MR safety investigation of RF heating of a generic wire-shaped device immersed to a human body simulating medium at 63.58 MHz (1.5 T MRI-equivalent)

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Purpose:

Apart from all benefits of using Magnetic Resonance Imaging (MRI) as a non-invasive imaging technique, possible risks due to the Electro Magnetic (EM) fields needs to be investigated, and in particular the field and SAR distributions when a metallic implant or catheter is immersed to the patient's body during imaging. In this study, a representative implant model has been investigated in 64 MHz (1.5 T MRI) aiming at the behavior of an insulated/uninsulated wire shaped medical catheter, deep brain electrodes or other similar implants with respect to RF induced heating in an operating MR environment. This wire could be modeled as an antenna in conjunction with an equivalent circuit. Hence, this implant could be viewed as an antenna in a lossy medium when immersed into the body.

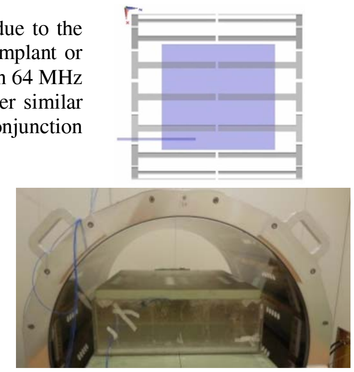

Fig.1 Simulation and measurement test setup with a birdcage coil, a phantom filled with gel and a generic implant.

Method:

The quantitative analysis of induced E-field due to presence of medical catheter implants during MRI become particularly critical if the implant is only semi immersed into the human body where a part remains outside. The power deposition to the tissue in these cases strongly depends on shape, configuration and orientation of these series of catheter implants. As an example, deep brain electrodes are immersed into the brain and partly extended outside to provide stimuli or transfer remotely sensed data like e.g. pressure and temperature to the corresponding main unit. In addition, there are various EEG and ECG electrodes, which are attached to the body (head and chest, respectively) and therefore considered as zero immersing configurations. Not only the penetration depth and the configuration of electrodes inside the body is important but also the location where the electrode is introduced, the length and the shape of the remaining outer part of the electrode could affect the power deposition to the human tissue and lead to non-reversible damage due to the temperature rise. As an example, very large temperature rise could be registered during MRI in cases of deep brain sensors with external long cable connections within the scanner bore which also be influenced significantly by the shape of outer part.

Setup:

The test setup contains an approximately 40 x 40 cm phantom filled with 9 cm saline gel placed in the center of a generic RF body birdcage coil. The coil is shielded with 128 cm long cylindrical shape shield and loaded with the gel filled phantom. Two 30 cm long generic catheter implants – an insulated and uninsulated version – have been immersed step by step into the gel at a location close to the phantom wall in order to be imposed with the higher intensity of the tangential E-field component that is generated in the vicinity of the rungs of the birdcage coil (cf. Fig. 1) based on ASTM F2182-11a [1]. Hence, maximum heating is expected, if the main axis of the implant extends parallel to the local E-field polarization direction respective the surface of the implant's conductive material is perpendicular to the dominant H-field components. Different length of the same non-isolated implant has been additionally simulated in full immersion (i.e. the middle of the tissue simulating medium) in order to track down the worst-case length with the highest induced SAR. This case is then compared to scenarios of the insulated and uninsulated implant at different penetration depths. As a result, the dominant effect of the outer part of the implant on the induced heating inside the body has been confirmed. To conform to a more realistic clinical catheter, all studies will therefore rely on an insulated wire with one centimeter of the isolation being removed at both ends.

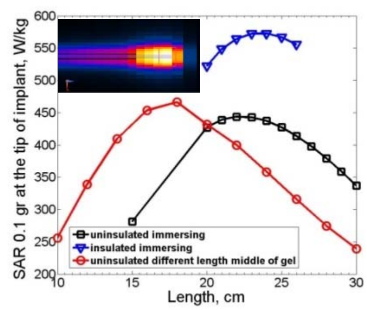

Fig.2 Numerical analysis of the SAR owing to the immersion effect of insulated, uninsulated generic implants for different penetration depths compared to a fully immersed uninsulated implant (in the middle of phantom) at different lengths. The inset shows the SAR averaged on 0.1 gr. Distribution in gel at the exposed end of the insulated implant.

Results and conclusion:

As a result of the numerical simulations, SAR value in the surroundings of the tip of the generic implants due to the induced RF fields inside the phantom is obtained. The effect of the penetration depth of the immersed implant with respect to the maximum induced SAR is shown in Fig. 2. Three setups have been designed for this study, starting with an uninsulated straight wire implant immersed into the gel starting from zero to full immersion. The induced SAR of the uninsulated wire is partly displayed in Fig. 2 (in black/square line) against the penetration depth into the gel. The same procedure is repeated for the insulated wire, where the induced SAR is shown in blue/triangle line. The plot reveals that although the resonance length is not significantly changing due to the isolation, the amount of induced SAR yields a significant 30% increase. Since the induction mechanism of the current in the wire is virtually the same for both cases, but the ohmic contact of the conductor with the conductive gel is much more confined for the partly insulated wire compared to the bare wire, a much higher current density is expected in the gel adjacent to the wire ends. The third setup depicted as red/circle line shows the fully immersed configuration of the uninsulated same wire centered within the phantom for different lengths. The worst-case immersion/length of the implant in terms of RF-heating has been derived by numerical simulation using a full-wave electromagnetic simulation software (3D-FDTD, SEMCAD X v.14.8, SPEAG) among all three cases. From simulations one gets to the following observations: Although the same length of the semi or fully immersed uninsulated implant is exposed to the gel, the highest RF heating is expected to occur at different lengths of the implant. However the maximum level of the induced heat is not significantly different from each other. Regarding the insulated implant the insulation leads to a much higher induced heat at both exposed ends. As shown in Fig. 3 for the temperature measurements, the semi-immersed insulated implant yields a slightly larger worst-case length compared to simulations, which leads, though, to a much higher temperature rise compared to other two configurations, which could virtually lead to serious risk of tissue burning. The experiments are carried out at the worst-case lengths estimated from numerical simulations, taking into account two additional adjacent lengths for validation purposes. To conclude, insulated deep body electrodes are not necessarily safer compared to the uninsulated ones.

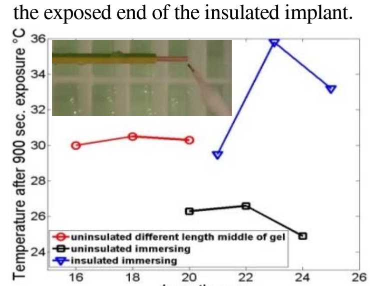

Fig.3 Temperature measurement using an in-house RF test laboratory system. The inset shows the temperature probe at the exposed end of the insulated implant.

References:

1. ASTM F2182-11a; 2011, www.astm.org