In silico and in vitro investigation of temperature elevation close to an aneurysm clip at 7T

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Introduction: High-field MRI at 7T has demonstrated strong clinical benefits in neuroimaging, e.g. diagnosis of tumorous entities[1], assessment of patients with multiple sclerosis[1], or TOF angiography[1,2] for the depiction of blood vessels as well as aneurysms. Furthermore, MR angiography at 7T has shown comparable image quality to conventional angiography[3] and could very well become a non-invasive clinical tool in the near future allowing a decrease of ionizing radiation for the diagnostic and the post-surgery follow-up of patients with aneurysms. Especially for patients with multiple aneurysms and, hence, different therapy approaches (coiling, clipping, growth monitoring), MRI is the indicated imaging modality for post-surgery follow-up[4, 5]. Since MRI of patients with implanted aneurysm clips has only been verified safe or conditional for some known clips in an MR environment up to 3T, a detailed compliance test for 7T is a prerequisite to any patient 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. Due to the rather small dimensions of the 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) multiple clips at a certain distance to each other can hence 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. In a previous study, it was found that the dependency of the SAR elevation on E-field polarization must be taken into account for the safety assessment of aneurysm clips[6], and that quite high elevations for the 1g- and 10g-averaged SAR of up to 140% and 17%, respectively, can occur. Since it is problematic to assess the safety of small implants based on averaged SAR, RF heating around an aneurysm clip is investigated at 7T using a simplified head model. To this end, RF field and temperature simulations as well as field measurements with RF field probes are carried out.

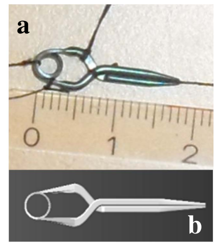

Fig 1: (a) Aneurysm clip; (b) CAD model.

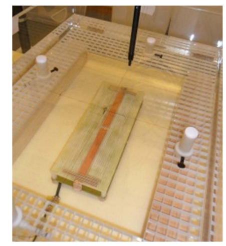

Fig 2: Set-up for RF field measurement

Material and Methods:

<u>*Aneurysm clip:*</u> An aneurysm clip (No. 07-934-02, Mizuho Medical Inc., Tokyo, Japan) made of titanium alloy with dimensions of 1.8 cm x 0.5 cm x 0.3 cm was used (Fig. 1a). A similar clip (No. 07-93-10) from the same manufacturer and product series has been tested safe at 3T regarding force and torque[7]. For the simulations (SEMCAD X, SPEAG, Zurich, Switzerland) a CAD-based model of the clip was generated (Fig. 1b).

<u>*Electromagnetic simulation:*</u> The aneurysm clip was placed in the center of a phantom filled with tissue-simulating liquid (relative permittivity 45.3 and conductivity 0.87 S/m)[9], 3 cm above the inner surface of the phantom and 5 cm above the center of a single meander stripline element[8] placed below the phantom. Since it is known that the highest SAR elevation occurs for the stripline aligned parallel to the major axis of the clip[6], only this configuration was tested. E and H field distribution were extracted along lines parallel to the major axis of the stripline 10 mm above the clip, both with and without the clip in place. All fields were normalized to an accepted power of 1.9 W at the feed port of the stripline.

<u>*Validation of numerical results:*</u> To safely rely on the calculated RF fields and subsequent thermal simulations, the numerical model was validated by use of a homogeneous phantom filled with head-simulating liquid. The measurement set-up was identical to the simulation model described above. A computer-controlled positioning device was used to position the RF field probes (SPEAG, Zurich, Switzerland) (Fig. 2). E and H field were measured parallel to the longitudinal axis of the stripline 10 mm above the clip with a spatial resolution of 1 mm.

<u>*Thermal simulation:*</u> For the thermal simulations the power loss density was extracted from the previous EM simulation for the configuration with clip. Thermal parameters for the head-simulating tissue were chosen equal to brain tissue[10]. Temperature was extracted at a point 1 mm away from the tip of the clip. It was investigated at which reference E-field (magnitude of the E-field at the location of the clip in absence of the clip) a steady-state temperature of 39°C (temperature limit given in the guidelines[11]) was reached.

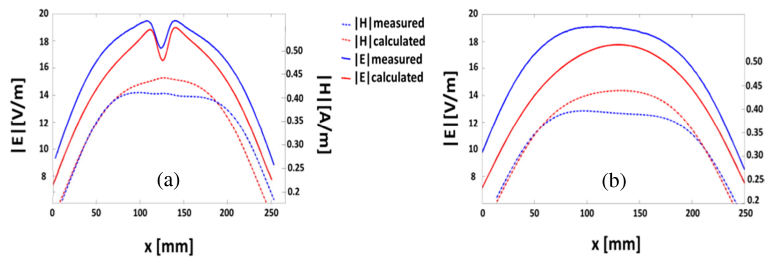

Fig 3: Validation: measured and calculated field distributions 10mm above the implant (a) with and (b) without the aneurysm clip

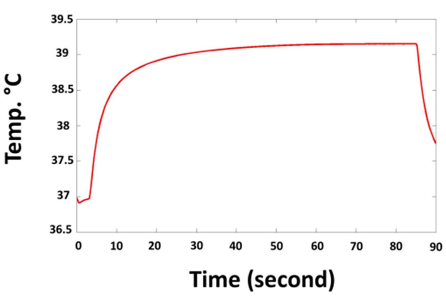

Fig 4: Temperature elevation at the tip of the clip for an accepted power of 2.55 W

Results:

<u>*Validation of numerical results:*</u> Fig. 3 shows the comparison of measured and calculated field distributions on an axis 10 mm above the implant with and without the aneurysm clip. The mean of the absolute normalized deviation between measurement and simulation with the implant were 4.7% and 8% for the E-field and H-field, respectively. Without the implant, the values were 6.1% and 12% for E and H-field.

<u>*Thermal simulation:*</u> Fig. 4 shows the temperature rise during a time interval of 90 seconds at a point 1 mm away from the tip of the clip. At a time-averaged input power of 2.55 W for the stripline, a steady-state temperature of 39°C was reached after approx. 60 seconds. The corresponding reference E-field in the homogenous phantom without implant was 30 V/m (rms).

Discussion and conclusion: The validation procedure for the RF field distribution showed good agreement between simulated and measured results, demonstrating that the numerical model properly describes the measurement set-up. If the aneurysm clip is placed at a location with a reference value for the electric field of 30 V/m (rms) in worst-case orientation, parallel to the E-field polarization, a maximum local temperature of 39°C is reached after approx. 60 seconds. For realistic exposure scenarios with typical RF transmit coils at 7T, the field distribution inside the human head is extremely inhomogeneous. There are typically regions with E-field strength below the reported reference value of 30 V/m (rms) as well as regions with fields above the reference value. Therefore, to transfer the presented temperature elevation obtained in the simplified model to realistic field distributions, further evaluations of RF and temperature simulations inside heterogeneous head models need to be performed for typical RF head coils. These investigations are mandatory before a final safety assessment of the aneurysm clip can be performed.

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