Resolving Local SAR In Vitro from RF-Field Induced Heating of a 5.0 cm Long Titanium Rod at 64 MHz and 128 MHz

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INTRODUCTION

- Local SAR is defined as RF-induced power absorption per mass of an object (W/kg) [1].
- Local SAR can be assessed *in vitro* by directly measuring RF-induced heating of an elongated conductive 10.0 cm long Ti rod within a standardized phantom [2].
- A frequency dependent scaling factor, χ, normalizes the temperature rise, ∆T, to a local SAR value that would be present in the rods absence [2] by:

$$SAR = \frac{\Delta T_{360s}}{\chi}\,.$$

- The 10 cm rod length limits the spatial resolution in probing SAR "hot-spots". The SAR distribution depends on the employed RF coil design and phantom shape and size.
- A rod with reduced length would allow higher resolution SAR estimation while permitting greater probing accessibility in tighter areas found in more complex phantom geometries.
- In this study, we exploit the RF-related heating on a shorter, 5.0 cm long Ti rod to estimate and validate local SAR deposited by scaling the measured temperature rise at both 64 and 128 MHz.

METHODS

- A representative experimental setup is shown in Figure 2. All measurements were performed on two different commercially available transmit body RF birdcage Medical Implant Test Systems (MITS) 1.5 and 3.0 [3], corresponding to frequencies of 64 and 128 MHz, respectively.

Table 1: MITS sequence parameters (Software v1.12.10, [3]).

Parameter`	MITS 1.5	MITS 3.0
RF Application [s]	360	360
Pulse type	sinc2π	sinc2π
Duty cycle [%]	40	40
Pulse repetition rate [kHz]	1.0	1.0
Polarization [º]	270	90
Frequency [MHz]	63.33	127.51
Power [dBm]	59.0	60.2
Whole-body SAR [W/kg]	3.14 ± 0.10	3.27 ± 0.04
$B_{1,rms}$ [μT]	4.78	2.97

- A phantom container representing the human torso was utilized as per ASTM specifications (42 × 60 × 16.5 cm) and filled with gelled Hydroxyethyl cellulose, formulated to match the electrical conductivity (0.47 S/m ± 10 %) and thermal convection properties of human tissue.
- The geometric center of the phantom was aligned with the center of the MITS.
- 5.0 and 10.0 cm long titanium rods were machined from 1/8-inch diameter Grade 5 Ti, with two 1.0 mm diameter holes drilled through and placed 1.0 mm from each end of the rod (Figure 1).

Figure 1: 5.0 and 10.0 cm Ti rods.

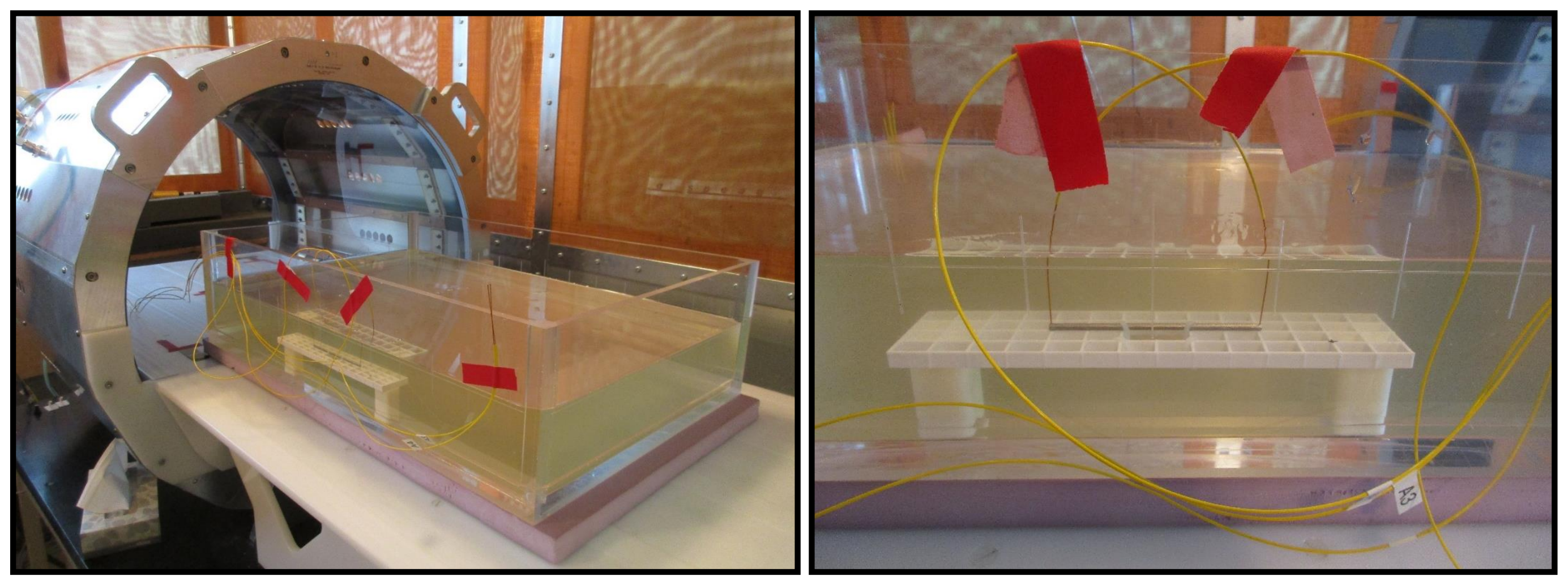

Figure 2: (left) Representative measurement setup with MITS 1.5 and a standardized phantom and (right) the 10 cm Ti rod with optical temperature sensors placed in symmetrically opposed holes.

