Design and SAR Estimation of a Segmented Loop for Dual Coil CASL at 9.4 T

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Introduction

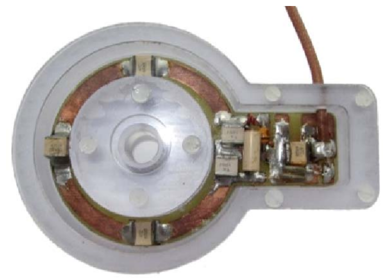
Dual Coil Continuous Arterial Spin Labeling (DC-CASL) increases SNR and reduces the underestimation of cerebral blood flow due to magnetization transfer effects significantly [1,2]. In DC-CASL, special labeling coils are positioned in the neck of the subject, just above the carotid arteries to provide a flow driven adiabatic inversion. We have developed a balanced detunable segmented loop coil for DC-CASL in humans at 9.4 T. Furthermore, Finite Difference Time Domain (FDTD) simulations were performed to show that this labeling coil can be operated safely within the SAR limits of the IEC safety regulations and to estimate the phase shift that lead to similar transmit fields in the left and right common carotid artery.

Materials and Methods

CASL Coil: The developed circular CASL coil (Ø=50 mm, f_r=399.72MHz) consists of four evenly distributed capacitors. To create a matching and active detuning capacitor, the input capacitor was split further. Since the coil was fairly insensitive to load variations, a variable tuning capacitor was not necessary. The coil input was matched to 50 Ω and connected to a coaxial cable through a cable trap. The housing was made of acrylic glass and designed so that all conducting parts of the coil are separated from the subject's skin by at least 5 mm. To have more degrees of freedom in coil positioning, we decided not to fix the geometric angle between the coils as previously proposed for 3 T or 7 T CASL coils [3,4].

FDTD Simulation and Duty Cycle Calculation: The electric and magnetic fields were simulated with XFDTD (Remcom, State College, PA, USA) for each coil separately. Both CASL coils were positioned carefully in the area of the common carotid arteries (CCA) of the HUGO human body model which was meshed with a spatial resolution of 1.8x1.8x1.8 mm³. This fairly high resolution was necessary to be able to realistically model the labeling coil. The resulting complex magnetic fields of both channels were combined using Matlab (Mathworks, Natick, MA, USA). Static phase shimming was performed by varying the phase of one of the coils in steps of 15 degrees. The optimum phase shift φ_{opt} was defined as the one that yields minimum differences between the average B_1^+ in the blood voxels of left and right CCA. The phase delay obtained was used to calculate the SAR in any 10 g of tissue, SAR_{10g}, for 1W input power per coil. Furthermore the worst case $SAR_{10g\ worst}$ was determined by summing the magnitude of the electric fields of both coils.

For a CASL sequence, the maximum duty cycle is given as where: τ is the labeling duration and T_R is the repetition time of the sequence. Using the calculated duty cycle, the maximum power, P_{max}, to drive the CASL coils within IEC the safety limits for SAR in any 10 g of tissue, , was determined as , where: σ denotes an additional safety of 25 %. Furthermore, the strongest possible transmit field of the labeling pulse for a given was calculated as using the mean value of the maximum B_1^+ in the left and right CCA along the z-direction for 1 W input power, .



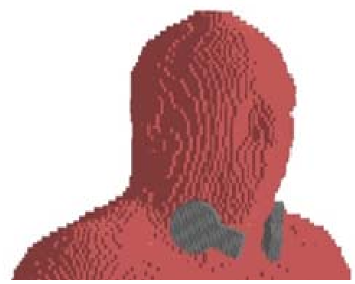


Fig.1: Top: Segmented loop coil for DC-CASL at 9.4 T. Bottom: positioning of coils on HUGO model.

Results

One of the DC-CASL coils for 9.4 T is displayed in Figure 1 (top) and its position on the neck of the XFDTD human model (bottom). Figure 2 shows the transmit pattern for the obtained optimal phase shift φ_{opt} = 90° and 1 W input power per coil. Mean and maximum B_1^+ obtained in the left and right CCA for the same input are listed in Table 1. The simulations returned a maximum local SAR value of 6.2 W/kg for the optimal phase shift condition and 6.8 W/kg in the worst case condition. The results of the calculation of in dependence of the duty cycle are plotted in Figure 3. Since an additional safety of 25 % and the worst case SAR value has been used for the calculation of the maximum input power per coil, the total safety margin amounts to 37 %.

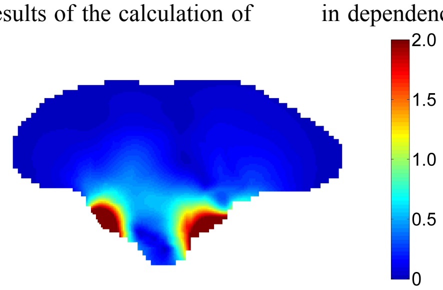


Figure 2: Transmit field pattern in µT for optimized phase shift of 90°. 1 W input power per coil.

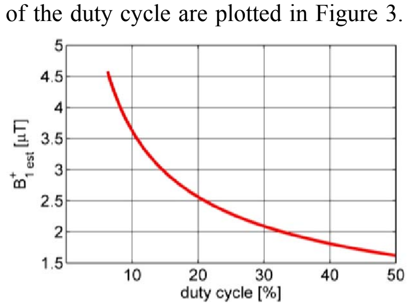


Figure 3: $B_1^+{}_{est}$ over duty cycle (SAR = 75 % of IEC limit of 10 W/kg).

	left CCA	right CCA
mean B_1^+ [µT]	0.87	0.79
max B_1^+ [µT]	1.26	0.95

Table 1: Mean B_1^+ and maximum B_1^+ along z-direction in left and right CCA respectively. Values obtained with 1 W input power per coil.

Discussion and Conclusion

According to previously performed Bloch equation simulations, a minimum labeling pulse power of about 2.3 µT is necessary to obtain sufficient labeling in DC-CASL [2]. Although higher power levels are necessary at high field strengths, our simulations show that this level can be achieved without exceeding the IEC safety regulation limits even at 9.4 T for . A safety margin of 37 % was included in the simulations to account for deviations in the position of the coils.

References

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