Real-time Global and Local SAR Monitoring for Parallel Transmission Systems

I. Graesslin[1], S. Biederer[2], B. Annighoefer[3], H. Homann[1], H. Stahl[1], P. Vernickel[1], U. Katscher[1], D. Glaesel[4], and P. Harvey[5]

[1]Philips Research Europe, Hamburg, Germany, [2]University of Lübeck, Lübeck, Germany, [3]TU Hamburg-Harburg, Hamburg, Germany, [4]Research Establishment for Applied Science, Wachtberg, Germany, [5]Philips Healthcare, Best, Netherlands

Introduction

Achieving RF safety in parallel transmission [1] is particularly challenging, due to the extra degrees of freedom. A comprehensive RF safety concept for parallel transmission MRI systems can be realized by verifying the SAR limits [2] before the scan [3] and monitoring the RF signal during the scan [4]. However, using a pre-calculated safety margin over-estimates the actual SAR and is thus non-optimal and results in a prolonged scan time. This abstract extends the concept of pre-calculated safety margins with a real-time global and local SAR monitoring system. This new concept allows for a significantly increased permissible RF duty cycle and improves the detection of violations of SAR limits or any unsafe condition. The impact of patient motion on SAR is analyzed, and a scan termination in case of unsafe system operation is demonstrated.

Methods

Finite-difference time-domain simulations ("XFDTD MicroCluster", Remcom Inc., USA) were carried out for an ideally decoupled 3T eight-channel body coil [5]. The coil was loaded with various bio-mesh models with a resolution of 5mm, including the "Visible Human Male" [6] in different postures ("Varipose", Remcom Inc., USA). Scan-specific information like patient weight, sex, and position in the MR scanner are used to find the appropriate pre-processed bio-mesh model required for the SAR calculation.

For the SAR calculations, the resulting electric fields were post-processed according to [7] and superimposed according to the individual RF samples acquired in real-time from the pick-up coils (PUCs). The samples represent the currents in the RF transmit coil elements during RF transmission. In order to fit the RF simulation model to the real coil configuration for correct SAR calculations, an active decoupling approach [8] was used as well as a calibration of the PUCs. Thus, the RF pulses were pre-compensated to account for coil coupling, which virtually decouples the elements of the multi-channel body coil (MBC).

The described calculation of the SAR from the electric fields was performed in real-time. For this reason, the software was highly optimized and parallelized using Compute Unified Device Architecture (CUDA, Nvidia Corporation, USA) to run on two high performance graphics cards (EVGA GeForce GTX280, EVGA® Corporation, USA), integrated into an eight-channel transmit 3T MRI system [9] (based on Achieva, Philips Healthcare, The Netherlands). A watchdog timer secures the safety critical monitoring software. It leads to a scan termination in case of a too large deviation of the PUC signals or SAR values from their demand in order to achieve patient safety.

Volunteers were asked to move during the scan to study the impact of motion on SAR.

The SAR increase for various safety margins (PUC signal deviation from RF demand waveform) between quadrature excitation and Transmit SENSE were compared. The Transmit SENSE excitation RF pulses [1] were calculated for various local excitation patterns including segmented liver and kidneys [10] for reduction factors $R \leq 8$.

Results and Discussion

Using the 2×240 parallel processors of a GPU allows for 50 updates/s of the global and local SAR values (considering all PUC samples in an interval of 20ms). The sampled RF pulses as well as the current SAR can be displayed in real-time on the scanner console (see Fig. 1). The real-time estimation of the SAR has a significant advantage compared with the worst case calculation of a safety margin. First, the calculation of the SAR for a safety margin is very expensive and overestimates the SAR significantly. For the example of a safety margin of 20%, the SAR is overestimated by more than 200% (see Fig. 2). For Transmit SENSE pulses, these values were reduced by a factor of approximately 3. Modest to medium volunteer movement inside the scanner resulted in local trunk SAR increase of up to 240% (see Fig. 3, red circle). In this example, this is not a problem as these signals need to be averaged over a period of 10s as well as 6min [2] so that deviations occurring only for short time periods are not critical (see Fig. 3, solid line). The SAR limit according to [2] has been added as a dashed line.

It is worth mentioning that also the lower bound of the SAR safety margin is important. For instance, in the presence of a resonant object, the RF amplitude might drop significantly, and in turn, the SAR goes down in spite of the hazardous situation. On the other hand, large patient movements might cause an increase of the RF amplitude. In both cases, the scan must be stopped because the electric fields assumed for the local SAR calculation are likely to be incorrect.

Conclusion

Achieving RF safety is particularly challenging for parallel transmission systems. RF signal monitoring alone is sub-optimal with respect to the RF duty cycle. In this study, it was demonstrated that real-time global and local SAR monitoring is feasible and provides a more accurate SAR estimation while ensuring patient safety.

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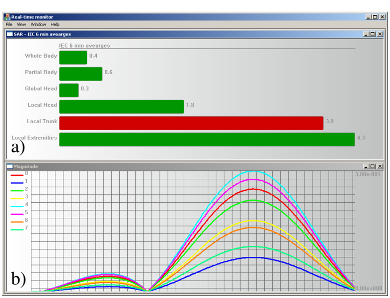

Fig. 1: Real-time display of global/local SAR with SAR violation in red (a) as well as the RF pulses for each RF Tx channel (b).

ΔA	Δφ	SAR Type	Standard	Kidney	Liver
5%	3°	wb	19,28	10,96	11,38
		trunk	39,07	11,57	13,13
10%	6°	wb	43,1	24,37	25,51
		trunk	86,98	28,72	25,73
20%	12°	wb	114,79	53,01	55,69
		trunk	205,77	61,74	55,24

Fig. 2: Worst case SAR increase for different safety margins'. For the quadrature excitation more than 200% SAR increase was observed. For parallel Tx pulses up to 62%.

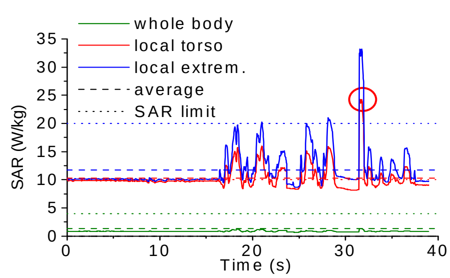

Fig. 3: Global and local SAR changes due to different movements inside the scanner. Up to 240% SAR increase was observed in this example.

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