Is a “one size fits all” many-element bore-lining remote body array feasible for routine imaging?

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TARGET AUDIENCE: RF coil designers, and anyone who has contemplated the possibility of replacing local coil arrays with remotely-placed encircling arrays.

PURPOSE: It has long been understood that signal-to-noise ratio (SNR) diminishes with increasing distance of coils from a body, and this rule of thumb has motivated the design of close-fitting arrays for applications requiring high SNR. However, if a many-element array could be mounted behind the scanner covers while preserving much of the SNR performance of close-fitting arrays, the benefits for patient comfort and simplicity of workflow would be dramatic. Some intriguing evidence suggests that high-performance remote encircling arrays might not be out of the question. It has been shown, for example, that ultimate intrinsic SNR in the center of a cylindrical body is independent of distance from the body, at least in the absence of coil noise [1]. We have performed simulations suggesting that, with modest conductor losses and even in the presence of some degree of parallel imaging acceleration, SNR in deep-lying body regions such as the abdomen may be preserved as compared with close-fitting array geometries. As shown in **Fig 1**, we have also previously demonstrated that, for deep regions far from a loop coil, liftoff of the coil from the object surface actually improves SNR at field strengths of 3T and higher [2]. This result, though potentially counterintuitive, is consistent with previous theoretical observations [3], and it raises the question of whether liftoff benefits might increase for large numbers of coils operated together, and might counterbalance some effects of coil noise in a suitably designed array. We therefore set out to simulate and build a remote body array prototype at 3T. We report our experience to date, including practical design choices, quantitative validations, and unexpected challenges encountered in the process.

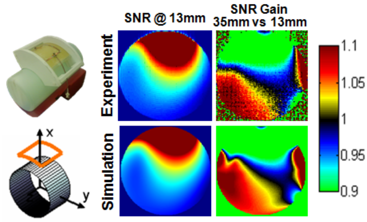

Fig. 1. Simulations and experiments confirm SNR increases in deep-lying regions with liftoff of a loop coil from the surface of a phantom at 3T (1).

THEORY AND METHODS: Small-scale prototypes and validations: *Simulations:* A dyadic Green’s Function (DGF) framework for cylindrical geometry was used for numerical simulations of ultimate intrinsic SNR and of the performance of particular array designs [4]. A detailed noise model including the effects of cross-sectional current patterns in coil conductors, lumped circuit elements, radiation losses, etc, was used, with calibration of free parameters using measurements in carefully-constructed single coil elements [5]. *Experiments:* 24- and 30-element prototype cylindrical arrays closely matching simulated designs were constructed (**Fig 2**), with wire elements to limit copper loading from other elements [6]. 14x14cm rectangular elements were overlapped to null inductive coupling and were the same size in both arrays, resulting in a diameter of 31.5cm for the 24-element array, and 39.4cm for the 30-element array, respectively. Data were acquired in a long fluid-filled cylindrical phantom of 29.5cm diameter ($\sigma = 0.604$S/m, $\varepsilon_{rel} = 81.81$) on a Magnetom TIM Trio 3T scanner (Siemens, Erlangen, Germany), with the array and the phantom positioned at isocenter in place of the retracted patient bed. Large-radius 124-element prototype: *Simulations:* DGF simulations were used to explore a large design space for fully-encircling arrays as well as for 72-element curved top segments. Parameters studied included coil array diameter, number of elements, proximity to RF shield, coil temperature, etc. *Experiments:* The design selected for construction consisted of a 72-element cylindrical top segment (diameter = 50cm) and a 52-element flat bottom segment which sits in the patient table (**Fig 3**). Array segments consisted of 10.75x11.5cm overlapping wire coils in the cylindrical anterior array, and 7.5x10.5cm etched copper coils in the well-loaded posterior array. Top and bottom segments were designed to nest with minimized inductive coupling. Tuning, matching, and overlap were optimized inside a 60cm bore simulator with a detuned birdcage body coil in place, to compensate for interactions with body coil rungs and end rings. Preamplifiers were mounted on coil elements, and cables were bundled into sets of 9, then combined into bundles of 18 with multiple cable traps, and connected to our 128-channel Magnetom TIM Trio scanner. The same large cylindrical phantom was used as for small-scale models.

