# RF Safety of Aneurysm Clips at 7 Tesla: Effect of Field Polarization

Yacine Noureddine[1,2], Oliver Kraff[2,3], Mark E. Ladd[2,3], Gregor Schaefers[1], Karsten H. Wrede[4], and Andreas K. Bitz[2,3]

*[1]MR:comp GmbH, MR Safety Testing Laboratory, Gelsenkirchen, NRW, Germany, [2]Erwin L. Hahn Institute for Magnetic Resonance Imaging, University Duisburg-Essen, Essen, NRW, Germany, [3]Department of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Essen, NRW, Germany, [4]Clinic for Neurosurgery, University Hospital Essen, Essen, NRW, Germany*

**Introduction:** High-field MRI at 7 Tesla has already demonstrated clinical benefits in neuroimaging, e.g. TOF angiography for the depiction of blood vessels and aneurysms [1]. Especially for patients with multiple aneurysms and, hence, different therapy approaches (coiling, clipping, growth monitoring), post-surgery follow-up imaging is mandatory. MR angiography at 7T has demonstrated comparable image quality to conventional angiography [2] and may establish itself as a noninvasive alternative to reduce overall exposure to ionizing radiation in these patients. To allow for MRI of patients with implanted aneurysm clips under safe conditions, compliance with safety standards has to be guaranteed [3]. Since most implants have only been verified safe for use in an MRI environment up to 3T, a detailed compliance test for 7T is a prerequisite to examination. Whereas the action of forces and torques on the aneurysm clip in the static magnetic field is reduced or avoided by non-ferromagnetic materials, RF-induced heating as a result of electric field elevations in the tissue close to the metallic clip is the major concern with respect to patient safety, even though the overall dimensions of aneurysm clips are rather small. Such field elevations occasionally depend strongly on the orientation of the elongated implant with respect to the polarization of the electric field. Since the position and orientation of clips inside the head can vary significantly, a detailed investigation of the polarization dependency has to be performed. This is especially important in high-field MRI, since field distribution and polarization are significantly non-uniform in the human head and, moreover, depend on the design of the local transmit coil and the size and tissue distribution of the head. Due to the rather small dimensions of aneurysm clips it can be assumed that (i) the coupling to the RF Tx coil is negligible, (ii) field elevations occur only in a limited region around the clip, (iii) hence multiple clips at a certain distance to each other can be treated separately, and (iv) that the elevations can be normalized to the local field magnitude and polarization at the intended location in the head. Previously published data concerning SAR and temperature elevations near aneurysm clips [4,5,6,7] were not referenced to the magnitude and polarization of the local field distribution. Therefore, the data were obtained for a random orientation of the clips and the results cannot be generalized. The presented investigation of the polarization dependency was performed by numerical computation (SEMCAD X, SPEAG, Zurich, Switzerland) and field measurements with RF field probes (SPEAG, Zurich, Switzerland).

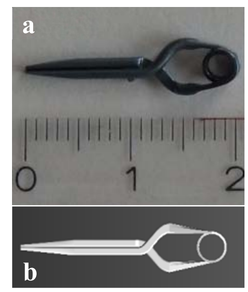
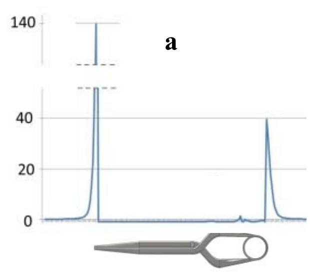



**Fig 1**: Aneurysm clip (a) and CAD model (b).

**Methods:** An aneurysm clip (No. 07-934-02, Mizuho, Medical Inc., Tokyo, Japan) made of titanium alloy with dimensions of 2 cm x 0.5 cm x 0.3 cm was utilized (Fig. 1a). A similar clip (No. 07-934-10) from the same manufacturer and product series has been tested safe at 3T regarding force and torque [6]. For the simulations a CAD-based model of the clip was generated (Fig. 1b) and placed in the center of the computation space, which was homogeneously filled with tissue-simulating liquid (relative permittivity 45.3 and conductivity 0.87 S/m). A uniform plane wave was used to study the influence of the polarization and direction of wave propagation on the field and SAR distribution. To this end, polarization and incident angle of the uniform plane wave were varied in steps of 90 degrees. The orientation of the model for the clip in the computation mesh and, thus, the discrete clip model were kept constant. For this reason, effects from model generation can be excluded. The numerical model consists of 63 million mesh cells with a spatial resolution in the region of the aneurysm clip of 0.15 mm. For a single parameter set, the computation time was 20 minutes. The point-wise, 1g-averaged, and 10g-averaged SAR were evaluated on orthogonal axes through the center of the clip, and the normalized SAR elevation was computed by calculating the difference between the SAR with and without implant normalized to the SAR without implant. In addition to the simulations, field measurements were performed. The aneurysm clip was placed on the inner surface of a phantom filled with tissue-simulating liquid and then centered at a distance of 3 cm to a single meander stripline element [8]. Afterwards, the SAR distribution in a 4 cm x 3 cm plane 4 mm above the clip was measured with a spatial resolution of 1 mm. Next, the normalized SAR elevation was calculated for the longitudinal axis of the clip aligned parallel or orthogonal to the stripline.



