# Experimental and numerical determination of SAR and temperature distribution of a human endorectal coil for MR imaging of the prostate at 7T

**A. K. Bitz[1], D. W. Klomp[2], and M. E. Ladd[1]**

[1]Erwin L. Hahn Institute for Magnetic Resonance Imaging, Essen, Germany, [2]Radiology, Radboud University Nijmegen Medical Centre, Nijmegen, Netherlands

**Introduction**

MR (spectroscopic) imaging (MR(S)I) of the prostate has been shown to help in the detection of prostate cancer [1]. In order to address some challenges of MR(S)I of the prostate at 7T, an endorectal coil to be positioned close to the prostate via the rectum was constructed. Use of a small RF coil for transmit and receive in combination with adiabatic RF pulses allows high bandwidth excitation and refocusing pulses to be obtained at relatively low RF power. However, due to the close proximity of RF-radiating structures of the coil to the human tissue, a carefully performed compliance test with respect to the specific absorption rate (SAR) and temperature limits [2] is essential for safe operation of the coil. Therefore, the power absorption as well as the resulting temperature increase in the surrounding tissue were determined by measurements and numerical calculation.

**Materials & Methods**

The endorectal coil (obtained from Medrad, Pennsylvania) consists of an insulated conductor (diameter 1 mm, insulation diameter 4 mm) shaped as an elliptical loop (length 7 cm, width 3.5 cm). The loop is tuned by two series 8.6 pF capacitors at the feed point of the loop and a third series 4.7 pF capacitor at the center of the loop. A parallel 10 pF capacitor is used to match the loop to the 50 Ω coaxial cable interfaced to a 7T whole-body MR system (Magnetom 7T, Siemens, Erlangen). Numerical computations of the RF field distribution and the corresponding SAR were performed [3] based on a detailed simulation model of the coil and the surrounding tissues including the prostate (cf. Fig.1) which dimensions were estimated from high-resolution MR images of the human prostate obtained at 3T. Permittivity and electric conductivity of the tissues were taken from literature [4] and the TEM wave of the coaxial cable was used for RF field excitation. In addition to the numerical calculation, MR thermometry was performed for the coil positioned in a homogeneous phantom made of gel to check the correlation of the calculated SAR and measured temperature distribution as well as to confirm that the location of highest RF power deposition from the numerical simulation coincided with the location of highest temperature elevation in the phantom. To determine the maximum temperature increase due to local RF absorption at a max. 10g-averaged SAR of 10W/kg during a typical MR(S)I of the human prostate incl. active heat transfer mechanisms of the human body (e.g. blood perfusion, thermoregulatory system, etc.), in vivo temperature measurements were performed. For this, the endorectal coil and a fiber-optic thermometer at the location of the calculated and experimentally validated hot-spot were positioned close to the prostate through the rectum of a healthy volunteer. In addition, spin echo images were obtained to determine the $B1^+$ field distribution and efficiency of the coil.

