

# Experimental setup with a whole-body resonator for investigating thresholds of tissue damage in swine model exposed at 123 MHz – First measurement results

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## Introduction

Numerous simulations using realistic voxel models of humans with a torso centrally positioned in a typical whole-body radio frequency (RF) resonator of a clinical magnetic resonance (MR) scanner predict that the local specific absorption rate (SAR) within the torso may be up to a factor 10-20 in excess of the global whole-body SAR (SARwb) [1, 2]. According to the IEC 60601 2-33 standard [3] a SARwb up to 4 W/kg is allowed to be applied if volume type of transmitting (Tx) coils like conventional whole-body resonators are used. Consequently the local SAR could reach values up to 80 W/kg in the patient. However, the IEC standard does not require monitoring of the local SAR for this type of RF coils. On the other hand the IEC standard defines local SAR limits of 10 W/kg for the torso region for so-called "local Tx coils". Obviously the local SAR limit (valid for local Tx coils) tends to be very conservative compared to the global whole-body SAR limit of 4 W/kg (valid for volume Tx coils). This poses the following questions: a) How realistic are the simulations, b) What are the temperatures at the locations of the SAR maxima in reality, considering the complex thermoregulatory mechanisms in a true patient, and c) What should be the reasonable limits for both the whole-body and local SAR values, so that tissue damage can be surely excluded, and – at the same time - the application performance will not be limited more than necessary.

## Methods

A whole-body resonator (a 16 rung bird cage type) of a conventional 3T MR system operating at 123 MHz in a quadrature mode was connected via a 90° hybrid to a 35 KW RF power amplifier (RFPA). The applied RF power was monitored via two directional couplers inserted into the transmission line between the hybrid and the 0° and 90° ports of the resonator. The coil efficiency was controlled via two pick-up coils located opposite to the input stage of the 0° and 90° at the end ring of the bird cage. RF pulses of 1 ms duration were applied. The time-averaged power was set to the desired value using an appropriate RF duty cycle. In a first step the determination of the power absorption was validated via calorimetric measurements using the so-called ASTM phantom [4] filled with NaCl solution (electrical specific conductivity 0.47 S/m). In the second step, the local RF power absorption was simulated using a realistic voxel model of a swine. A temperature solver presented in the appendix of Nadobny et al 2007 [1] was applied. Note that zero perfusion was assumed in order to model a dead swine. For the swine positioned head first, lying on the left side with the torso centered in the resonator, the simulation shows two major hot spot locations indicated as HS1 and HS2 (Fig.1). For this position the RF heating at the muscle band located at the right-hand side of the swine at the ribs (hotspot HS2) is slightly more intense compared to the hotspot HS1 in the muscle along the spine. The maximum local SAR at HS1 occurs at ~ 30 mm below the skin. Note that the thickness of the muscle at the HS1 location is around 60 mm. In contrast, the thickness of the power absorbing tissue in HS2 is only about 15 mm, and the maximum SAR location is only a few millimeter below the skin. The simulation results in Fig. 1 indicate the location, size and intensity of the expected hot spots after 30 minutes RF exposure at 6.5 W/kg SARwb. In the third step the temperature probes of a 6 channel fiber optic measurement device were placed to a dead swine (ethical approval #G 0256/09) that had a shape and weight similar to that simulated in a voxel model (70 kg). The probes #1 to #4 were placed at the predicted hot spot area HS1, the probes #5 and #6 at HS2 (Fig.2). The insertion depth of the probes was 30mm for HS1, and ~ 8 mm for HS2. After the preparation the swine was exposed for 30 minutes to a whole-body SAR of 6.5 W/kg. During the RF exposure the temperature values of the 6 probes were recorded continuously (s. Fig. 3). Additionally, infrared (IR) based temperature measurements of the skin surface were performed before the start and after the end of the RF exposure (Fig. 2). Finally, in order to examine possible tissue damage, tissue probes were taken in a final step from the areas where the temperature probes had been placed.

