Reference-free Detection of RF Unsafe Conditions and Countermeasures for Implantable MR-conditional Devices

Ingmar Graesslin[1], Johannes Achtzehn[1], Sascha Krueger[1], Peter Vernickel[1], Kay Nehrke[1], and Steffen Weiss[1]
[1] *Philips Research, Hamburg, Germany*

Introduction Implants usually represent a contraindication for MR examinations, and MR-guided interventions are hampered by potential RF heating of devices. A concept based on parallel transmit technology was proposed to detect potentially RF-unsafe conditions. It monitors changes of RF currents in transmit coils caused by coupling to devices [1]. This method requires a reference scan without the device and hence can only be applied to interventional devices and not to implants. Subsequently, therefore, a method was proposed to obtain a reference for a patient with an implant from multiple scans of similar subjects without an implant [2]. Here, an alternative method is proposed that exploits the left-right symmetry of a patient to avoid the need for such a reference database. The basic feasibility of this approach is first evaluated in a *pseudo-in vivo* study with a pacemaker set up to be resonant. Then the method is evaluated in phantom studies for pacemaker leads in linear and realistic standard configurations that show weaker RF coupling. Finally, whether tip heating can be reduced by changing RF transmit phases is explored.

Methods Experiments were performed on a research 3T MRI system (Achieva, Philips Healthcare, The Netherlands) extended with eight individually-driven parallel RF transmission channels [3] that feed an eight-channel body coil [4] (Fig. 1a). A waveform monitoring system acquires the complex coil currents via pick-up coils (PUCs) [4] during RF transmission [5].

In the *pseudo-in vivo* experiment, a pacemaker with a 53cm lead that was partially inserted into a tube phantom (Ø=16mm, length=100cm) was placed alongside the volunteer's torso and thighs. This tube phantom was filled with a saline solution (conductivity σ=0.47S/m, relative permittivity ε_r=80). This setup had a resonance frequency of about 147 MHz and was covered with foam for patient safety. During a low SAR scan (<0.1W/kg), each of the five volunteers (without or with device) was moved feet first through the scanner at a constant velocity of 50mm/s while the PUC amplitudes of all eight channels were monitored. To identify the presence of the resonant device, the Pearson's correlation coefficients (PCC) were calculated for all channels with left/right symmetry (1 & 8, 2 & 7, etc.).

In the first phantom experiment, a pacemaker with four different connected leads of different types and lengths (1-3 connections and 53-76cm) from various manufacturers was used. These were placed inside an ASTM phantom [6] (2cm from bottom and side) as shown in Fig. 1(a,b). The phantom was filled with 49 liters of hydroxy ethyl cellulose gel [6] in order to reach a sufficient load. During signal acquisition, the phantom was traversed 135cm through the scanner bore at a constant velocity of 45mm/s. The PCC was calculated for those PUC signals that changed due to phantom loading as described above. In order to assess the RF induced heating at the tip of the lead, high SAR scans with a whole body SAR of 2W/kg were performed for 30sec for each lead at 28 different table positions, ranging from 40-175cm at intervals of 5cm. Simultaneously, tip heating was monitored using a high-accuracy commercial fiber-optic thermometer (LT-X7R, Ipitek, California, USA).

In a second phantom experiment, the temperature increase for three different lead configurations (Fig. 1c) was measured during imaging with a balanced FFE (bFFE) sequence at 2W/kg. The experiment was repeated with the RF phase of a particular transmit element reversed, aiming at reducing RF heating. The element selected was that which showed the largest PUC amplitude changes.

Results and Discussion The PUC signals of channel 4 & 5 and 2 & 7 are shown in Fig. 2 for the cases without and with device. Without device, the PCCs have a high correlation between corresponding elements, as shown for one example volunteer in Tab.1. When a device is present, a reduction in PCC is observed, which is largest for channels 2 & 7. The same qualitative findings were obtained for the other volunteers. The use of the PCC is important, because the shape of PUC signals is much less influenced by an asymmetric patient placement than by the absolute PUC signal level. The PCCs for the linear configuration shown in Tab. 2 allowed the detection of all leads. Only those PUC signals that resulted from phantom load changes were used, otherwise the PCC became too insensitive. It was observed that PCC-based device detection becomes more difficult for higher loading and less resonant devices. In Fig. 3a, it can be seen that the shape of the PUC signals varies for different leads. A lead that contains several wires and electrodes may lead to more than one peak. In Fig. 3b, the normalized amplitude (A_{max}=6.4%) and phase deviations (φ_{max}=8.9°) are shown for channel 7 and electrode 4 in relation to the heating deviation (T_{max}=4.3K), which suggests that the amplitude should be considered as well as the phase in future studies in order to detect unsafe situations. However, the quantification of RF heating from the PUC signals is not straightforward and needs further investigation.