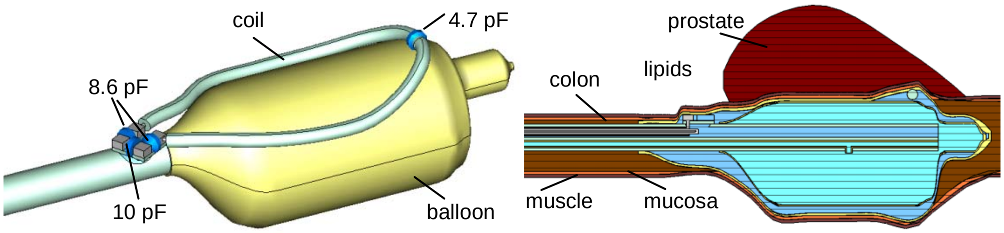


Fig. 1: (a) Model of the endorectal RF coil; (b) detailed tissue model

**Results**

Measured reflectivity and quality factor of the loaded coil are $S_{11}$ = -14 dB and 14, resp. The computed reflectivity vs. frequency shows a minimum of -15 dB and a Q factor of 15.5. As judged from the spin echo images (cf. Fig. 2), a correct spin flip has been accomplished at a distance of about 3 cm from the conductors at a reference power of 35 W (corresponding to a 90° flip angle with a rectangular RF pulse of 0.5 ms and $B_1^+$=12 μT). The calculated $B_1^+$ field at this power level and distance to the coil is 10.5 μT. As expected, the location of maximum RF power deposition is closest to the capacitors at the RF feed point of the coil (Fig. 3a). This result is verified by MR thermometry in the homogeneous phantom, which shows that the point of maximum temperature increase is also located close to the capacitors at the RF feed (Fig. 3b). From the numerical results, a maximum permitted power level of 0.76 W is obtained at which the max. localized 10 g-averaged SAR complies with the IEC limit of 10 W/kg. The measured temperature increase during an 8-minute scan protocol at 0.76 W of RF power was less than 1 °C close to the RF feed point of the coil at the rectal wall in vivo (Fig. 3c)

**Conclusion**

The results show that for a maximum permissible time-averaged power of 0.76 W, the proposed endorectal coil complies with the limits given in the IEC guidelines. The agreement between the measured $B_1$ field, $S_{11}$ reflection curve and location of the RF hot-spot with the numerical calculations of the electromagnetic field suggests that an appropriate model of the endorectal coil and the human prostate was used. As the major RF power deposition in the current design is focused around the capacitors, this model can be used to determine better locations or distributions of the capacitors to reduce the maximum local RF power deposition. In addition, as the loaded Q factor of the coil is low, investigation of multiple smaller coils with this model to improve SNR even further and allow parallel transmit and detection techniques appears worthwhile.

**References**

[1] Kurhanewicz, J., et. al.: Urology 2001; 57:124–128. [2] IEC International standard 60601-2-33; 2002: 29-31. [3] CST MICROWAVE STUDIO®, www.cst.com. [4] Gabriel C.: Compilation of the dielectric properties of body tissues at RF and microwave frequencies. Brooks AFB, TX: Brooks AFB, Tech. Rep. AL/OE-TR-1996-0037, 1996.

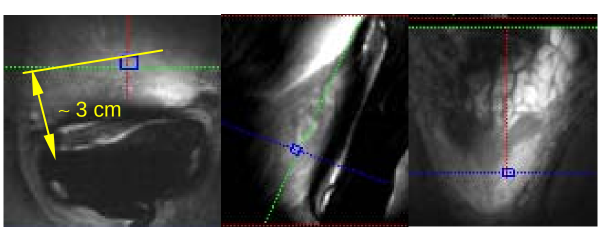


Fig. 2: MRI of human prostate indicating the estimation of 90° flip at 3 cm from conductors: (a) transverse, (b) sagittal, (c) coronal.

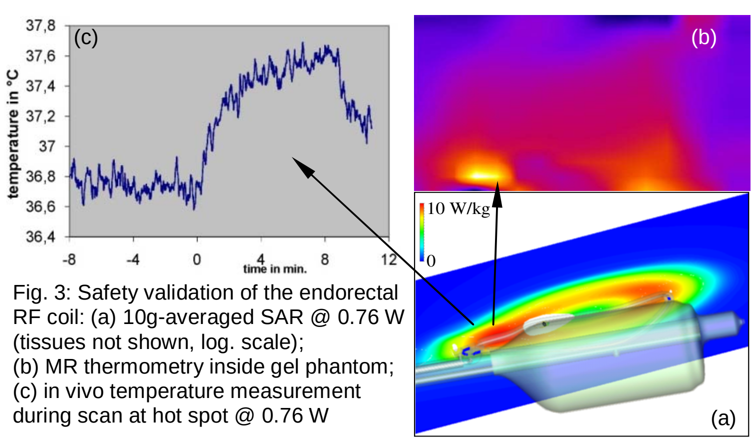


Fig. 3: Safety validation of the endorectal RF coil: (a) 10g-averaged SAR @ 0.76 W (tissues not shown, log. scale); (b) MR thermometry inside gel phantom; (c) in vivo temperature measurement during scan at hot spot @ 0.76 W