RF-induced heating in MRI of tissue around an aneurysm clip near the middle cerebral artery at 7 T under consideration of the Pennes bioheat equation

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Introduction: High-field MRI at 7 T has demonstrated strong benefits for clinical 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 7 T has shown comparable image quality to conventional X-ray-based angiography[3] and could very well become a non-invasive clinical tool in the near future, allowing a decrease of ionizing radiation for the diagnosis and 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-interventionfollow-up[4, 5]. Since MRI of patients with implanted aneurysm clips has only been verified to be MR Conditional for specific clips up to 3 T, a detailed compliance test for 7 T is a prerequisite before 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]. In this work, RF and thermal simulations are performed in phantoms and in an anatomical head model to investigate the SAR elevation and the RF-induced temperature increase close to an aneurysm clip.

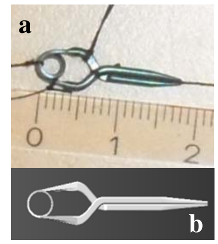

Fig 1: (a) Aneurysm clip; (b) CAD model.

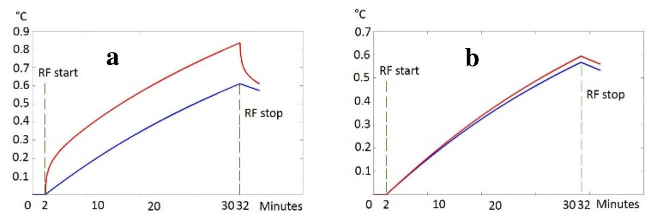

Fig 2: Temperature elevation at 1 mm from the tip of the clip for the implant (a) parallel and (b) orthogonal to the E-field polarization. Red: temperature with clip. Blue: temperature without clip.

Material and Methods:

Aneurysm clip: An aneurysm clip (No. 07-934-02, Mizuho Medical Inc., Tokyo, Japan) made of titanium alloy with dimensions of 1.8 cm × 0.5 cm × 0.3 cm was used (Fig. 1a). For the RF simulations (SEMCAD X, SPEAG, Zurich, Switzerland) a CAD-based model of the clip was generated (Fig. 1b).

RF and thermal simulations in a homogeneous head phantom: The aneurysm clip was placed in the center of a head phantom (elliptical cylinder, axes 21 and 18 cm, length 34.5 cm) filled with tissue-simulating liquid (relative permittivity 45.3 and conductivity 0.87 S/m). A 7 T head coil[8] made of eight meander stripline elements and excited with equal phase and amplitude was used for transmission at 298 MHz. Two orientations of the clip were investigated: parallel and orthogonal to the E-field polarization in the center of the phantom. Power loss density from the EM simulation was extracted for thermal simulation. Temperature was monitored at a distance of 1 mm to the tip of the clip after exposure duration of 30 minutes with an accepted power of 40 W. The heat convection between air and the surface of the phantom was set to zero to get a real worst case scenario. .

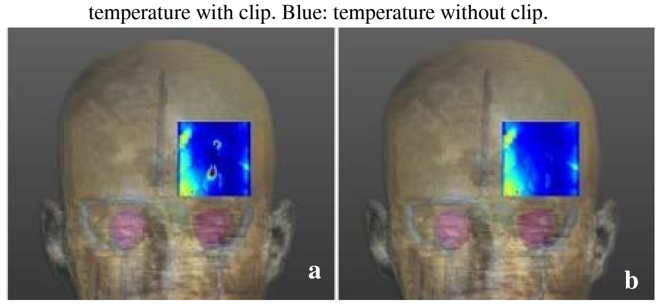

Fig 3: Distribution of point-wise SAR ion the heterogeneous head model (b) with implant and (c) without implant.

Simulations in a heterogeneous head model: Numerical simulations in a heterogeneous head model[9] (female, 1.63 m, 58.7 kg, tissue resolution 1.5 mm) were performed to determine both SAR elevations and RF-induced heating caused by the clip. The head model was positioned centrally within the RF head coil. The clip was placed in the location of the middle cerebral artery (MCA). Again two orientations of the clip were investigated: parallel and orthogonal to the E-field polarization in the anatomical head model. Simulations were evaluated with regard to both point-wise and 1g-averaged SAR. Simulations were performed for a total input power of 40 W (maximum 10g-averaged SAR inside the head equal to IEC limit of 10 W/kg), exposure duration of 20 minutes, a background temperature of 22 °C, and a blood temperature of 37 °C. The thermal and dielectric parameters of body tissues such as blood perfusion and metabolism were taken from Ref. 10. Heat convection coefficient between the skin of the model and the air was set to 6 W/ (K×m^2).

Results:

Homogeneous head model: Fig. 2 shows the temperature elevation during 30 minutes of exposure for the clip in the parallel and orthogonal orientation. For parallel orientation a temperature elevation of 0.83 °C was recorded 1 mm from the tip of the clip. Without the clip the temperature elevation was 0.59 °C at the same location. For the clip in the orthogonal orientation, a maximum temperature elevation of 0.59 °C was recorded, whereas the elevation without the clip was 0.56 °C.

	Clip parallel to E-field polarization	Clip orthogonal to E-field polarization
Point-wise SAR elevation	180	10.5
SAR_{1g} elevation	1.43	0.11
Maximum absolute temp. (tip of clip)	37.33°C	37.32°C
Maximum absolute temp. (tip of clip) without the clip	37.31°C	37.32°C

Table 1: Results of SAR and temperature for both orientations of the clip.

Heterogeneous head model: Table 1 summarizes the results obtained in the anatomical head model. Point-wise SAR distributions for the clip parallel to the E-field polarization for the configuration with and without implant are shown in Fig. 3a and b respectively.

Discussion and conclusion: Thermal simulation in the homogeneous head model with clip showed an additional temperature increase of 0.24°C compared to the temperature elevation without clip. However, for the anatomical head and if bioheat mechanisms, e.g. blood perfusion, are taken into account, the implant-related temperature elevation is only 0.02°C. Hence, the local blood perfusion reduces the RF-induced heating considerably. The maximum local temperature remained well below the temperature limit of 39 °C for the clip location considered in this work, the particular head coil, excitation mode and input power considered in this work.

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