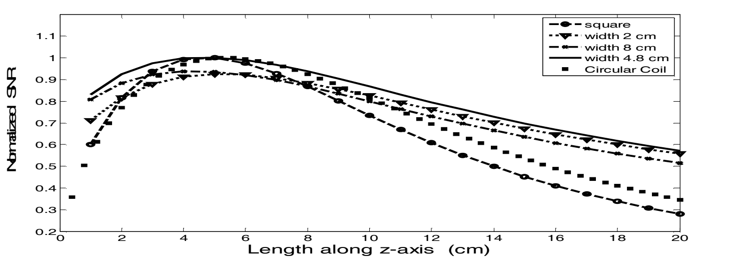

Fig.1. *Numerical simulation for the SNR due to the rectangular coils of different length and width. Rectangular coils have the length along z-axis (direction of applied field B_o) and width along-x axis.*

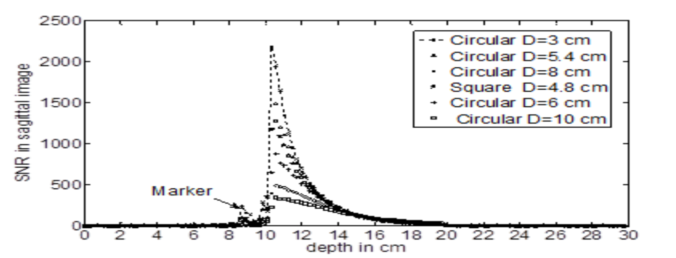

Fig.2. *Experimentally measured value of SNR along the axis of the circular coils of diameter 3 cm, 5.4 cm, 6 cm, 8cm and 10 cm and square coil of diameter 4.8 cm at the various depths.*

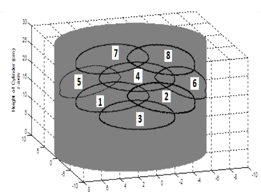

Fig.3. *8–channel phased array coil on the surface of the cylinder with radius 6 cm.*

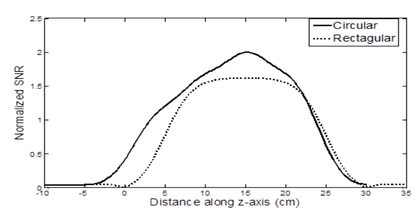

Fig.4. N*ormalized SNR at the depth of 6 cm for a 8-channel phased array coil constructed on the surface of cylinder of radius 6 cm.*

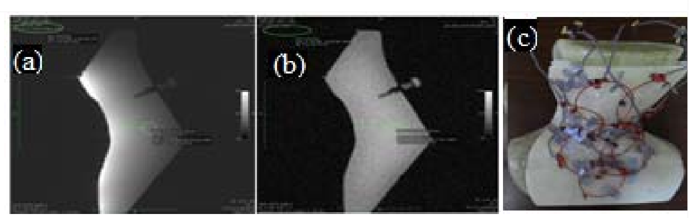

Fig.5. *Image obtained from phased array coil (a), from the Siemens' body coil (b) and constructed phased array coil with phantom(c).*

CONCLUSIONS: At a specific depth from a single-planar surface coil, the maximum SNR is achieved with a particular size and shape of the coil. The SNR using the optimal circular and square coils are almost the same for a given depth. However, among the family of rectangular coils, square coil with optimal size has better SNR than any other rectangular coils for the given depth.

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