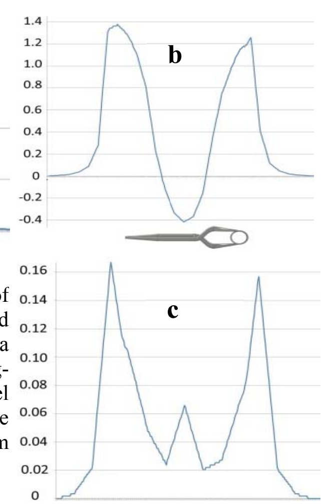




**Fig 2**: Normalized elevation of the point-wise (a), 1g-, (b) and 10g-averaged (c) SAR for a uniform plane wave with orthogonal propagation and parallel polarization with respect to the longitudinal axis of the aneurysm clip.

**Results:** Fig. 2a shows simulated results for the normalized elevation of the point-wise SAR for a uniform plane wave with orthogonal direction of propagation and parallel electric field polarization with respect to the longitudinal axis of the aneurysm clip. The parallel field polarization produces the highest field elevations at both ends of the implant. For the point-wise SAR, the maximum normalized elevation is about 140. Fig. 2b and 2c show the normalized SAR elevation of the 1g- and 10g-averaged SAR. As expected, the averaging reduces the normalized elevation significantly to 1.4 and 0.17 for the 1g- and 10g- averaging, respectively. Fig. 3 shows the SAR elevations obtained from the measurements, which support the simulation findings for the polarization dependency. Again, the parallel polarization produces the highest SAR at both ends of the aneurysm clip, whereas for the orthogonal polarization the field distortion is significantly reduced. As expected, compared to the results in Fig. 2a, the maximum obtained elevation of 0.3 for the parallel polarization turned out to be smaller due to the effective sensitivity area of the field probe and the distance of the measurement plane to the clip.

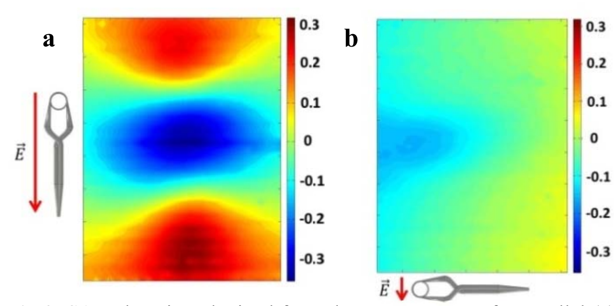



**Fig 3**: SAR elevation obtained from the measurements for parallel (a) or orthogonal (b) polarization in a plane of 4 cm x 3 cm and 4 mm above the aneurysm clip.

**Discussion & Conclusion** The presented results show that the dependency of the SAR elevation on polarization must be taken into account for the safety assessment of aneurysm clips. Since the polarization is difficult to determine in realistic exposure scenarios, the worst-case should be assumed for the safety assessment. It should be mentioned that the validity of 1g- and 10g-averaged SAR for the compliance testing of small implants is problematic. Therefore, the presented results will be further evaluated by temperature simulations under consideration of bio-heat transfer mechanisms and realistic field distributions produced by typical RF transmit coils. Only based on the temperature results the considered clip can be classified as safe or unsafe. Configurations with aneurysm clips located very close to each other or with direct contact also need further investigation.

[1] von Morze, J Magn Reson Imaging 2007;26(4):900-4
[2] Kraff, Invest Radiol 2011;46(4),246-54.
[3] ASTM Standard F2182-11a
[4] Ibrahim. J Magn Reson Imaging 2007;26:1362-1367
[5] Lauer. Magn Reson Imaging 2005;23:563-569
[6] Shellock. Am J Neuroradiol 31:615-19
[7] Watanabe. Neurosurgery 61:5:1062-1066
[8] Orzada. Proc. ISMRM 16 (2008), 2979.