A Multi-Channel SAR Prediction and Online Monitoring System at 7T

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Introduction

SAR prediction and monitoring are essential for the safe operation of MR systems, especially at higher field strengths due to higher power absorption. With the application of multi-transmit approaches in high field MRI, RF monitoring becomes an even more challenging task, since several channels have to be supervised simultaneously. Multi-transmit systems attempt to optimize the transmit parameters for each channel. For example, RF shimming [1, 2] utilizes different amplitudes and phases per channel to achieve high uniformity of the B1+ field. These parameters depend on the particular exposure scenario, e.g. type of coil array, subject under examination, and region of interest. Therefore, a careful individual SAR prediction has to be performed before each measurement. In the following, a procedure is proposed which describes a suitable RF safety concept for B1 shimming systems. This concept includes SAR prediction and online monitoring during the scan.

Methods

For this study a 7T whole-body MR system (Magnetom 7T, Siemens Healthcare, Erlangen, Germany) was used which has been extended with a custom-built eight-channel B1 shimming system. Before beginning the actual measurement of a subject, B1 mapping is acquired in order to calculate the requisite amplitudes and phases for the B1 shimming method. The online SAR supervision consists of three logarithmic root-mean-square (RMS) power meters (TALES, Siemens Healthcare) equipped with directional couplers for each channel which monitor the excitation signal delivered to each coil element. Each power meter is capable of monitoring the forward and reflected power of up to three channels.

The maximum permissible input power for a given exposure scenario, as determined by the coil array, the subject under examination, and the actual shim parameters, is estimated based on simulated field distributions [3] of the individual array channels using suitable numerical human body models [4]. After vector combination of the electric field distribution according to the shim parameter set, a fast and parallelized SAR averaging scheme is applied for the evaluation of the maximum localized (10g-averaged) and partial-body SAR, from which the maximum permissible RF power is derived.

Before commencement of scanning, the sequence parameters are checked with regard to the maximum allowed power. If the permissible power should be exceeded, the operator can change parameters, e.g. flip angle and TR.

During scanning, custom online monitoring software checks whether the power deposition remains within the previously defined limits. Each RMS power meter works in a multiplexed mode, which means that the incoming signal from each power meter has to be demultiplexed at a sampling rate of 500 kHz. This is achieved by a real-time field programmable gate array (FPGA) acquisition card (PXI 7852 R, National Instruments) which has been programmed utilizing Labview 8.5. The software computes average power per channel over specified time intervals of 10 s and 6 minutes according to the IEC safety guidelines. If the safety limits are exceeded, the software switches off a set of relays, which halts RF transmission from the system, and issues an error message.

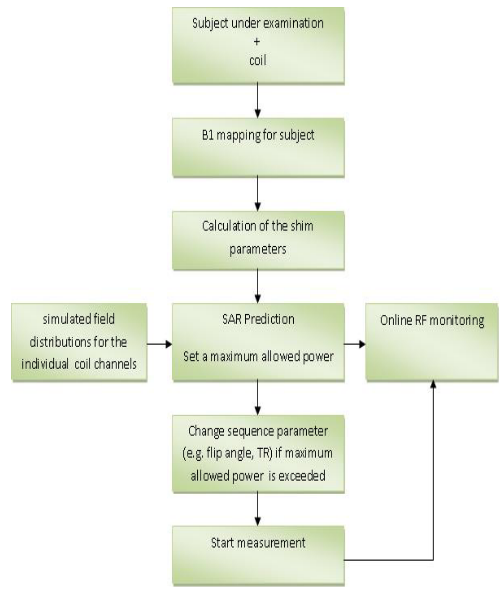

Fig 1: RF safety concept for B1 shimming

Results and Discussion

The monitoring software was successfully implemented as part of the custom RF shimming system and can supervise eight transmit channels simultaneously. Fig 2 shows the measurement values for a single channel during a sequence which was monitored in real time. The sequence was set up to have a TR of 100 ms and a train of 32 RF pulses, with a SINC excitation envelope (time bandwidth product of 8, duration of 1 ms). The software is capable of acquiring the details of each pulse over the duration of the complete sequence. As shown in the insert in Fig 2, the sampling rate of the FPGA card is high enough to resolve the SINC RF envelope of the transmitted power, and the time-averaged transmitted power can thus be calculated from the sampled data with sufficient precision.

Fig 3 presents the SAR prediction procedure. Fig 3 a. and b. show the electric field distributions for channels 2 and 6 of a flexible body array placed dorsal and ventral to the abdomen. After combination of the electric field distributions, the voxel-based SAR is obtained (Fig 3 c.). Finally, the maximum localized 10g-averaged SAR is evaluated (Fig 3 d.), which is used to determine the maximum permissible input power of the channels.

This real-time RF supervision system has been tested successfully in combination with several multi-channel transmit arrays and ensures secure SAR monitoring for individual subjects under examination.

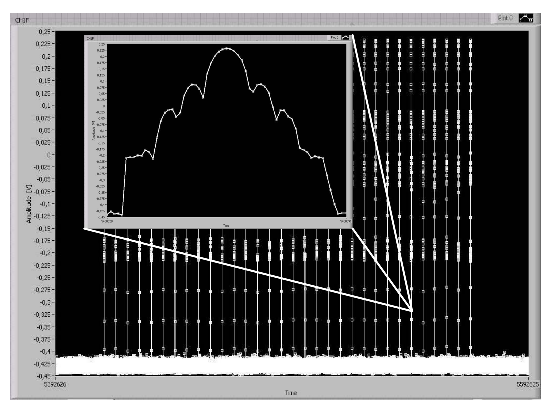

Fig 2: Excerpt from the monitoring software (log scale)

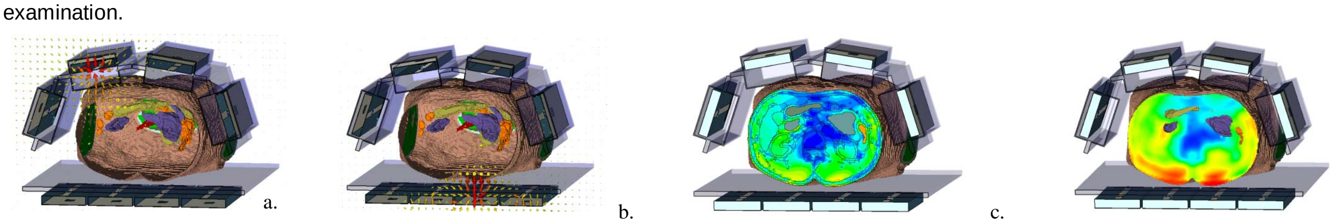

Fig 3: SAR estimation for 8-channel flexible body coil

References [1] Vaughan et.al. Proc. ISMRM 2005, 953 [2] Collins et.al. Proc. ISMRM 2005, 874 [3] CST MICROWAVE STUDIO ® CST GmbH, Version 2008, Darmstadt, Germany [4] Virtual Family Models, http://www.itis.eth.ch/index_humanmodels.html