Construction of a 4-channel Transmit/ 4-channel Receive Neck Array for Carotid Artery Vessel Wall Imaging at 7 Tesla

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Target Audience: In this study, a 4Tx/4Rx neck coil was constructed for high-resolution carotid artery vessel wall imaging. The coil was used in parallel transmit mode and its RF safety was thoroughly assessed. Thus, this study is of particular interest to ultra-high field MRI scientists working on RF coil design, parallel transmission (pTx) and coil safety as well as clinicians.

Purpose: Atherosclerotic plaques in the bifurcation of the carotid artery vessels can pose a significant stroke risk from stenosis, thrombosis and emboli, or plaque rupture. However, the possibility of the latter depends on the structure of the plaque and its stability. So far, the assessment of such depositions, and the evaluation of the risk they pose, is not satisfactory with 3 Tesla black blood imaging [1]. It is expected that the SNR increase at 7 Tesla, together with an appropriate and patient-safe RF coil, will result in higher resolution images that would help in better assessing the composition of atherosclerotic plaques in vessel walls. A custom-built neck array was designed and constructed, with the aim of investigating the benefits of the higher field strength using DANTE-prepared black blood imaging [2]. In pTx mode the safety of the subject may be compromised through excessive RF heating and thus the coil must be operated under specific power restrictions.

Methods: A 4-channel transmit array was designed to generate the required B1+ field for the DANTE module to be used, translating into a B1+ field of at least 8μT for 100 mm inferior to the carotid bifurcation (Figure 1). A separate close fitting 4-channel receive array was preferred for improved SNR and parallel (receive) imaging. Geometric, active, passive as well as pre-amp decoupling schemes were employed for adequate isolation between the arrays and their channels. Electromagnetic simulation software, Semcad X (SPEAG, Zurich), was used for safety assessment with human phantoms (Virtual population) [3]. The E-fields for 1 Watt transmission per channel were calculated for each element and their magnitudes were superimposed for the worst case SAR estimation. The transmission power limits per channel were set according to the 10g SAR limit of 20W/kg (IEC 60601 [4]). For simulation validation, temperature measurements were performed on a meat phantom as well as surface heat profile comparison with the help of temperature-sensitive crystal sheets. Finally, a healthy male subject was scanned using a protocol consisting of B1 mapping, RF shimming at an ROI, and 2D and 3D DANTE-prepared FLASH. The selected DANTE parameters were: 150 pulses of 200μs width; flip angle 15°; inter-pulse spacing 1.5ms; gradient strength 18mT/m for Gx, Gy and Gz. Parallel receive imaging was set at R=2, 15° flip angle, 256 X 256 matrix size, 150mm FOV, TE/TR: 3.68ms/5s.

Results & Discussion: The worst-case heating scenario, as defined in the methods section, generated a maximum local SAR of 7.65 W/kg for 1 Watt per channel input. Thus, for 1st level mode (20W/kg max [4]), the power limit was set at 2.6 W per channel. The heating profile was similar to that simulated and the measured temperature increase was within a ±10% margin relative to the simulation. The global SAR power limit per channel was found to be higher (i.e. more allowed power) than the worst case local SAR power limit, and thus did not impose additional power penalty. Figure 2 shows the images from the DANTE-prepared protocol and figure 3 shows a set of anatomical images in the 3 planes. The resolution achieved was 0.6mm isotropic for the 3D protocol and 0.6×0.6×2.5mm for the 2D protocol. The average SNR was measured within the vessel wall location of the two carotid arteries (red circle in figure 2-D) and found to be 27±6 for the DANTE images and for the static tissue closer to the skin the SNR was 55±2 (yellow circle in figure 2-D).

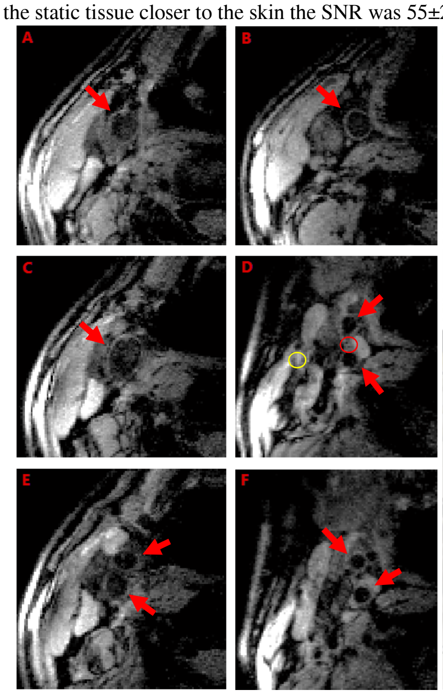

Figure 2: 3D-A, C, E and 2D B, D, F DANTE-prepared FLASH images of a healthy subject. Effective blood suppression, marked with red arrows, will help assess carotid artery plaque in patients. Circles in D show the SNR measurement points.

