Optimized Coil Design for Parallel Imaging

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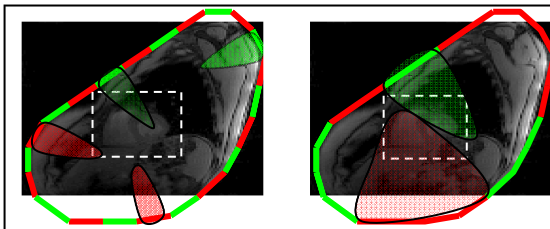
INTRODUCTION:

Parallel MRI utilizes multiple RF receiver coils as encoding engines, whereby the spatial sensitivity profiles of these coils is used in unison with phase encoding to obtain higher accelerations with reduced folding artifacts. The current state-of-the-art in electronics and manufacturing allows construction of coil arrays with a greater and greater number of **similarly shaped** coil elements, resulting in a considerable increase in data volume., and leading to overload of computational resources and impractical image reconstruction times. This increasing number of coil elements has not been proportional to the increase in the speed of imaging, or to a decisive scalable advantage in image quality. This is due in part to the physics of electromagnetic fields, which limit the RF coil sensitivity profiles to smooth functions, as well as to the coil design techniques that are currently being adopted. Spatial sensitivity profiles and B1 field penetration of individual coil elements are the major determinants of the effectiveness of a coil array, and are a direct function of coil size, shape and location with respect to the desired Region of Interest (ROI);, However, no systematic investigation of the effect of varying individual coil element size and shape has been conducted to date. Massively parallel image reconstructions provide an SNR advantage close to the coil surface, but no substantial advantage deeper within the imaged structure. Hardy et al. showed that smaller elements on the anterior side of the torso, and larger elements on the posterior side produced better g-factor maps at the heart, as compared to similarly sized elements on both sides [1]. These results indicate that, for parallel imaging, optimal coil arrays should have smaller coil elements in the vicinity of the ROI, which deliver high SNR and large intensity variations in the ROI, and also contribute most of the spatial encoding, and larger coils for elements further away, in order to insure that these elements receive a significant signal contribution, as opposed to noise from the ROI, and primarily contribute to SNR enhancement, but less to spatial encoding. In this work, we show that it is possible to follow a simple intuitive approach, to reduce the size of the array without loss of image quality or acceleration speed by linearly combining subsets of small coils into larger coil elements, where these elements have differing sizes.

METHODS

We utilized a 2D cardiac image dataset courtesy of Massachusetts General Hospital, which was acquired using 128 coil elements having similar size and shape arrayed around the torso. Fig.1a shows the sum of squares image from all the coils as well as a schematic representation of the coils shown in red and green for clarity. We pick the ROI to be a white square around the heart and show the penetration of four coil elements in the array, schematically represented with partially transparent colored areas; this shows that, due to the size of the elements, coils which are furthest away from the ROI. have little or no contribution to the ROI individually. Fig.2b shows the same cardiac image, with the same coils combined to form larger elements, whereby the size of the elements closest to the ROI is small compared to the ones further away to insure that all elements have a lobe pattern with sufficient SNR within the ROI so as to provide reliable magnitude and ***phase*** information from this region. The penetration of two elements is shown schematically with partially transparent colored areas.

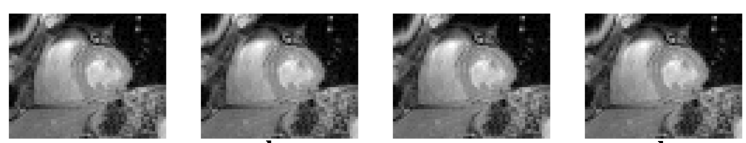


a **Fig.1** b

Fig.1 demonstrates the principle we used in order to combine the elements in the 128-coil array, thus minimizing the size of the array and achieving an optimal coil configuration for accelerations within the chosen ROI. We use SENSE to compute accelerated images. Starting from the 128-coil dataset, we compute accelerated reconstructions. The image acceleration factor is increased until aliasing artifacts become apparent in the ROI; we then use the highest acceleration, which is free from visible artifacts as the reference image. Subsequently, we combine the elements, as described in Fig.1, in order to form arrays that have 16, 32 and 64 elements. This is done by insuring that all the elements in the newly formed arrays, maintain a minimum signal intensity within the ROI which is above a threshold, defined as the sum of the minimum signals from all the 128 coils within the ROI, divided by the number of coils in the reduced array. Once the new coil combinations are defined, new datasets are computed for the combined elements, and SENSE accelerated reconstructions are computed for the highest acceptable acceleration found for the initial dataset. Finally, the reconstructed images are compared for SNR and artifact power to the reference image computed from the 128-coil array, within the heart ROI.

RESULTS

The maximum artifact-free 2D acceleration achieved in the ROI using the 128-coil array was found to be 5, and is shown in Fig.2a. Reconstructions of 5x accelerated images for the 64, 32 and 16 element arrays are shown respectively on Fig.2b-d. No visual difference can be noticed. Fig.3 shows the plots of the SNR and the Artifact Power within the ROI for all coil configurations. Image Reconstruction times for the 128, 64, 32 and 16 element arrays were computed on a Macintosh computer having a 2.2Ghz clock speed using MATLAB to be, respectively, 6247s, 780s, 92s, and 8s.



a b c d
Fig.2

DISCUSSION

Our study demonstrates that the advantages of image acceleration speed and image quality within the ROI achieved using massively parallel coil arrays, are best maintained using carefully designed coil arrays having a reduced number of less coil elements. These results will be directed towards development of an approach to **designing optimized RF coil arrays for parallel imaging, where the number of coil elements is minimized for a desired acceleration factor**. These coils will be able to achieve the same or better performance than the currently designed massively parallel (32, 64, 128.. elements) arrays, but with fewer elements, eliminating data overload issues, and allowing for real-time image reconstruction speeds. The study is geared towards identifying new principle of coil design for parallel imaging of structures further from the body surface, and will be used for building and testing optimized coils that may prove useful for higher spatial and temporal resolution cardiac imaging. The designs will take into account the relative contributions of coil Ohmic noise and subject noise on coil design.

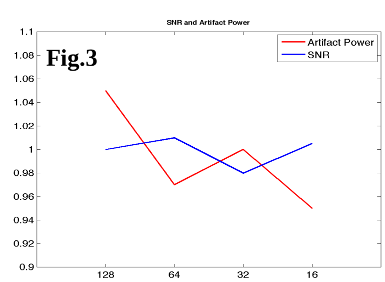


Fig.3

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[1] Magn. Reson. Med., 55:1142-1149, 2006.

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