- T1C fiber optic temperature sensors [4] (resolution=0.1 ° C, accuracy=0.2 ºC) monitored temperature with a calibrated Omniflex signal conditioner [4].
- E-field-resolved local SAR measurements were obtained independently with a calibrated E-field RMS probe (EX3DV4, EASY4MRI standalone data acquisition system, [5]) and by using the 5.0 or 10.0 cm Ti rods.
- Data were taken at points submerged in the gel parallel to the long-sided wall at different spatial increments (2.0 to 5.0 cm) along the z-axis direction, 33 mm from the x-axis wall and 52 mm from the phantom floor (y-axis).
- The measured temperature change from the 10.0 cm rod was normalized by a local SAR scalar factor of 1.30 ºC/W/kg for 64 MHz and 1.45 ºC/W/kg for 128 MHz [2]. Evaluation of scalar factors for a 5.0 cm was determined based on computational simulations using SEMCAD X v14.8.6.1 [5].

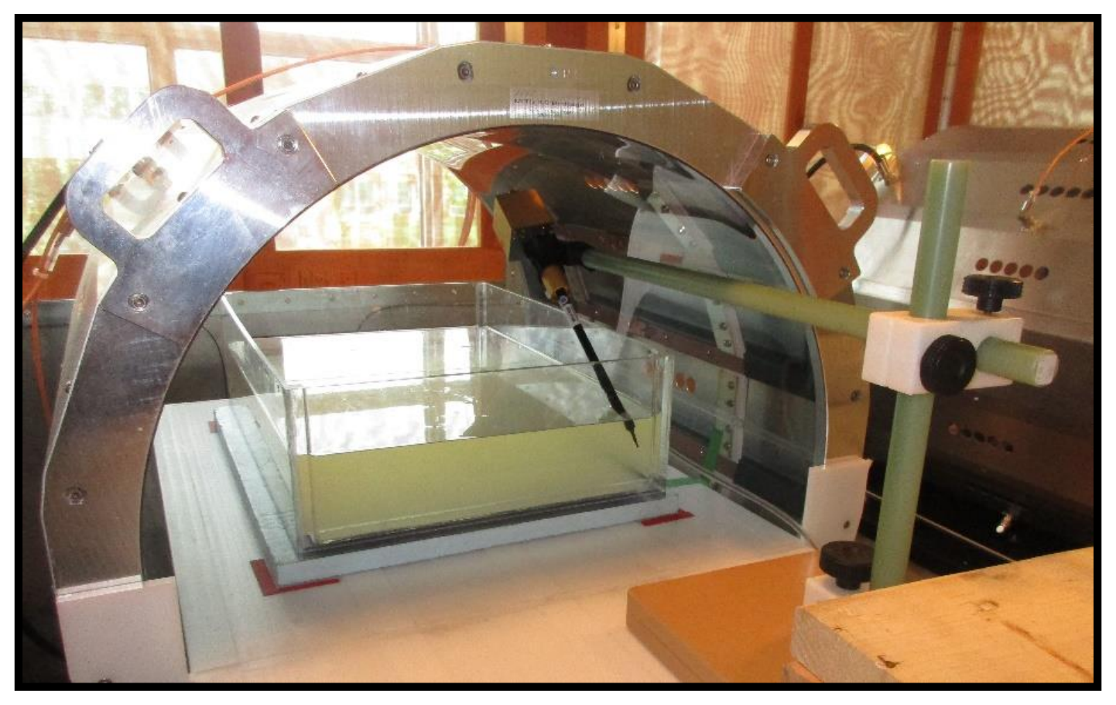

Figure 3: Representative measurement setup using a calibrated EASY4 E-field RMS probe in the MITS 3.0.

