The Influence of Design and Position of the Labeling Coil on the Efficiency in CASL Experiments at 7 T – A Computer Simulation

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Introduction: Perfusion weighted imaging using continuous arterial spin labeling (CASL) is capable of measuring cerebral blood flow [1, 2]. Measurements at ultra-high field strengths, such as 7 T, are expected to be more sensitive because of the increased signal-to-noise ratio and the prolonged T_1 relaxation time of arterial blood. However, if a separate surface coil is used for the adiabatic inversion of arterial spins the profile of the produced $\mathbf{B}_1^+$ field depends strongly on the coil design. As this is true for all field strengths it is more pronounced at 7 T. This and the position of the coil may influence the efficiency α of the inversion. For quantification of perfusion in CASL experiments, however, a reliable estimation of the inversion efficiency α is required. Therefore, a wide range of simulation software was developed [3, 4]. In the presented work the influence of the position of the labeling-coil as well as the labeling-coil design on the produced $\mathbf{B}_1^+$ field profile and therefore on the achieved inversion efficiency is investigated. The $\mathbf{B}_1^+$ profile at the position of labeling (expected position of carotid artery) was determined under conditions close to reality.

Method: The determination of the inversion efficiency was based on a solution of the Bloch equations using the hard-pulse approximation [5, 6]. The simulation of the time dependent magnetization was started far below resonance and ended above resonance at a distance of 3 cm. T_1 and T_2 relaxation times of 2000 ms and 250 ms for arterial blood at 7 T were assumed. It should be noted that slightly different values for T_1 and T_2 do not affect the results of the simulation substantially. As the inversion efficiency is relatively insensitive to the blood flow velocity within the physiological range [3] and as the influence of the cardiac cycle can be neglected as long as the labeling pulse comprises at least one cardiac cycle [4], a constant blood flow velocity of 20 cm/s was assumed. The $\mathbf{B}_1^+$ field of the labeling-coil was determined by simulations using the HFSS software package (Release 11.1, Ansoft Corp.) A circular (r = 3 cm) and an ellipsoidal (minor axis 3 cm, major axis 6 cm) [7] coil design were assumed. The coils consisted of copper stripe with a width of 2 mm. Two trim capacitors were placed opposite from each other (for the ellipsoidal design at the ends of the major axis). Each coil was driven with a power of 5W. For simulation of the $\mathbf{B}_1^+$ field the coils were placed at the neck of a human head model (one type of tissue, resolution 1 x 1 x 1 mm³) with the coil center above the left carotid artery. For the circular design an identical coil was also placed above the right carotid artery (double-coil approach). The $\mathbf{B}_1^+$ profile was determined at the expected position of left carotid artery, hence, 2.5 cm below the skin surface along head-feet direction. As the distance between the coil and the skin surface was 1 cm the overall distance between coil and carotid artery was 3.5 cm. However, in a real experimental setup it cannot be assured that the center of the coil is placed exactly above the carotid artery. Also the distance of the artery from the skin surface may vary. Therefore, the expected position of the carotid artery was varied parallel and perpendicular to the coil plane and the resulting $\mathbf{B}_1^+$ profiles and inversion efficiencies were determined.

Results: The profiles of the $\mathbf{B}_1^+$ fields produced by the different coil designs along the expected position of the left carotid artery in head-feet direction are shown in Fig.1. The zero-point of the graph corresponds to the center of the coil projected to the expected position of the carotid artery (2.5 cm below skin surface). It can be seen that the shape and the amplitude of $\mathbf{B}_1^+$ is different for both designs. The resulting inversion efficiencies for different gradient strengths are summarized in Tab. 1. In Fig. 2 and 3 the inversion efficiencies in dependence on the distance of the carotid artery from the coil plane and on the position of the carotid artery shifted parallel to the coil plane are shown, respectively. The circular coil design and the left carotid artery were investigated (G = 1.5 mT/m). In Fig. 3 the zero-point of the graph corresponds to the center of the coil projected to the expected position of the carotid artery. It should be mentioned that the abscissa in Fig. 1 corresponds to a spatial variation along the carotid artery (head-feet direction) whereas the abscissa in Fig. 3 corresponds to a parallel translation of the whole artery at a distance of 3.5 cm from the coil plane. It can be seen that in a wide range of positions of the carotid artery the coils are able to provide sufficient inversion efficiencies (> 80%). However, the optimum region is not symmetrically around the coil's center (Fig. 3).

