Simultaneous B_{1+} homogenisation and SAR hotspot suppression by a phased array MR transmit coil.

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Introduction

The application of MR imaging at high field ($B_0 \geq 3$ T, f ≥ 128 MHz) faces considerable challenges with respect to uniformity of the RF magnetic excitation (B_1^+) field and power deposition. Wave behaviour and penetration effects causing severe degradation of the image quality, have been reported both numerically and experimentally [1,2]. Furthermore, the stronger coupling of the RF field to small anatomical features with high dielectric contrast can lead to local high SAR values [3]. This concern has become more acute at high field MR imaging since the RF dissipation increases quadratically with the Larmor frequency.

To challenge these concerns, we investigated the potential of phase/amplitude controlled coil designs [4]. These systems offer more possibilities to steer the RF field distribution than the conventional resonant coil structures. Our aim is twofold, i.e. to improve for high field MR B_1^+ homogeneity on the one hand and to reduce simultaneously SAR hotspots on the other hand. For this purpose we make extensive use of our modelling platform that includes a large database of realistic dielectric patient models and advanced electromagnetic and thermal modelling techniques [5].

Methods

For this study, a 12 elements phased array TEM coil was modelled operating at 128 MHz (3T). The coil model was loaded with various realistic dielectric patient models, varying in physical proportions from normal to obese. Separate FDTD simulations were performed to calculate the magnetic and electric field response of each TEM antenna element. A special optimisation program was developed in which the phase and amplitude of each element was varied freely to minimize the standard deviation of the $|B_1^+|$ distribution in a transverse cross section through the pelvis or abdomen. Simultaneously, the SAR deposition was reduced by implementing a SAR constraint in the optimisation process.

Results

The simulations at 3 Tesla showed that standard quadrature drive of the coil resulted in a diagonal modulation pattern in the B_1^+ distribution for all dielectric patient models. This pattern was especially pronounced for the obese patients. Globally, the pattern shows high resemblance to B_1^+ distributions of elliptical homogeneous phantoms [6]. Typical regions of elevated SAR deposition were found around the pubic bone, above the Iliac crest and in particular for the obese patients, in the muscle layers at both lateral flanks. Application of phase/amplitude optimisation yielded a significant improvement in B_1^+ uniformity and a simultaneous reduction of SAR hotspots. The average standard B_1^+ deviation for the four patients was reduced by 45 % with respect to quadrature drive. Partial body SAR was decreased by 15 to 40 % while a factor of 1.3 to 1.9 reduction in peak $SAR_{1\ gr}$ values were obtained. Since the B_1^+ patterns for the different patients were very similar, we investigated whether generic phase/amplitude port setting were possible. Application of mean of the optimised phase/amplitude settings to all patient models, showed in fact reduction of B_1^+ non-uniformity as well as SAR deposition in all cases.

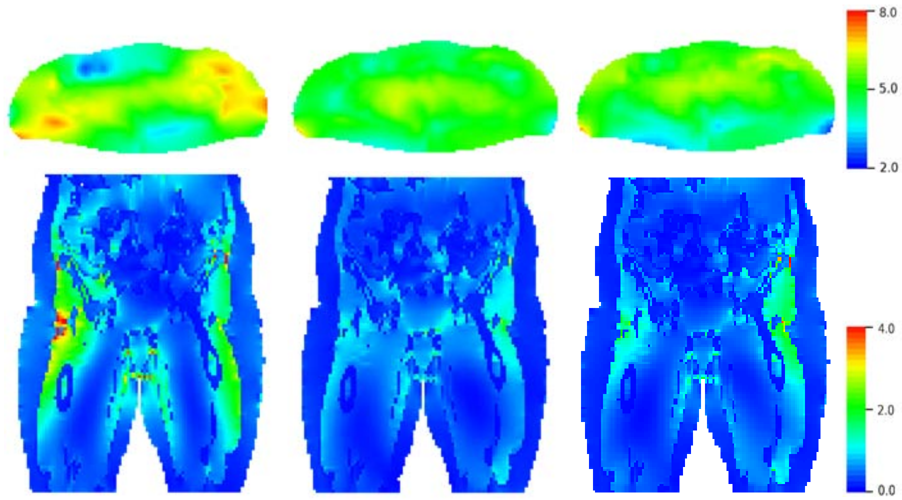

Fig. 1. Example of transverse B_1^+ distribution (above) in uT and coronal SAR distribution (below) in W/kg for one patient model. Quadrature (left), patient specific (middle) and generic optimised (right) settings.

Discussion and Conclusions

The results indicate that the global B_1^+ non-uniformity pattern for the human pelvis at 3 Tesla is mainly due to its elliptical shape. Induced eddy currents at the lateral flanks enhance the B_1^+ field in two contra-diagonal quadrants, while in the other contra-diagonal quadrants the eddy currents have opposite direction and diminish the B_1^+ field [6]. Similar effects were observed for circular geometries in linearly polarized RF field [7].

Phased array drive was shown to be able to reduce B_1^+ non-uniformity and SAR peaks considerably. It is believed that this compatibility originates from the suppression of the large induced eddy currents flowing at the lateral flanks by optimising the destructive interference of the main electric field. This approach was especially successful for obese patients. In these patients quadrature performance, i.e. the destructive interference of the electric field, is severely deteriorated by wave propagations effects. Since these effects lead to similar B_{1+} non-uniformity patterns for different patient models, generic phase/amplitude settings are possible which would simplify the practical feasibility of this coil concept considerably. This work shows that for whole-body imaging at 3 Tesla, quadrature excitation is no longer optimal. Phase/amplitude controlled coils can dramatically reduce flip-angle uniformity and SAR deposition simultaneously.

References:
[1] Ibrahim et al, Magn. Reson. Med. 54 (3) 2005.
[2] Collins et al., Magn. Res. Med. 47(5) 2002.
[3] Van de Kamer et al. Phys. Med. Biol.46(4) 2001
[4] Ibrahim et al., Magn. Res. Imag. 18(6) 2000]
[5] Van de Kamer et al. Int. J. Hyper. 2001, 17(3)
[6] Sled et al., IEEE Med. Imag. 17, 1998
[7] Hout et al, J.Magn. Res. Imag. 12, 2000