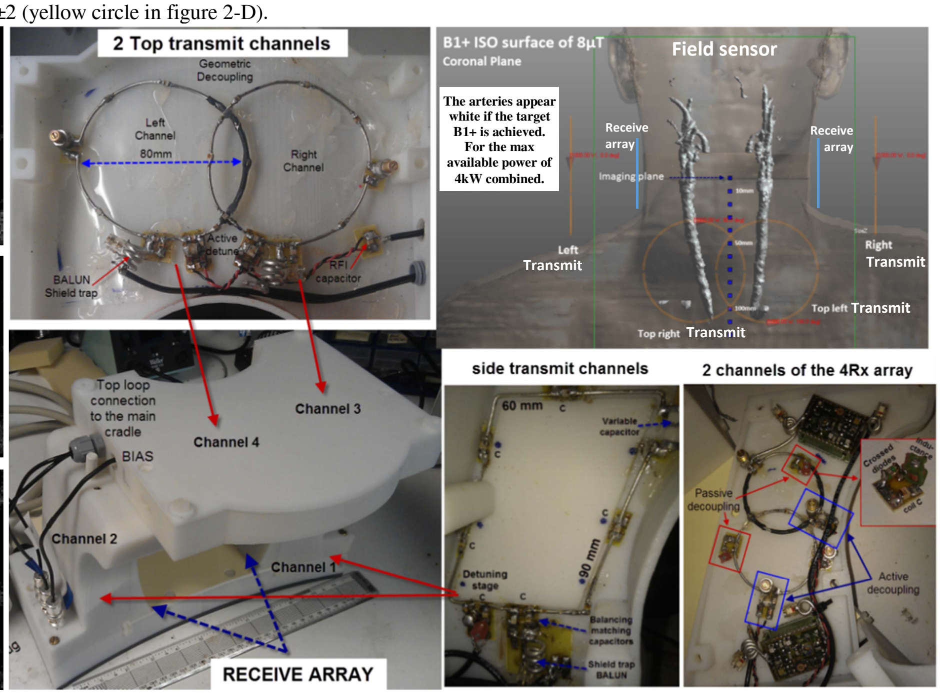

Figure 1: The coil was designed to generate the required flip angles for the available power and for the known DANTE module, i.e. 100mm depth from the imaging plane (Top right). The bottom left image shows the finished coil. The top Tx coils are shown top left and one of the two side coils is shown on the bottom center; one of the two identical sides of the Rx array is shown bottom right.

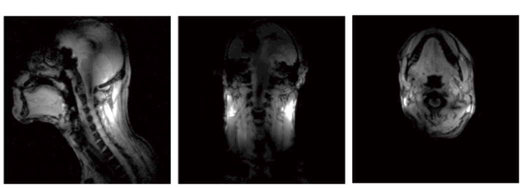

Figure 3: FLASH localizer for the healthy volunteer. The significant B1 inhomogeneity was addressed via B1 shimming at the imaging plane.

Conclusion & Future Work: A 4Tx/4Rx coil was designed to target the carotid arteries operating under pTx mode and a black blood imaging sequence was implemented for blood signal suppression and vessel wall imaging. The initial results from the subject and phantom imaging show satisfactory blood suppression and high spatial resolution. In future work, the use of B0 shimming, volume B1 shimming as well as careful sequence optimization could help further improve the tissue SNR. Additional loops in the receive array could also boost SNR, reduce the parallel imaging noise (g-factor) or scan time.

References: [1] Den Hartog AG et al. Curr. Cardiol. Rev. 7:28–34, 2011, [2] Li L et al, Mag Res ed, 68:1423-1438, 2012 [3] Christ A et al, Phys. Med. Biol. 55:N23-N38, 2010 [4] IEC, 60601-2-33, 2010.