An Eight-Channel Transmit/Receive RF Array for Imaging the Carotid Arteries at 7 Tesla

O. Kraff[1,2], A. K. Bitz[1,2], S. Orzada[1,2], S. Maderwald[1,2], S. Kruszona[1,2], L. C. Schaefer[1,2], J. Y. Grootfaam[1,2], M. E. Ladd[1,2], and H. H. Quick[1,2]

[1]Erwin L. Hahn Institute for MRI, Essen, Germany, [2]Department of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Essen, Germany

Introduction: Atherosclerosis is a serious disease of the vessel wall causing high morbidity and disability worldwide. Accurate characterization and quantification of the plaque components in relation to the fibrous cap and the lumen is important to identify high-risk patients[1]. 3T MRI, with its ability to increase the spatial resolution, has already improved vascular imaging compared to 1.5T MRI[2]. A first glance at the potential of 7T carotid imaging was presented at last year's ISMRM[3, 4], indicating a demand for new dedicated RF coils to allow both parallel imaging techniques as well as imaging both carotid arteries for a side-by-side comparison.

In this work, an eight-channel transmit/receive RF array was built for imaging the carotid arteries at 7 Tesla. The array was made of four overlapping loop coils per side to assess both arteries in one acquisition. We characterize this prototype in simulations and bench measurements and show first in vivo results.

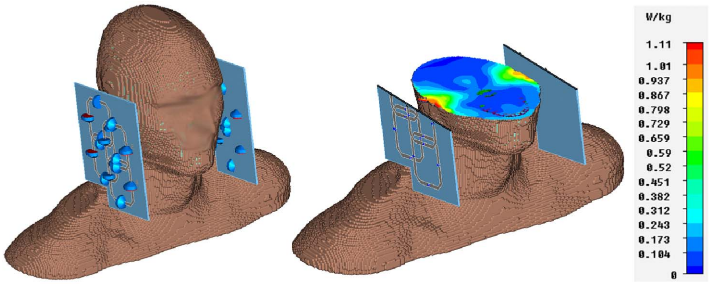

Fig. 1 – The array geometry and model for calculation of the SAR distribution is shown (left). Safety validation of the carotid RF array was obtained inter alia from the male member of the Virtual Family[6] (10g-averaged SAR, linear scale) on the right side.

Methods: Eight 0.8-mm-thick surface loop coils with a dimension of 6 x 7 cm were machined from FR4 circuit board material. Each coil element has 5-mm-wide circuits with a copper-clad layer of 35 µm thickness. Three 2 mm gaps were bridged by 8.2 pF capacitors on each element. To allow imaging of both sides of the neck, two coil clusters, each with four loop elements, were combined to one RF array. Prior numerical simulations[5] of the field distribution indicated use of a shifted and overlapped arrangement of the coil elements, which significantly improved the isolation between neighboring coils (see Fig. 1). Common mode cable current suppression was provided by a cable trap located directly at each coil element. The preamplifiers and transmit/receive switches (Stark Contrast, Erlangen, Germany) of the coil were placed next to the array, behind the subjects head. Care was taken to ensure the same cable length for all elements, which were fed with opposite polarity between the left and right coil rows of each coil cluster to provide a 180° phase shift, which was found in the numerical simulations to increased the B_1^+ amplitude along the center line of the coil, i.e. in the region of the artery. The elements were matched to 50 Ohms at 297 MHz.

A phantom made of body simulating liquid ($\varepsilon_r = 43$, $\sigma = 0.8\ \mathrm{Sm}^{-1}$) was used for tuning and matching on the bench with a network analyzer (Agilent E5061A). Additionally, loaded and unloaded Q values were obtained with this set-up.

For safety validation, numerical computations[5] of the RF field distribution and the corresponding SAR were performed based on the HUGO dataset[5] (100 kg male) as well as on a member of the Virtual Family[6] (70 kg male).

In vivo images of a healthy volunteer were assessed with a T1-weighted 3D spoiled gradient echo sequence (FLASH-3D; TR/TE = 5.5/1.8 ms, 15° flip angle, resolution 0.75 mm isotropic, GRAPPA factor 2, TA = 3:11 min.) for high resolution non-contrast-enhanced MR angiography. Additionally, pulse-triggered PD- and T2-weighted turbo spin echo (TSE; TR = 550 ms, TE = 27/81 ms, 150° flip angle, resolution 0.4 x 0.4 x 2 mm^3, GRAPPA factor 2, TA = 1 min.) sequences were used for detailed classification of the vessel wall and lumen.

