A 20 Coil Array System for Parallel Imaging-Accelerated Multiple Mouse MRI

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Introduction

The reduction of MRI acquisition time by parallel imaging (PI) with phased array coils has standardized the inclusion of multichannel receivers in modern clinical systems. Dedicated small-animal research systems have also provided an increasing number of receiver channels in recent years. For small-animal MRI, the use of multichannel receivers permits not only PI-accelerated acquisitions of a single subject [1], but also improving throughput by simultaneously scanning several animals at once [2]. This is particularly important to reduce MRI usage cost, because scanning many animals is often required to achieve adequate statistical power. To date, the common methodology for multiple-mouse MRI has been to dedicate an independent volume coil to each mouse and to increase the number of mice scanned at once, *N*, to improve throughput [3]. However, many routine mouse imaging protocols are relatively short, and as such, the animal preparation time rather than the imaging time can limit study efficiency, particularly for studies involving complicated preparation such as tail vein catheterization. It is therefore important to consider a paradigm shift from imaging as many animals at once to imaging a more manageable number with higher acceleration per animal [4]. The goal of this work was to simulate and manufacture a throughput-optimized small-animal MRI system that best utilizes the next generation of small animal MRI systems that will be equipped with 16 receiver channels.

A number of multianimal array configurations, that varied the *N* mice that could be simultaneously scanned and the number of receive array elements *C* that could be dedicated to each mouse, were previously simulated and analyzed in terms of PI performance (i.e. achieving low *g*-factors for high reduction factors, *R*) [5]. In this work, we present the throughput-optimized system, consisting of a 5-element transmit and 15-element receive array capable of simultaneously imaging $N = 5$ mice with a $C = 3$ element subarray dedicated to each mouse, and demonstrate its use for PI-accelerated multiple-mouse MRI on a 7T 30-cm bore Bruker Biospec MRI scanner.

Methods and Materials

Receive coil circuitry was milled from a flexible copper substrate and wrapped around G10 tubing with a 30-mm outer diameter (OD) and a 28-mm inner diameter (ID). The coils were populated with ceramic capacitors, RF chokes, and PIN diodes to achieve the desired tuning, matching, and active decoupling from the transmit circuitry. Each of the $N = 5$ volumetric subarray consisted of $C = 3$ rectangular elements measuring approximately 2 cm along the z direction and 3.5 cm along the angular direction. A benefit of three-element circumferential arrays is that each element can be overlapped with both adjacent coil loops to minimize mutual coupling between coils. The proper coil overlap was determined experimentally and low input impedance preamplifiers were used as additional compensation for imperfect overlap geometries.

The use of individual shielded transmit coils confined the receive subarray coil sensitivities to a single mouse and reduced *g*-factors over the full field of view (FOV) for a given PI reduction factor [5]. Therefore, a set of $N = 5$ birdcage coils were fabricated around a 51-mm OD G10 tube with RF shielding surrounding a 64-mm OD tube. Active PIN diode decoupling of transmit from receive coils was employed. After bench and image-based testing, the array modules were assembled into a fabricated coil holder (Fig. 1) that fit snugly into the 20-cm ID permanent gradient insert. Although a side-by-side geometry is more desirable for 2D multislice multianimal imaging, the coil subarrays had to be staggered due to limited bore space. However, by using an encoding scheme in which the receiver channel center frequency is shifted according to the associated mouse position along the readout direction (here along the U-D direction), all mice can be simultaneously encoded with a FOV covering only a single mouse [2]. Likewise, PI acceleration for all mice can be accomplished by setting the PI acquisition for only one mouse. The SNR of the imaging system compared to the conventional Bruker 35-mm mouse birdcage coil was tested on phantoms with T_1-weighted MSME acquisitions (TE/TR = 14.5/1000 ms; FOV = 3.42 × 3.42 cm^2; matrix = 128 × 128; slice thickness (ST) = 1 mm; NR = 100). Noise correlation matrices were calculated from acquisitions through all coils with the transmitter disabled. To demonstrate the multianimal acquisition scheme *in vivo*, T_2-weighted RARE images (TE/TR = 57/3500 ms; matrix = 256 × 256; ST = .75 mm; 3 averages; acquisition time = 3 min 40 s) of five tumor-bearing mice were acquired through each subarray with a single mouse FOV (3.42 × 3.42 cm^2) that aliased along the PE dimension (L-R) to encode all mice.

Results and Discussion

Average noise correlation between intraarray elements (i.e. the adjacent elements dedicated to a common mouse) was 9.66% while average interarray element correlation was 1.46%. S_{12} measurements indicate that coils are sufficiently decoupled to perform PI on each mouse without contamination by the aliased signal from other mice. Through baseline unaccelerated acquisitions, the 3-element subarrays achieve in the worst-case (i.e. in the image center), twice the SNR achievable when using the conventional mouse birdcage coil. Therefore when desired, SNR can be traded for acquisition speed through the use of PI with good results achieved so far with up to $R = 1.6$ per mouse (Fig. 2). T_2-weighed images demonstrate the ability to encode all mice with a FOV appropriate for a single animal (Fig. 3). When study throughput is preferred to image quality, the presented array system can achieve an eight-fold imaging throughput, by combining multimouse and PI strategies, compared to standard imaging hardware.

References

[1] Doty FD *et al* NMR Biomed 2007, 20:304-325. [2] Bock NA *et al* Magn Reson Med 2003, 49:158-167. [3] Bishop JE *et al* Proc ISMRM 2004, 1753. [4] Ramirez MS *et al* Magn Reson Med 2010, 63:803-810. [5] Ramirez MS *et al* Proc ISMRM 2010, 1487.

Fig. 1 20-coil array

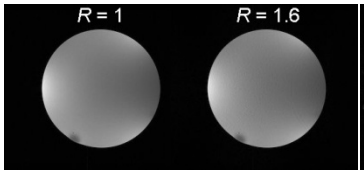

Fig. 2 Subarray phantom images

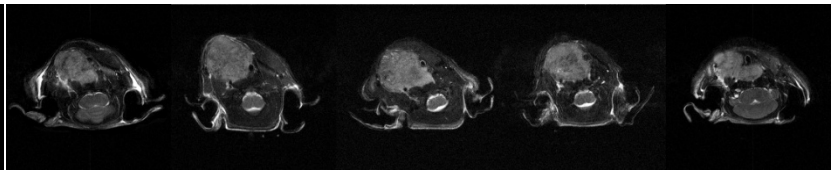

Fig. 3 T_2-weighted images of five mice bearing thyroid tumors