Optimization of Transmit Efficiency for a T/R Whole Body Coil at 3T

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Introduction

Patient scanning is becoming as routine in 3T whole body MRI systems as in 1.5T systems. The main RF safety concern at 3T is the possible high SAR from the transmit body coil. Scan software often restricts operators from applying high B_1-field strength or limits duty cycle. Constraints that are too strict can reduce scan efficiency, which is not desirable to clinical users. We calculate SAR according to different longitudinal patient positions relative to a transmit body coil. Results suggest that smart scan software could be designed to maximize the transmit efficiency while keeping SAR within the safety limit.

Methods

As an example, a 16-element band-pass T/R quadrature body coil (QBC) for a 3T whole body MRI system is modeled using a commercial software package (Remcom, Inc., State College, PA) based on Finite Difference Time Domain (FDTD) method [1]. The QBC with a mean diameter of 60cm and length of 40cm is modeled with an isotropic resolution of 5mm. Copper strips and rods in the QBC were modeled as conductors with conductivity $\sigma = 5.8\times10^7$S/m. Capacitors in the coil rungs and end rings were modeled by assigning passive loads in the gaps opened at their locations. The body coil was fed in quadrature by assigned sinusoidal voltage sources (f =128MHz) consistent with the birdcage theory [2]. The QBC is shielded by a RF screen with the diameter of 68cm and length of 1m. A realistic human body model with 23 distinct types of tissues (Remcom, Inc.) is used to simulate a patient. Portions of the arms in the original human body model were removed to eliminate contacts between the hands and the torso. To calculate SAR at different image positions, the human body model is placed on a fixed horizontal level and moved inside the body coil from head to toe. Fig. 1 shows the diagram with the initial position at z = 0. Steady-state solutions are recorded for each loading position and B_1-field in the laboratory frame is converted to the B_1^+-field in the rotating frame using the formula in Ref [3]. Whole-body SAR and partial body SAR are calculated by averaging SAR in the whole body and body portions inside the QBC. Head SAR is calculated by averaging SAR in the head, and local SAR is calculated by averaging SAR over 10 grams of tissues in the extremities and in the trunk, respectively. All SAR values are rescaled with respect to a fixed average $|B_1^+|$-field over the central transverse slice across the isocenter of the QBC and a fixed duty cycle.

Results

In Fig. 2(a), we plot the calculated whole body SAR, partial body SAR and head SAR vs. moving distance z. The SAR values are arbitrarily scaled to an average $|B_1^+|$ of 10μT over the central transverse slice with 5% duty cycle. It shows that SAR values vary with different image positions. Head SAR is important only when head is centered, while whole body SAR is meaningful when one scans the torso. If the scan software restricts the allowed transmit $|B_1^+|$-field strength or duty-cycle to one fixed value for all imaging positions in order to keep SAR within a safe level, scan efficiency will be greatly reduced. Fig. 2(a) suggest that, in practice, adjusting transmit $|B_1^+|$-field or scan repeat time T_R according to the patient's position to the QBC will have great advantage. Using the IEC's SAR guidelines [4], we find that, for this QBC configuration, local SAR is the leading SAR limit rather than head SAR or whole body SAR. When IEC's local SAR guideline is satisfied, all other SARs are automatically within their IEC's guidelines. In Fig. 2(b), we plot the maximum allowed duty cycle vs. moving distance z for a fixed transmit $|B_1^+|$-field strength of 10μT using the calculated local SAR values in the extremities or in the trunk. It shows that longer duty cycle can be used for head and leg imaging than for torso imaging. Thus the scan efficiency for head and leg/knee scans of a patient can be improved while all SAR categories are kept within the safety limit.

Conclusions

For a 3T whole body QBC, limiting transmit $|B_1^+|$-field strength or duty-cycle is an effective way to control SAR within the safety limit. But over constraints can reduce scan efficiency and result in longer scan times. This is not desired in clinical scans and in some advanced applications where high $|B_1^+|$-field or short T_R is an advantage. The design of smart scan software that accounts for the patient's position relative to the QBC can allow an operator to apply higher $|B_1^+|$-field strength or shorten T_R accordingly, thus improving scan efficiency. Although we conduct the calculation for a 3T QBC, the concept is valid for other high field whole body MRI systems as well.

References

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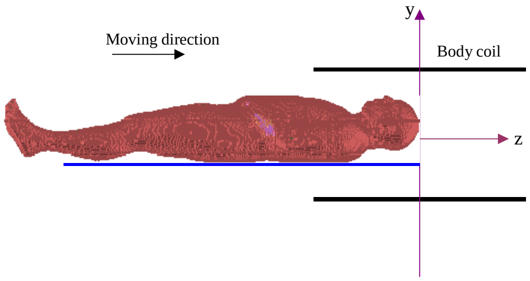

Fig 1. Diagram of the initial z = 0 position of a human body model moving into a 3T QBC.

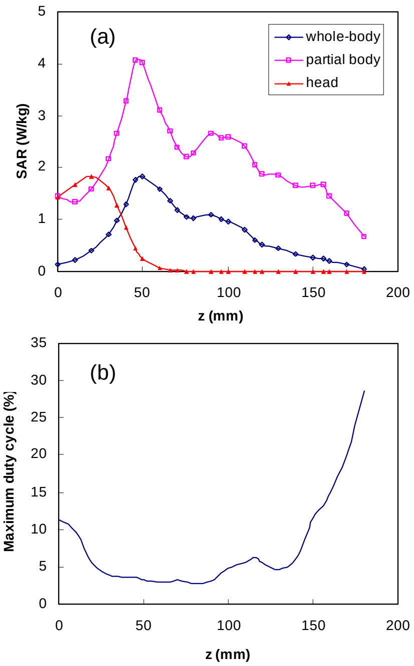

Fig 2. (a) SAR vs. moving distance z; (b) Maximum duty cycle vs. moving distance for a fixed applied $|B_1^+|$-field strength of 10μT.