

# MR Safety Assessment of Potential RF Heating from Cranial Fixation Plates at 7 Tesla

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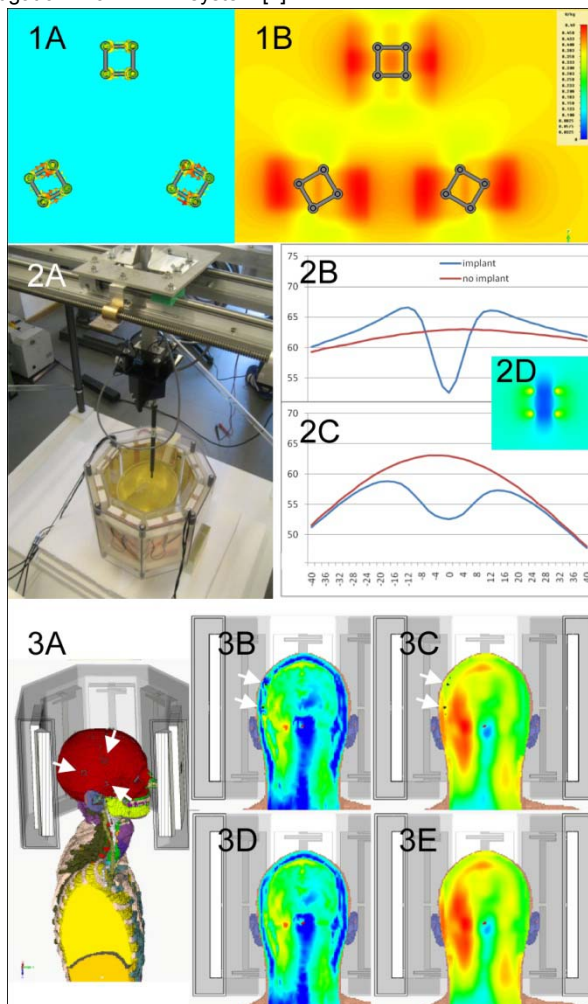
**Introduction:** With the increasing number of clinically-oriented MRI studies at 7T, examination of patients with implants has become relevant at research facilities with ultra-high field strength systems. Since most implants have only been verified safe for use in an MRI environment up to 3T, a detailed compliance test for 7T is a prerequisite to examination. In this study we focus on miniplate implants used for refixation of the bone flap after craniotomy as a standard procedure in neurosurgery. Patients often require imaging following cranial reconstruction to assess the surgical outcome. A post-surgery follow-up MRI at 7T of these patients is of high scientific interest. Since typical temperature measurements performed with fiber-optic probes to assess potential heating yield only point-wise information, a much more detailed assessment of MRI-related heating due to interactions of the RF field with the implants was performed.

**Methods:** The miniplates (Biomet Microfixation, Jacksonville, FL) are quadratic (12.5 mm x 12.5 mm), 1 mm thick, and each plate can be fixated with 4 screws of 4 mm length. Typically, 2 or 3 such plates are used for refixation (Fig. 1A, 3A). Both the miniplates made of pure titanium (according to ASTM-F63) and the screws made of alloyed titanium (according to ASTM-F136) are considered safe with regard to B<sub>0</sub> for use in an MRI environment up to 3T magnetic field strength [1]. Furthermore, for other neurosurgical implants (CranioFix clamps, Aesculap AG, Tuttlingen, Germany) also made of alloyed titanium, no torques were observed in a recent investigation in a 7T MRI system [2].

The test protocol included full wave simulations (CST Microwave Studio, CST GmbH, Germany) for the two most critical cases: (1) for a magnetic flux orthogonal to the plate, and (2) for a uniform plane wave with both E and H parallel to the plate. The electromagnetic field distribution and corresponding specific absorption rate (SAR) were calculated for three miniplates screwed onto a numerical model made of 4 different tissue layers: skin, muscle, bone, and brain. External measurements of the H and E field and SAR distribution were performed in a plane proximal and parallel to the implants and subsequently compared to the numerical simulations. The probes (SPEAG, Zurich, Switzerland) were positioned with a computer-controlled positioning device (Fig. 2A). A custom-made 7T transmit/receive head coil made of 8 stripline elements [3] was used for transmission. Additionally, simulations in a heterogeneous head model [4] were performed to investigate effects on the coil characteristics caused by the implants.

**Results:** Figure 1 shows the geometry and typical arrangement of three miniplates on a circle of approximately 6 cm diameter. In Figure part 1A surface currents on the implants are shown caused by an incident uniform plane wave. Figure part 1B shows the corresponding 10-g-averaged SAR. The miniplates caused an increase of 10% in 10-g-averaged SAR compared to the case where no implants were present. The numerical simulations were then compared to external field measurements. In Figure 2A the setup is shown. A phantom simulating head and shoulders for realistic loading of the RF coil was used. The implants caused a maximum difference of 6% in the H fields compared to a reference measurement without implants. For the point-wise SAR measurements, a maximum difference of 25% was observed. The numerical simulation yielded a similar difference between the calculations with and without implants for the H field, and around 40% difference for the point-wise SAR. Distortions of the E field distributions for two orthogonal axes approximately 5 mm above one implant are shown in Figure 2B (along the stripline) and 2C (orthogonal plane). Field elevations in Figure 2B and decrease of the E-field in the center of the implant correspond very well with simulations (Fig. 2D). Three miniplates were also positioned on the skull of a heterogeneous head model (Fig. 3A, arrows). Simulations showed negligible effects of the implants on the coil characteristics. While very small differences were observed in the point-wise SAR as shown in Figure 3B (with implants, arrows) and 3D (without implants), the 10-g-averaged SAR remained unchanged (Fig. 3C/3E). No effect of the implants on the location and absolute value of the maximum 10-g-averaged SAR were observed.

**Discussion:** Consistently, only minor disturbances of the H field from the implants were found in the external field measurements and numerical simulations. Distortions of the E field were the strongest impact of the implants. A large difference of 25-40% in the point-wise SAR between the two cases with and without implants resulted in an increase of around 10% in 10-g-averaged SAR in a simplified 4-tissue model. The comparison between field measurements and numerical simulations with a uniform plane wave and planar tissue layers showed that the simulations slightly overestimated the SAR and, hence, provide an additional safety margin. Further simulations on a heterogeneous human head model revealed that the implants do not affect the amplitude and location of the maximum 10-g-averaged SAR generated by the RF coil.



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