During temperature measurements for the typical pacemaker configurations (Fig. 1c), significant RF heating was only observed for lead configurations 1 and 2. However, RF phase reversal of the element that showed strongest coupling resulted in a reduction in tip heating of a factor of 6 without significant change of imaging results (Fig. 4). This experiment shows the potential of using a multi-channel transmit system to increase device safety, but it is still necessary to explore how RF amplitudes and phases can be adjusted optimally. Previously, a similar approach using a two-channel transmit system demonstrated a reduction in device-induced RF heating [7]. Future transmit arrays with more channels located closer to the body may be even more suitable for device detection and reduction of heating.

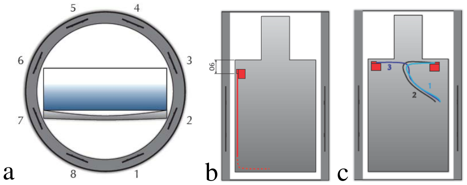

Fig. 1: Body coil and ASTM phantom. (a) Schematic view of coil and ASTM phantom, (b) linear PM configurations, and (c) three typical PM configurations.

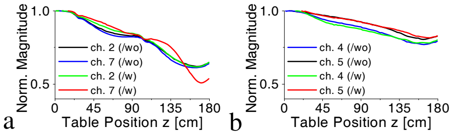

Fig. 2: PUC signals for moving volunteers through scanner. (a) PUC signals with (/w) and without (/wo) device for channel 2 & 7, and (b) 4 & 5.

Channel pairs	1-8	2-7	3-6	4-5
Without device	1.00	1.00	1.00	0.99
With device	0.99	0.96	0.97	0.98

Tab. 1: PCCs for left-right symmetry of channel pairs. The PPCs for the case without and with device.

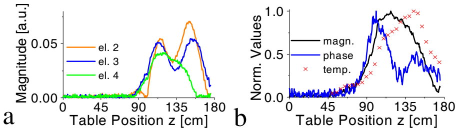

Fig. 3: PUC signal deviations and temperature measurements. (a) PUC signal deviations for leads with different numbers of connector. (b) temperature at tip of lead as well as amplitudes and phases (normalized).

	Channel pairs			
Electrode number	1-8	2-7	3-6	4-5
-	1.00	1.00	1.00	0.99
#1	0.99	0.98	0.99	0.98
#2	0.98	0.98	1.00	1.00
#3	0.99	0.98	0.99	1.00
#4	1.00	0.98	0.99	1.00

Tab. 2: PCCs for left-right symmetry of channel pairs. The PPCs are shown for the empty ASTM phantom (first row) and 4 different electrodes.

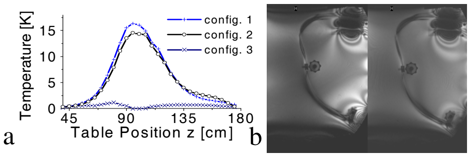

Fig. 4: Temperature over z-location and SFFP images. (a) The temperature is measured at different z-locations for 3 different electrode configurations. (b) bFFE images for lead configuration 2 and a reversed

Conclusion The detection and monitoring of RF-unsafe conditions for implanted and temporarily introduced devices is important to prevent potentially unsafe situations for the patient. A concept based on using parallel transmit technology to detect potentially RF-unsafe conditions has been improved, making a reference scan without device unnecessary. This also allows the approach to become applicable to patients with implants. The technical feasibility of device detection was demonstrated in phantom and pseudo-in vivo experiments for various pacemaker leads. Moreover, it was shown that device-induced RF heating can be reduced significantly by reversing the phase of the transmit coil element that coupled most strongly to the device. By making use of this concept, the safety of MR-conditional devices may be further increased.

Acknowledgements We would like to thank R. Luechinger, Universitaetsspital, MR-Zentrum VMR30, Zuerich for support and helpful discussions.

References [1] Krueger S, et al. [2008] ISMRM 16:896, [2] Graesslin, I. et al. [2008] ISMRM Safety WS #40, [3] Graesslin I, et al. [2006] ISMRM 14:129, [4] Vernickel P, et al. [2007] MRM 58(2):381-9, [5] Graesslin I, et al. [2008] ISMRM 16:74, [6] ASTM [2011] F2182-11a, [7] Eryaman, et al. [2007] MRM 65:1305-13