Results: Measured reflection and coupling between neighboring elements of the loaded coil are $S_{11} = -16$ dB and $S_{12} = -17$ dB, respectively. The unloaded to loaded Q ratio was 2 for a single element in the presence of all other elements.

From the numerical results, a maximum permitted power level of 9 W (total = left + right side) is obtained at which the maximum localized 10 g-averaged SAR complies with the IEC guidelines of 10 W/kg. Comparable results were found for both calculations, i.e. with the Visual Human dataset as well as with the Virtual Family dataset.

In vivo images reveal a good excitation of both sides and a high vessel-to-background image contrast for the non-contrast-enhanced FLASH-3D sequence (Fig. 2 A-D). Although the signal intensity is less for the pulse-triggered TSE compared to the FLASH-3D, the vessel walls of the internal and external carotid arteries are well visualized (Fig. 2 E).

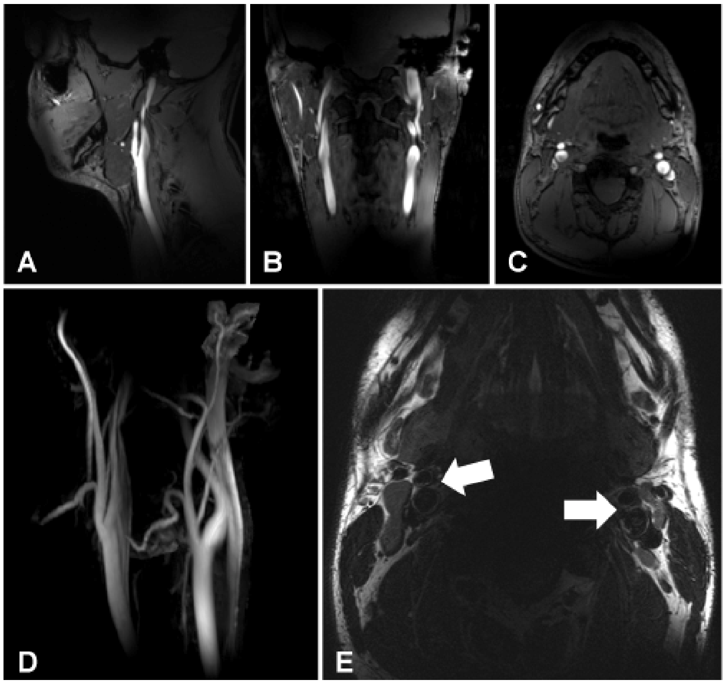

Fig. 2 – All three orientations are given in (A)-(C) for the non-contrast enhanced FLASH-3D sequence. In (D) a MIP of the FLASH-3D shows superb visualization of both carotid arteries. A classification of the vessel walls can be obtained from the axial T2-w TSE image in (E). Arrows point to the external and internal carotid arteries on both sides.

Discussion: This study demonstrates that the concept of two four-channel transmit/receive RF arrays for each side of the neck can be used for in vivo MR imaging of the carotid arteries at 7 Tesla. Work is underway to optimize sequences for an investigation of pathologies as well as to assess patients with atherosclerosis.

References:

1. *Virmani R, et al. Pathology of the thin-cap fibroatheroma: a type of vulnerable plaque. J Interv Cardiol. Jun 2003;16(3):267-272.*
2. *Cury RC, et al. Vulnerable plaque detection by 3.0 Tesla magnetic resonance imaging. Invest Radiol. Feb 2006;41(2):112-115.*
3. *Kraff O, et al. In-Vivo Plaque Imaging of the Carotid Arteries at 7 Tesla. Proceedings 16th ISMRM, 2008; Toronto.*
4. *Piccirelli M, et al. Carotid Artery Imaging at 7T. Proceedings 16th ISMRM, 2008; Toronto.*
5. *CST MICROWAVE STUDIO®, CST GmbH. Version 2008. Darmstadt, Germany.; **6.** Virtual Family Models, http://www.itis.ethz.ch/index/index_humanmodels.html.*