Numerical examinations of energy absorption in simplified spondylodesis models

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Abstract – A simplified model for spondylodesis, i.e. fixation of vertebrae by osteosynthesis, is developed for virtual magnetic resonance imaging (MRI) examinations to numerically calculate energy absorption. This paper presents results of calculated energy absorption in body tissue surrounding titanium rod implants. In general each wire or rod behaves like an antenna in electromagnetic fields. The specific absorption rate (SAR) profile describes dependence of implant size. SAR hotspots appear near the rod edges. Depending of the size of implant fixation SAR is 62% (small fixation) up to 90.95% (large fixation) higher than without implants. In addition, local SAR profile displays local dependency on tissue: SAR is lower between the vertebrae.

Introduction: Nowadays MRI is the most secure imaging in medical diagnosis [1]. But different electromagnetic fields obtain safety hazards for the human body. Especially the pulsed high frequency field B_1 causes energy absorption resulting in potential temperature increase of tissue [2]. The quantity for energy absorption by human tissue in electromagnetic fields is the SAR. Energy absorption depends on intensity of induced electric field E and specific electric conductivity σ of tissue and its density ρ. $SAR = \sigma E^2/2\rho$. It is specified by international safety norm IEC 60601-2-33. SAR refers to the volume of defined body parts, in this work volume mass is $m = 10\ g$. The absorbed energy is converted to heat. In medical application the body tissue temperature should not increase more than 1° C, which approximately corresponds to $SAR = 4\ W/kg$ in whole body or dependent of region $SAR = 4\text{-}10\ W/kg$ of body weight. Temperature of 43° C or more causes tissue injury, in worst case the patient might die [2, 3]. MRI examinations on patients with implants are at discretion of medical professions and associated with individual risk. In this paper the focus is on calculation of energy absorption of the B_1-field in virtual 1.5 T MRI for patients with simplified models of spondylodesis. Spondylodesis is an implant where concerned spine segments are fixed with screw-rod-system.

Methodology: For numerical examinations of energy absorption in models with spinal implants during MRI the software High Frequency Structural Simulator (HFSS) by Ansys Inc. is used. The torso phantom is a plexiglas body filled with soft tissue [4]. It represents a human torso lying on his back in the MRI. Two kinds of simplified spondylodesis models are developed: a small fixation, a fixation over nine vertebrae. They concentrate on the ventral static support of motion elements of spine. The high frequency field of the virtual MRI is generated by a birdcage coil [5]. Inside the coil an almost homogeneous magnetic field B_1 is generated. Electromagnetic fields are calculated by solving Maxwell equations. For SAR calculation first the particular tissue densities and local SAR in finite elements must be determined. Then the SAR algorithm runs on voxels, which are generated from finite elements [6].

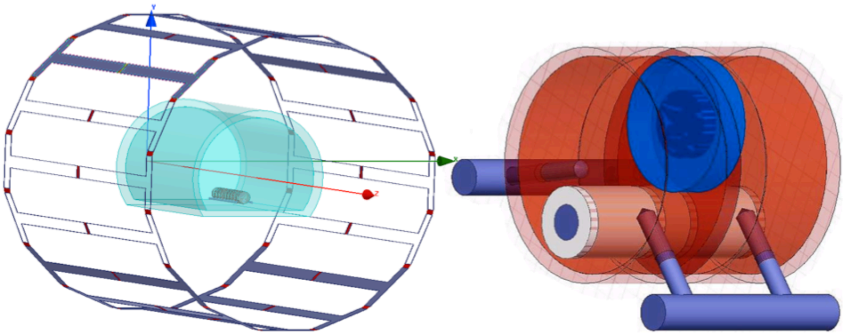

Figure 1: Left - Simulation model, torso phantom positioned in middle of Birdcage Coil. Right - Simplified spondylodesis model over two vertebrae (brown: vertebrae, blue: spinal disc, white and grey cylinder: spinal cord, grey rods: fixation system).