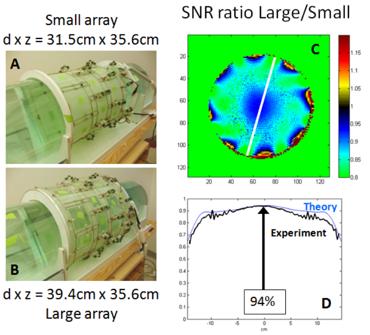

Fig. 2. Validation of simulations and demonstration of preserved central SNR with lift-off in encircling arrays at 3T. A) 31.5cm diameter 24-element array. B) 39.4cm diameter 30-element array. C) SNR ratio. D) Profile (along white line) through SNR ratio. Note correspondence of theory and experiment, and loss of only 6% central SNR with large diameter array.

RESULTS: **Fig 2** illustrates the good match obtained between simulations and experiments for the small-scale prototypes, with only very modest SNR loss associated with a substantial increase in array radius. **Fig 3** juxtaposes a schematic design with a photo of the 124-element prototype. **Fig 4** shows that, despite a good match in qualitative sensitivity patterns, measured SNR for the 72-element top segment is significantly less than predicted by simulations. The primary cause of this proved to be noise coupled from other coils’ preamplifiers [7]. **Fig 5** demonstrates how the presence of other active coils degrades SNR of a single element. The added noise cannot be removed through matched-filter optimum-SNR reconstruction. Interestingly, the high Q of the lightly loaded coil elements in this case enhances preamplifier noise coupling, such that it becomes a significant player in overall performance.

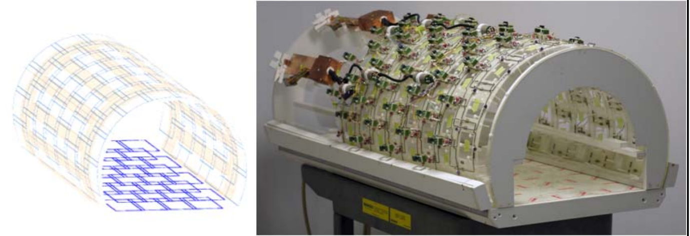

Fig. 3. Schematic (left) & photo (right) of 124-element remote body array prototype.

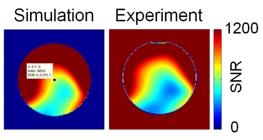

Fig. 4. Simulated (left) and measured (right) SNR of the 72-element top segment of the remote body array. Measured central SNR is 25% lower than predicted.

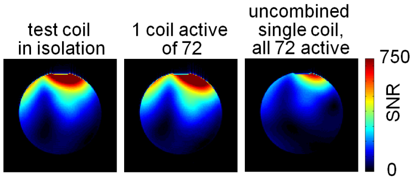

Fig. 5. SNR degradation due to the many-element milieu of the remote body array. Preamplifier noise coupling contributes substantially to this loss.

DISCUSSION AND CONCLUSIONS: Despite encouraging preliminary data in smaller-scale models, we encountered unexpected practical challenges in matching predicted SNR performance for our full-scale remote body array prototype. Much of the performance degradation was attributed to preamplifier noise coupling, which may be mitigated to some degree by appropriate broadband matching strategies [7,8] and by use of lower-noise preamplifiers. Further improvements would likely result from removing the scanner’s resident body coil, whose influence was limited but by no means eliminated in our design (and in this case multi-element RF transmission capability would represent a natural extension of the design). At field strengths higher than 3T, the incorporation of electric dipole elements represents a promising option for further performance enhancement [4,9]. Coil cooling might also be considered, but our simulations suggest that the resulting SNR gains would likely not justify the added complexity. In summary, while a “one size fits all” remote body array remains a tantalizing proposition, many challenges must still be overcome for it to be considered as a practical design option for routine imaging.

REFERENCES: [1] Schnell W et al. IEEE Trans Ant Prop 2000;48(3):418-28. [2] Duan Q et al. ISMRM 2009, p. 4742. [3] Vesselle H et al. IEEE Trans Biomed Eng 1995;42(5):497-520. [4] Lattanzi R et al. MRM 2012;68(1):286-304. [5] Duan Q et al. ISMRM 2010, p. 3858. [6] Wiggins GC et al. MRM 2009;62(3):754-62. [7] Wiggins GC et al. ISMRM 2012, p. 2689. [8] Vester M et al. ISMRM 2012, p. 2690. [9] Wiggins GC et al, ISMRM 2012, p. 541.