Local SAR elevations in the human head induced by high-permittivity pads at 7 Tesla

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Target audience: Researchers involved in RF safety and/or high-field MRI

Introduction: It has already been shown that dielectric pads with high permittivity can be used to improve transmit/receive sensitivities and, consequently, image quality in brain imaging [1]. Whereas first publications focused mainly on B_1 homogeneity and SNR improvement [2], recently also the effects on the specific absorption rate (SAR) have been discussed. Whereas most studies reported a SAR decrease if dielectric pads are placed at certain distance to the head [3,4], one study showed a 64% increase of the maximum local SAR for a specific configuration of three pads [5]. With respect to the local field behavior, it is well known from constitutive relations that media with high permittivity have a direct effect on the electric field distribution. For example, normal electric field components show a discontinuous behavior at the boundary between low (air, body tissue) and high-permittivity media, with field elevations inside the medium with lower permittivity. Additionally, there are further coupling mechanisms which are responsible for dependencies on pad orientation and size. In summary, the SAR distribution depends on several parameters, e.g. polarization and distribution of the incident field, tissue distribution, and the actual geometry and position of the pad as well as its permittivity. In this work, we investigate several combinations of these parameters by RF field simulations to determine under which conditions SAR elevations are likely to occur or can be avoided. Effects on B_1^+ distribution will not be discussed, since the scope of this work is the evaluation of RF safety when using high-permittivity dielectric pads and not the comparison of imaging performance for configurations with and without pads.

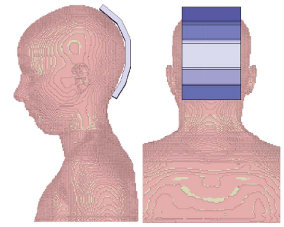

Fig. 1 Female model with high-permittivity pad.

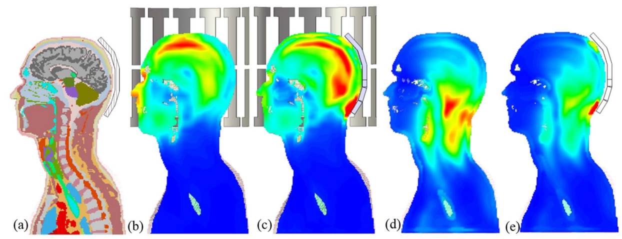

Fig. 2 SAR_{10g} in center sagittal plane in male model. (a) Tissue distribution, (b) birdcage without pad, (c) birdcage with pad, (d) plane wave without Pad, (e) plane wave with Pad.

Methods: To account for different head sizes and tissue distributions, simulations were performed with a male (Duke, 34y, height 1.77 m, body mass 72.4 kg) and a female body model (Ella, 26y, height 1.63 m, body mass 58.7 kg) [6]. Dielectric pads were modelled with dimensions of 195 mm x 110 mm x 10 mm (L x W x H) and with dielectric parameters of $\varepsilon_r' = 110$, $\sigma = 0.0918$ S/m at 297.2 MHz. A pad was placed at the back of the head with its longitudinal axis parallel to the body axis (Fig. 1). To reproduce results from Ref. 5, a configuration with two additional pads left and right of the head was also considered. The pads were bent around the head models to conform to the head's contour. Two different excitation scenarios were considered: 1.) A 32-channel receive / volume transmit head Coil (Nova Medical, Wilmington, MA, USA). The volume coil was modelled as a shielded bandpass birdcage coil with 16 rungs, diameter of 30 cm, and length of 26 cm. Dimensions of the shield were 36 cm in diameter and a length of 34 cm. 2.) A uniform plane wave (UPW) with propagation direction from posterior to anterior and electric field vector parallel and perpendicular to the longitudinal axis of the body. The uniform plane wave was chosen because of its well-defined polarization of the incident electric field. The results for the birdcage configuration were normalized to an input power of 1 W; the SAR for the plane wave configuration was computed for an incident electric field of 1 V/m. Simulations were performed with CST Studio Suite 2014 (CST AG, Darmstadt, Germany). The maximum 10g-averaged specific absorption rates $SAR_{10g,max}$ for the different configurations were determined, and SAR elevations were compared for configurations with and without pads. Additionally, for the female model, configurations with a permittivity of 500, a doubled pad thickness of 20 mm, and a spacing of 10 mm between pad and head were taken into account to investigate the effect of these parameters on the local SAR.