RESULTS

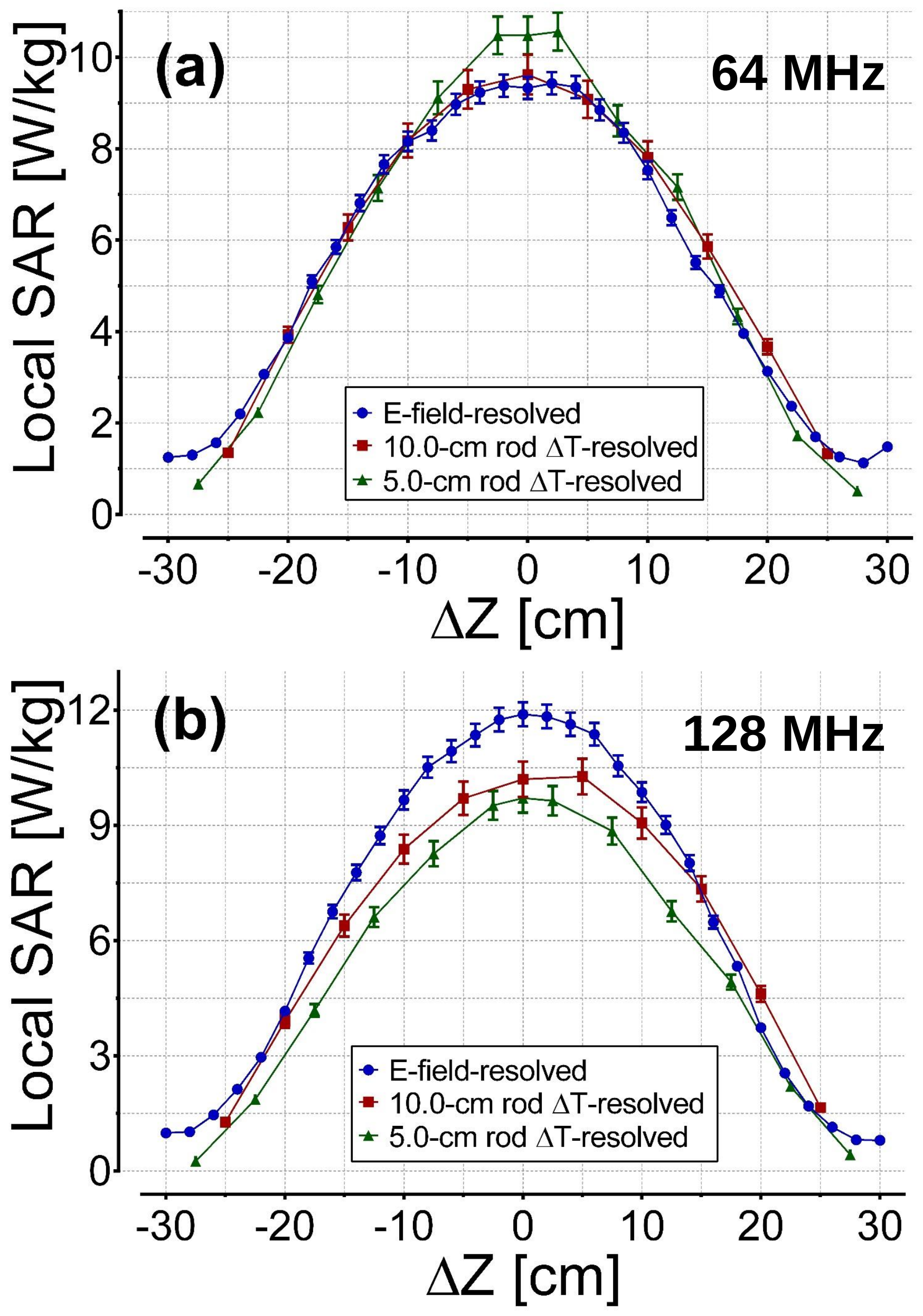

Figure 4: z-axis spatial distribution of local SAR in the phantom for **(a)** 64 MHz and **(b)** 128 MHz. Local SAR were resolved from measuring: local E-field RMS (Circle-markers), and 6-minute RF-heating on a 10.0 cm Ti rod (Square-markers) and 5.0 cm Ti rod (Triangle-markers). The vertical error bars represent standard deviation (percent uncertainty) of three repeated measurements at ΔZ = 0 cm.

RESULTS

Table 2: Local SAR scalar factors [ºC/W/kg] determined by simulation.

Frequency [MHz]	5 cm rod	10 cm rod
64	0.40	1.30
128	0.48	1.45

DISCUSSION

- As seen in Figure 4, the peak local SAR values using the three different methods were within 11.6 % and 20.2 % of each other at 64 MHz and 128 MHz, respectively.
- Further work needs to be performed with different phantom containers and at various frequencies (21.3 MHz to 298 MHz) to verify the findings.
- The 5.0 cm rod offers a new possibility for assessing temperature change resolved local SAR in more elaborate (i.e. head-torso at shoulder area) or smaller (i.e. head only) phantoms, where the SAR is not expected to be uniform over a 10 cm region.
- In particular, it is expected that the 5.0 cm rod will provide an alternative/improved method for assessing temperature change resolved local SAR in a phantom at higher field strengths (7 T) where SAR distributions are highly spatially variable.

CONCLUSION

- This work demonstrates the feasibility of using a 5.0 cm long titanium rod as a reference implant to estimate or validate local SAR deposited by RF-induced heating.
- Results were in good agreement between resolved local SAR from the 10.0 cm ASTM rod and calibrated E-field probe. It is expected that the 5.0 cm rod will be more valid than the 10cm rod in cases of limited phantom geometry, but this will need to be verified in future work.

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