Results: The electromagnetic fields are examined in direction of the coil axis. Along the axis the electric field shows the posterior shape of vertebrae and spinal discs in models without implants. In models with implants this structure is still visible but with increasing and decreasing trend in its minimum intensities. The magnetic field in models without implants is parabolic and nearly homogeneous, from B_1 = 1.571 *μT* to 2.023 *μT*. The implants influence the magnetic field intensity. The larger the implant the higher the magnitude, for two fixed vertebrae it approaches B_1 = 2.023 *μT* and for nine fixed vertebrae B_1 = 2.199 *μT*.

The SAR intensity is monitored in the posterior layer between bones and tissue, indicated by a red line in the top plot of Figure 2, since generally the major absorption is posterior. As displayed at the bottom of Figure 2 the SAR profile in vertebrae models clearly describes positions of vertebrae and spinal discs. Major values are detected at vertebrae and minor values at spinal discs. The SAR intensity hardly differs in models without implants, SAR_{max} = 0.62 *W/kg* to 0.69 *W/kg*. As shown on top of Figure 2 the SAR profile in vertebrae models with implants describes same structure with decreasing values towards model center, SAR_{max} = 0.95 *W/kg* to 4.2 *W/kg*.

The SAR profile in two vertebrae model with implants has a major magnitude in implant sections. The values range from *SAR* = 0.2 *W/kg* to 0.95 *W/kg.* The SAR profile in nine vertebrae model with implants has at its proximal vertebra major energy absorption to distal vertebra. SAR values range from *SAR* = 0.05 *W/kg* to 4.2 *W/kg* with extinction towards the model center.

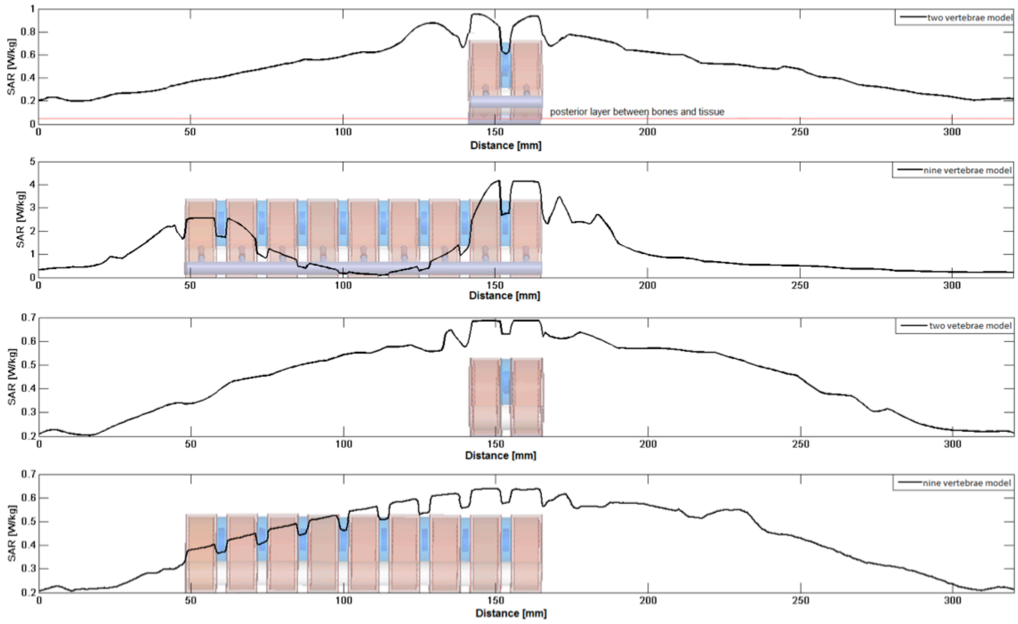

Figure 2: SAR profile of posterior layer between bones and tissue. On top simplified spondylodesis over two and nine vertebrae, red line marks layer between bones and tissue. At the bottom simplified vertebrae models. The shape of the models only enhances visualization of SAR profiles and relate SAR peaks to vertebrae and spinal discs positions.

Discussion: SAR hotspots appear near the rod edges and spread posterior between implants and MRI table. In small fixations, here demonstrated as two fixed vertebrae, the SAR is 62% higher than without implants. In fixation over nine vertebrae it shows an increase over 90.95%. So energy absorption is highly dependent on implant size. The results lead to assumption that the energy absorption thus temperature rises in lateral body also depends on bone and tissue geometry.

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