Efficiency of Single-loop and Quadrature Surface RF Coils in the Human Brain at 9.4 Tesla

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Introduction

NMR spectroscopy, especially in a single-voxel, is commonly performed with surface coils such as single-loop and "quadrature" coils since only a limited field of view is required and higher signal-to-noise ratio is achievable in comparison to single channel volume coils. However at high magnetic field transmit and receive B_1 profiles are significantly distorted as demonstrated previously at 7 T [1]. Here we investigate the impact of these B_1 field distortions in the human brain at 9.4 T when using single-loop and quadrature RF coils.

Methods

Home-built single-loop (10cm in diameter) and quadrature (two overlapping loops, each 7cm in diameter) RF coils were used to image the occipital lobe in humans. Healthy human subjects were studied in a 9.4 Tesla/65cm bore magnet [2] interfaced to a DirectDrive 8-Transmit Channel Varian console. $|B_1^+|$ maps were obtained with the two flip-angle technique [3]. To estimate the receive $|B_1^-|$ profiles, the product $\rho.|B_1^-|$ was also derived (ρ being proton density). The two loops of the quadrature RF coil were driven by two independent channels, rather than with a classic hybrid (transmit-splitter/receive-combiner), thereby enabling the use of any phase shift between the two loops instead of the fixed 90° phase with a hybrid. RF efficiency maps were obtained for the quadrature RF coil by dividing the actual $|B_1^+|$ by the sum of $|B_1^+|$ of each loop (range: 0→1). Data processing was carried out in Matlab.

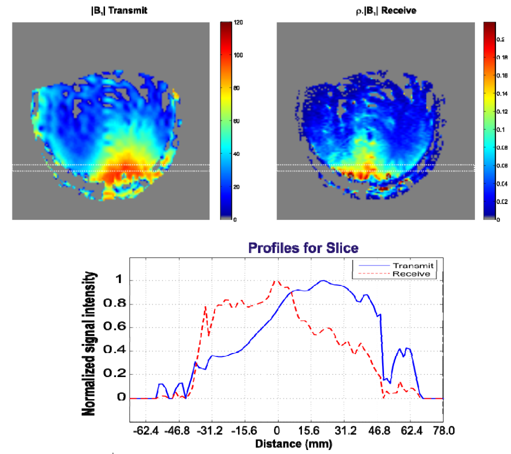

Fig. 1: $|B_1^+|$ and $\rho.|B_1^-|$ maps obtained with a single-loop coil in the human brain at 9.4 T with the mean profiles within the defined slice.

Results and Discussion

Single loop. $|B_1|$ maps in the human brain at 9.4 T with a single-loop RF coil clearly show two distinct patterns for B_1^+ and B_1^- with opposite rotational direction (Fig. 1). Here we use $\rho.|B_1^-|$ to approximate the overall $|B_1^-|$ profile. (Note that this lack of overlap between B_1 profiles is not observed in small animals where the sample size is smaller than the ^{1}H RF wavelength). Because transmit and receive profiles reach their maximum in different locations, a single voxel used in localized spectroscopy cannot be positioned optimally for both transmission and reception. In principle, higher RF power could be used to obtain higher peak B_1^+ in a voxel located where B_1^- is maximal. However, power deposition (SAR) becomes a limiting factor at very high field and increasing transmit power is not a favorable option. A classical approach to enhance RF efficiency is to use a 2-loop quadrature coil. However, it has been shown that at high field B_1^+ destructive interferences [4] can reduce RF efficiency between neighboring coils, thereby requiring proper adjustment of their relative phases [5,6].

Two loops ("quadrature coil"). Results show that when the two-loop coil was driven in classic quadrature mode, i.e. with a 90° phase between the loops, the transmit efficiency in a region-of-interest (ROI) located in the occipital lobe (black box in Fig. 2 left) was about 86% (Fig. 2, top). In contrast, when the transmit phase between these loops was locally adjusted using local B_1 phase shim [5,6], the transmit efficiency in the same ROI was increased to 98% (Fig. 2, bottom). As a result, the peak RF power was reduced by ~30% for a given excitation flip angle. Experimental measurements in a human head (Fig. 2, left) were highly consistent with simulated data obtained using similar RF coils design and a human head model (Remcom software) (Fig. 2 right). The phase shift calculated for local B_1 phase shim was 67° in experiments and 60° in simulations.

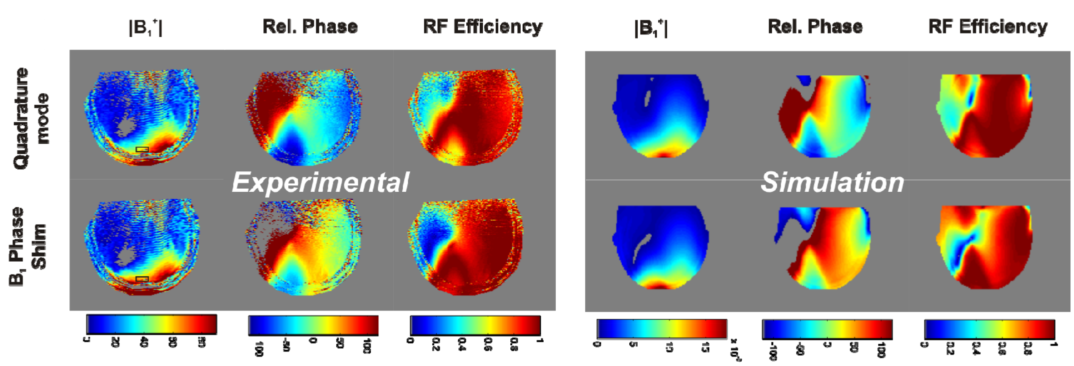

Fig. 2: $|B_1^+|$, relative phase difference between the loops and RF efficiency when using two loops in quadrature mode and with determined transmit phase. Experimentally measured maps in the human brain at 9.4 T (left) closely matched the simulated maps (right). RF efficiency is given by the ratio of actual B_1^+ to available B_1^+ [6].

Conclusion

Single-loop RF coils do not appear optimal for NMR spectroscopy in human brain at 9.4 T because of limited overlap between transmit and receive B_1 profiles. However, "quadrature" surface RF coils may be used as long as the relative phase between the two loops is optimized for a given ROI to maximize B_1 transmit efficiency, thereby reducing SAR.

References

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