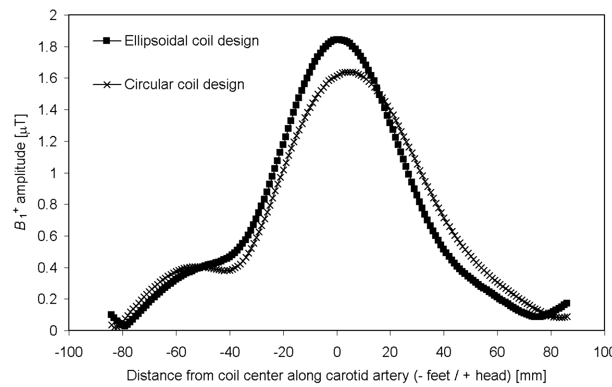

Fig 1. $\mathbf{B}_1^+$ profiles along the carotid artery for different coil designs.

Discussion and Conclusion: It was shown numerically that flow-driven adiabatic spin inversion is a robust method also at 7 T. A wide range of experimental and physiological parameters leads to inversion efficiencies above 80 %. A slight misplacement of the coil at the human neck does not affect the inversion substantially. However, for a quantification of α the design of the coil has to be taken into account. The ellipsoidal design which was determined as favourable because of SAR reasons [7] also leads to slightly higher inversion efficiencies. Further analysis showed that even for identical coil designs the $\mathbf{B}_1^+$ profiles and therefore the achieved inversion efficiencies were different for the left and right carotid artery, respectively (results not shown here). This and the asymmetry in Fig. 3 may be explained by possible coupling of the two coils positioned over both carotid arteries (double-coil approach) and the asymmetric nature of the $\mathbf{B}_1^+$ field.

Gradient strength	α (Ellipsoidal coil design)	α (Circular coil design)
G = 1.5 mT/m	91.2 %	90.2 %
G = 2.0 mT/m	90.2 %	86.9 %
G = 2.5 mT/m	87.6 %	82.5 %

Tab 1. Inversion efficiencies α for different coils.

References: [1] Williams DS et al, Proc Natl Acad Sci USA 1992;89:212-216. [2] Zaharchuk G et al, Magn Reson Med 1999;41:1093-1098. [3] Maccotta L et al, NMR Biomed 1997;10:216-221. [4] Trampel R et al, Magn Reson Med 2004;51:1187-1193. [5] Shinnar M et al, Magn Reson Med 1989;12:74-80. [6] Jochimsen TH et al, J Magn Reson 2006;180:29-38. [7] Wang S et al, Proc ISMRM 2008;16:1046.

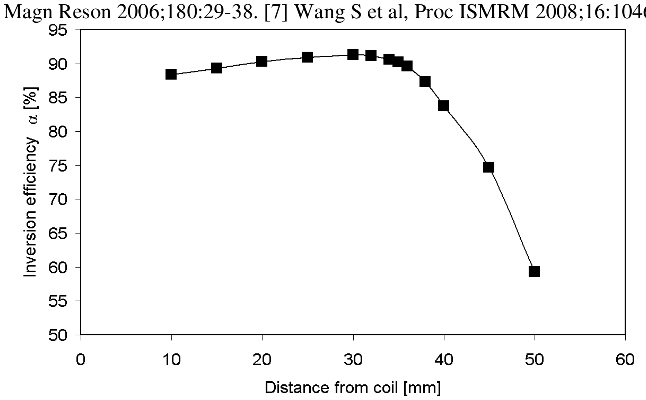

Fig 2. Dependence of the inversion efficiency α on the distance between labeling coil and carotid artery.

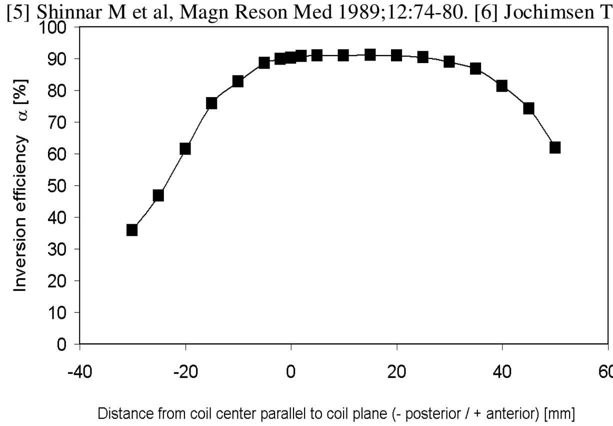

Fig 3. Dependence of α on the position of the carotid artery. The artery was "shifted" parallel to the plane of the labeling coil.