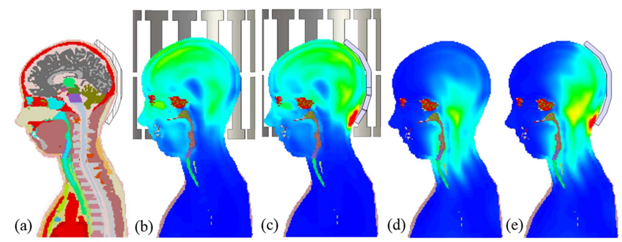

Fig. 3 SAR_{10g} in center sagittal plane in female model. (a) Tissue distribution, (b) birdcage without Pad (c) birdcage with pad (d) plane wave without pad, (e) plane wave with pad.

Results/Discussion: In Fig. 2 and 3 the tissue distribution in the head models and the SAR_{10g} in the central sagittal plane are shown for both excitation scenarios with and without pad. Corresponding $SAR_{10g,max}$ is summarized in Table 1. For the birdcage, $SAR_{10g,max}$ increases by 7% and 64% in Duke and by 44.3% and 30% in Ella for the one and three pad configurations, respectively. $SAR_{10g,max}$ is located occipital at the lower shorter edge of the central pad, whereas without pad $SAR_{10g,max}$ is located below the left frontal lobe. These results support the findings reported in Ref. 5. For the configurations with a single pad and UPW with electric field vector orientated parallel to the longitudinal axis of the body, similar elevations are obtained as for the birdcage. However, for an electric field vector perpendicular to the longitudinal axis of the body, no SAR elevation occurs, which indicates that local field behavior according to the constitutive relations governs the SAR close to the edges of high-permittivity pads. Fig. 4 shows results for an increased permittivity and variations of the pad geometry and position. For a permittivity of 500 as well as for a pad thickness of 20 mm, an even higher SAR elevation is observed by approx. 92% for the birdcage and 152% and 160% for the UPW, respectively (Fig. 4 and Tab. 1). However, for a 10 mm air gap between tissue and pad, a SAR reduction of 28% is obtained for the birdcage, and the location of the $SAR_{10g,max}$ is equivalent to the scenario without pad. Even for the UPW, the SAR elevation is significantly reduced.

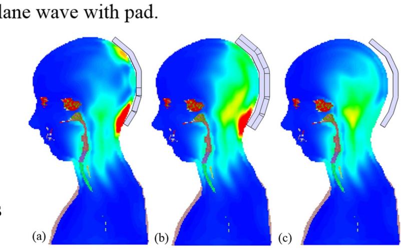

Fig. 4 SAR_{10g} in pad variations with uniform plane wave: (a) Pad with $\varepsilon_r' = 500$, (b) pad thickness of 20 mm, (c) pad distance of 10 mm to head.

Conclusion: The results support previous findings that certain variations in pad position as well as in pad geometry and material properties can lead to strong SAR elevations; these results are reproducible for multiple body models and excitation scenarios. Since the polarization of the incident field, which is difficult to determine inside loaded RF coils, is an important factor, detailed SAR analysis for any possible configuration is necessary. To account for the increased RF exposure of the volunteer, the maximum permissible input power of the RF coil must be decreased. Further, the results show also that an effective way to reduce the risk potential of high-permittivity pads is to allow for an air gap of 10 mm between pad and body tissue.

Table 1: $SAR_{10g,max}$ in W/kg and SAR elevation for exposure in a birdcage and a UPW and for different pad configurations and body models.

	Birdcage			Uniform plane wave		
	with pad	without pad	ratio	with pad	without pad	ratio
Duke	0.577	0.539	1.07	1.393E-4	1.285E-4	1.08
Ella	0.9	0.623	1.44	2.074E-4	1.367E-4	1.51
Ella (ε_r' = 500)	1.197	0.623	1.92	3.449E-4	1.367E-4	2.52
Ella (pad thickness 20 mm)	1.191	0.623	1.91	3.554E-4	1.367E-4	2.6
Ella (pad distance 10 mm)	0.445	0.623	0.72	1.578E-4	1.367E-4	1.15

References: 1. Teeuwisse, MRM 67:912-918 (2012). 2. Manushka et al. Proc. ISMRM 22 (2014) #0406. 3. Collins et al. Proc. ISMRM 22 (2014) #0404. 4. Collins et al. Proc. ISMRM 22 (2014) #1340. 5. Bitz et al. Proc. ISMRM 22 (2014) #3394. 6. Christ et al. Physics Med Biol 2010; 55(2):N23-38.

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