Concentric Coil Array with Multidimensional Symmetry for Parallel MRI of the Heart

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INTRODUCTION Parallel imaging techniques exploit the varying sensitivity patterns within arrays of radiofrequency detector coils in order to accomplish much of the spatial encoding that is normally achieved through the use of magnetic field gradients. Arrays that are used for parallel MRI typically consist of a set of elements aligned in a single preferred direction. Such arrays are effective at reconstructing data along a single dimension but are less effective when data is undersampled in planes that are oblique to the main axis of the array. This restricts the image planes that can be acquired using a particular coil array. It has also become clear that the greatest imaging speed benefits can be realized when data is undersampled and reconstructed in multiple directions at once (1). Thus, there is a need for arrays that have simultaneous sensitivity variations in several directions. While this multi-directionality can be achieved by using grids of coil elements, having a fixed number of digital receivers requires these grids to have fewer elements in any specific direction than an equivalent linear array.

A novel type of array has been proposed (2) that achieves multi-directional spatial encoding by using concentric coil elements that are placed on top of each other. The conductor path of each element is crossed several times in order to produce a series of "lobes" that have opposing current directions. For example, a 2-lobed coil is equivalent to the "figure 8" topology used in conventional quadrature surface coils. The concentric arrangement of coils means that while each coil element has more or less equivalent spatial coverage, the alternating current directions create phase variations that give the coil sensitivities enough distinctness to reconstruct parallel MRI data (3). In addition, the alternating symmetries of the current paths reduce both the inductive coupling and the noise correlations seen by the coil elements.

In this report, we describe initial applications of a concentric coil array with multidirectional symmetry to *in vivo* imaging. We present imaging results using an array that was optimized for viewing the heart. Cardiac imaging generally requires the use of several non-standard image planes, and therefore these applications are able to exploit the multidimensional nature of the sensitivity variations within the array.

MATERIALS and METHODS Our initial prototype consisted of four elements: a single square coil, two 2-lobed coils, and a single "cloverleaf" coil that had four lobes. While symmetry requirements constrained the design of the array to some extent, there was still a great deal of flexibility in choosing the size as well as the angular offset of each coil. We attempted to optimize our array for imaging at a depth of 10-15 cm below the surface of an infinite half plane. A Biot-Savart calculation was used to determine the coil sensitivities and a modification of the analytic calculation in (4) was used to determine the noise seen by each element.

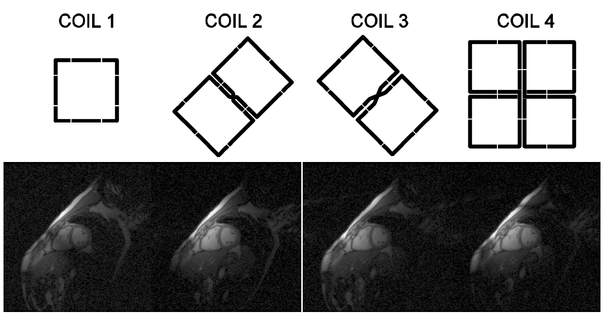

FIGURE 1

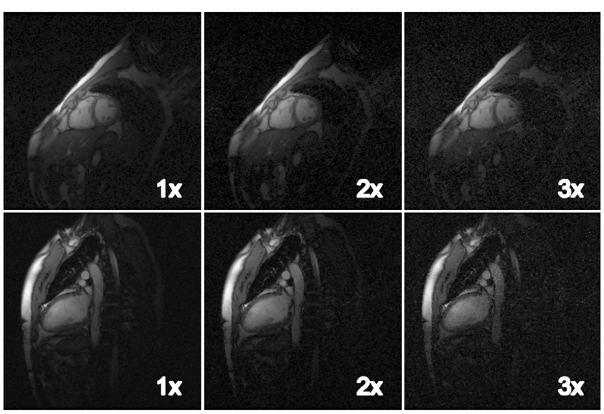

FIGURE 2

RESULTS Figure 1 (top row) shows a schematic diagram of the coils used in the final array. The square coil was 8.5 cm on one side. The two 2-lobed coils were both 18x10.8 cm and were aligned +/- 45 degrees with respect to the main magnetic field. The 4-lobed coil was 18 cm on each side, with the crossed portions aligned with the main magnetic field. Because the symmetry conditions of the concentric array required great precision in the conductor layout, the four coils were etched on a two-sided PVC substrate with 0.25-inch traces. The coils were each tuned to 63.86 MHz and matched to 50 ohms. Active pin-diode blocking was used to limit currents during RF transmit and wire-wound baluns were added to each coil input in order to reduce cable shield currents.

Figure 1 (bottom row) shows magnitude component coil images taken in a short-axis plane through the heart of an adult human volunteer. Imaging was performed on a 1.5 T GE Signa system with Excite technology and a cardiac-gated SSFP pulse sequence (TR=4.2 ms TE=1.9 ms $\alpha=45^o$ BW=125 kHz FOV=44 cm matrix 224x192). The coil elements show very similar magnitude variations, but the phase variations are still sufficient to reconstruct undersampled data.

Figure 2 shows composite short and long-axis images using the sequence described above. Fully gradient-encoded images (first column) show good coverage through the posterior surface of the heart. Also shown are 2- and 3-fold accelerated short-axis images reconstructed using the SENSE (5) algorithm. For these reconstructions, a separately-acquired image in the same plane was used as a sensitivity reference. No artifacts are seen in these images except for the expected loss in SNR that occurs with the use of parallel imaging.

DISCUSSION We have introduced a concentric coil array optimized for cardiac parallel MRI. In initial applications, the array provides good quality reconstructions and excellent coverage for both fully gradient-encoded and parallel imaging.

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