16 channel, Bell Shaped Surface Coil for Knee Imaging

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Introduction: Whole-volume surface coils have been demonstrated to deliver a high signal to noise ratio (SNR) in the near-surface region of the sample volume without diminution of the SNR in the center. In recent years, several musculo-skeletal MRI studies have ventured into the development of high channel count coils (> 4 elements) for knee imaging [1]. A 16-channel whole-volume coil array consisting of 16 surface coil elements has been reported in literature [2]. However, the performance of these coil arrays has been limited by the amount of vicinal (adjacent-adjacent) overlap of the coil array elements; one cannot increase geometric overlap of these circular coils beyond the geometric flux coupling null. Here we propose a novel coil configuration for 1.5 Tesla imaging and coil element (Bell shaped-coil, which the authors dub as bell-loop) ; it will be demonstrated that using such a shape of array element allows significantly greater vicinal overlap whilst maintaining the desired flux nulling. The base of the bell-loop is purposefully tapered, so that adjacent element overlap occurs only in the parallel sided region. It will be shown that the bell loop also exhibits the advantage of greater penetration depth compared to a simple loop coil of equivalent aperture. Due to very limited commercial availability of 16 channel knee coils, we evaluated the performance of the proposed coil array with that of a custom made 16-channel coil array with standard rectangular design elements. Experimental and simulation results with cylindrical phantoms are presented that demonstrate the high central SNR and rapid peripheral SNR rolloff of the design, two intrinsic benefits of the bell coil relative to the current art of loop coils.

Materials and Methods: Fig 1 illustrates the array design for both the cases. Adjacent bell-loop elements were overlapped to null mutual inductance. The bell loop coil pairs were organized into two adjoined concentric rings of eight elements; the rings were wrapped around a cylinder of length 21cm and 14 cm dia wrapped with foam to make the outer dia 21 cm. To compare the SNR experimentally, images of the same cylindrical knee phantom (relative permittivity = 72 and conductivity = 0.75 S/m) were acquired for both the arrays. 16-channel acquisition system (GE Excite, 1.5T) was used and a fast spin echo sequence was used with a TE of 14 ms, a TR of 500 ms and FOV of 24cm. The body coil was used to transmit signal for both the cases. The simulation of the coil was performed using finite element method based full-wave 3D electromagnetic simulation of the coil model, and post processing of the computed field. For exporting the field values from the tool, the volume of dielectric load (which approximates phantom or human anatomy Knee) was decomposed into voxel dimension of 5mmX5mmX5mm. The complex coil sensitivity (B1-map) S, was calculated using tangential magnetic fields, $S_i = -(H_{y(i)} - jH_{x(i)})/2$. SNR = $\sum_i((S_i{*}\ R_n{*}\mathrm{conj}(S_i)^T)^{1/2})$, where R_n noise correlation matrix .

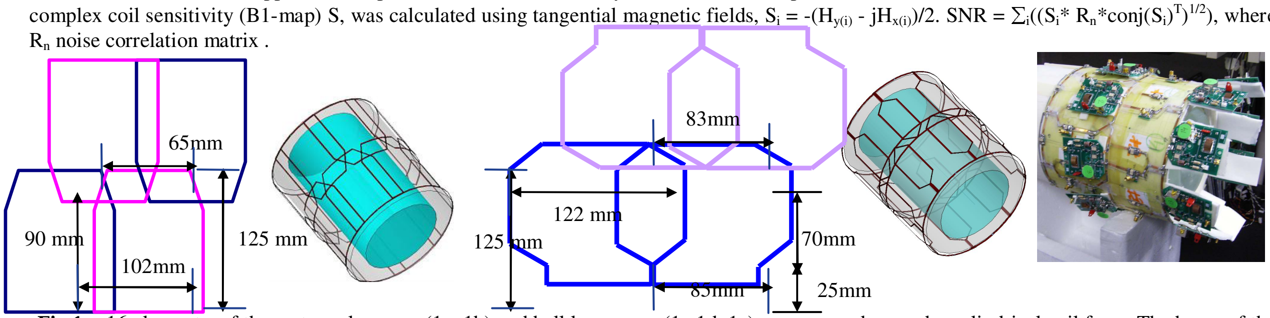

Fig 1: 16 elements of the rectangular array (1a, 1b) and bell loop array (1c,1d, 1e) are wrapped around a cylindrical coil form. The bases of the bell loops are placed side by side. There is no overlap at the bases of each coil; overlap occurs only at the wings.

Results: For the bell loop array, it was found that S12 coupling coefficient between nearest neighbor and 2nd nearest neighbor coil elements while loaded (and with preamp decoupling) were –16dB and –12 dB respectively. Fig 2 is a collection of spin echo images of a phantom, displaying images from each of the 16 individual receive coils as well as the sum-of-squares combination image (located at bottom left corner). Fig. 2 thus demonstrates good isolation between coil element. Fig. 3 shows the SNR profile through the center of the phantom for the 16-bell-loop and 16-rectangular coil arrays. The SNR values were obtained along the centerline of an axial image of a cylindrical knee phantom. The relative SNR gain provided by the bell-loop array compared to the rectangular array ranges from -1% at the periphery to 12% at the center, According to simulation SNR of bell loop array was 14.65% better than rectangular loop array which is close to the experimental results.

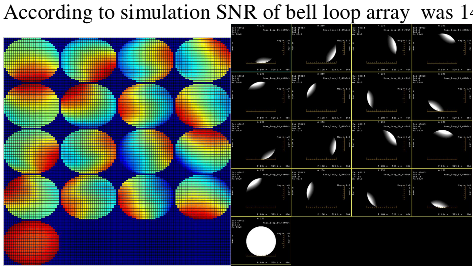

Fig 2: 16 channel simulated and experimental image of the Phantom from bell loop.

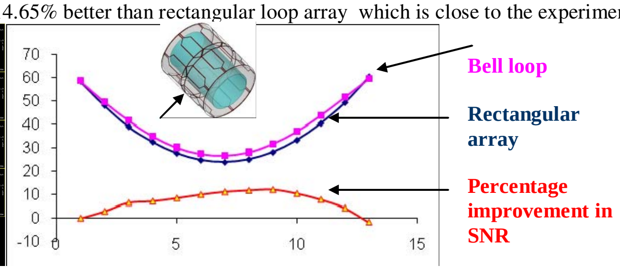

Fig 3: The SNR profile (plotted along vertical axis) through the center of the phantom for both the arrays (axial distance in cm, along x axis). The red curve shows the percentage improvement of the bell compared to the standard array.

Conclusion: 1.5 Tesla 16 channel bell loop array and standard rectangular array have been constructed and used in knee phantom imaging. The bell coil array provides significant SNR improvement over the rectangular coil. The improvement in the bell coil array sensitivity is highest at the center and falls off rapidly at the periphery, which is a desirable feature. The unique shape of the bell loop coil results in this desirable SNR profile.

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References: [1] "Quantative MRI of cartilage and bone: degenerative changes im osteoarthritis", Eckstein *et. al,* NMR Biomed. 2006: 19.
[2] 16 channel knee coil by MR Instruments.