## Results

The predicted hot spot areas (s. Fig. 1) were clearly visible in the IR picture (s. Fig. 2). Before the start of the RF exposure a temperature of about 31°C and 34°C at the surface of HS1 and HS2 respectively was measured. Three minutes after exposure the maximum IR temperatures were 45.8°C and 50.7°C (HS1, HS2), thus showing about 15°C and 17°C temperature rise, respectively. According to the simulation displayed in Fig.1 the maximum temperature increases had been calculated to 19.5 C and 21.6 C (HS1, HS2). Note that these are temperatures at a depth of 30 mm (HS1) and 8 mm (HS2). The measurements results in Fig.3 correspond well with the calculated values in Fig.1, showing a rise of 19.8°C (HS1) and of 20.2°C (HS2).

## Conclusions

The simulation was performed with a model originating from a different swine. Putrefaction in dead swine causes notable bloat of the abdominal area. Therefore the very good agreement of simulation and measurement must be considered carefully and needs further comparisons. Nevertheless these first results are very promising. Furthermore, with a dead swine the detected temperature increases at 6.5 W/kg SARwb for 30 minutes were sufficient to clearly cause tissue damage (qualitative visible already during the abstraction to the tissue probes). The histological analysis will be published elsewhere. The next step will be swine investigation in vivo. The current setup will allow experiments with SARwb values up to 11 W/kg. Although in the past studies on volunteers had been reported with up to 6 W/kg SARwb for 16 minutes without deleterious [5] effects, the potential of 11 W/kg SARwb can be expected to be sufficient to study tissue damage in living swine. Finally before transferring the results from swine to humans the varieties in the thermoregulation capacity must be considered.

## Reference

- [1] Nadobny et al., IEEE Transactions on biomedical engineering, Vol. 54, No. 10, October 2007. [2] Collins et al., Proc. Intl. Soc. Mag. Reson. Med. 14 (2006). [3] International Electrotechnical Commission, IEC 60601-2-33: 2002E. [4] ASTM Standards: F 2182 – 02a. [5] Shellock et al., Radiology 1994; 192:865-868.

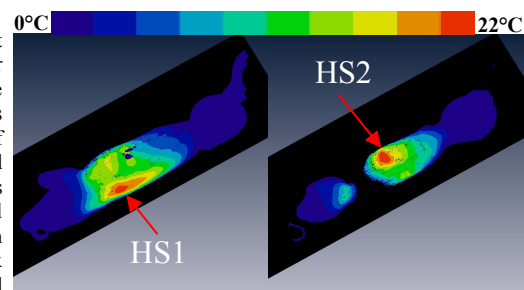


Fig. 1 Predicted hot spots: HS1 at the muscle band along the spine; HS2 ventral at right lower torso region; cross-sectional view through the hotspots. Note that zero perfusion was assumed in order to model a dead swine.

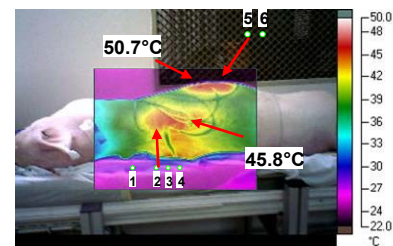


Fig. 2 Hot spot areas at dead swine after 30 min. @ 6.5 W/kg (IR picture). Locations of probes #1 - #6 are indicated by red arrows

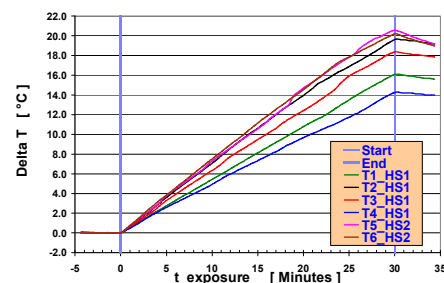


Fig. 3 Local temperature increase at the hot spots measured with fiber optic temperature probes