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Towards optical-based real-time evaluation of the local SAR: RF electrical field in biological sample

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Purpose/Introduction: The specific absorption rate (SAR) above regulation levels is considered a significant risk in MRI scanners¹. Indeed, the strength of the static magnetic field (B_0) and the radiofrequency (RF) electromagnetic field can lead to local heating of tissues. To ensure patient safety, it is therefore important to estimate the local SAR in addition to the global SAR. Various methods are used to assess the local SAR: dipole probes² that measure electrical field (E), or thermal sensors³. This work presents an optical probe based on Pockels effect and developed to measure precisely the E-field. Previous works^{4,5} have demonstrated the ability of this probe to perform E-field measurements in an unloaded birdcage coil. Here, in vitro E-field measurements are presented at different B_0 -fields strengths and RF coil geometries.

Subjects and Methods: The electro-optical effect was used to develop the optical-based probe consisting of an isotropic crystal illuminated by a laser. When the E-field is applied, the refractive indices of the crystal and the polarization state of the laser change. The polarization state modulation is analyzed then converted into an analog signal (proportional to the E-field) by means of a fast photodiode. Figure 1 presents the setup of the experiments performed in two different MR scanners (the used sequences and RF coils are described in Table 1).

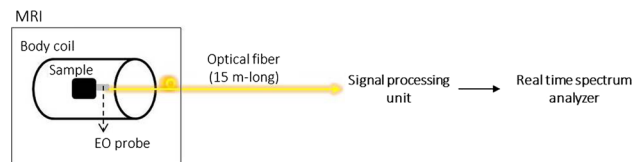


Figure 1 Schematic of the experimental setup for E-field measurements. The emitted and reflected lasers were transmitted through the same optical fiber. The signal processing unit contains optoelectronics components to analyze the polarization state modulation of the laser. A fast photodiode was used to ensure the optical-to-electrical conversion of the signal. A spectrum analyzer provides directly the temporal evolution of the RMS value corresponding to the E-field component. The probe was calibrated outside the MRI using a loaded transverse electromagnetic cell to determine the proportionality factor between the measured signal and the electrical field.

Results: MR images of an orange (fruit) were acquired with and without insertion of the optical probe (figure 2). The slight difference between the images was due to the mechanical insertion of the probe and not due to some possible perturbations of the probe. Table 1 summarizes results of the local SAR for different samples and experimental conditions at the center of the MRI. The presence of a

resonant circuit near a liquid-filled phantom caused an increase of the SAR by a factor of 7.76. Inside an orange, SAR values were 10.76 W/kg and 3.98 W/kg at 4.7-T and 3-T, respectively. Finally, the calibration of the probe shows that the relative E-field amplitude uncertainty does not exceed 1 dB.

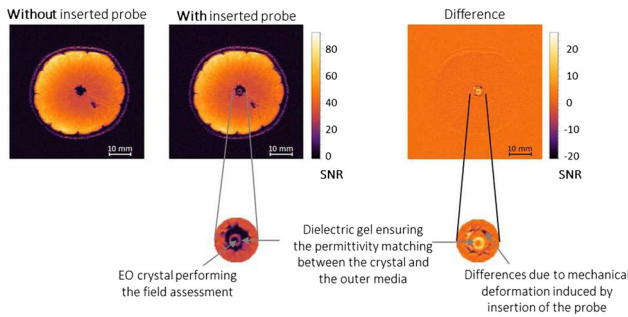


Figure 2 a) MR images of an orange with and without the insertion of the optical probe and the difference between the two images. The orange was located in the center of the body coil of a 3T clinical MR scanner.

MR systems	Sample	Approximate electrical conductivity ^{6,7} (σ , in S/m)	Approximate mass density (ρ , in kg/m ³)	Measured radial component of the electrical field (E_r , in V/m)	Local SAR ($SAR = \sigma E^2/\rho$, in W/kg)
Type: Bruker Biospin (4.7 T) Sequence: Flash (TR/TE=8.9/3.8 ms and Flip angle=90°) Coil type: Birdcage coil for emission and reception ($\delta = 60$ mm)	(1)	1	1120	45.18	1.82
	(2)	1	1120	125.02	13.96
	(3)	0.56	1200	151.87	10.76
Type: GEHC discovery MR750 (3 T) Sequence: Gradient echo (TR/TE=400/8.9 ms and Flip angle=80°) Coils: Body coil for emission and wrist coil for reception	(3)	0.56	1200	92.46	3.98
	(4)	1	1060	44.56	1.87

Table 1 The characteristics of the samples used in the experiments, the measured amplitude of the radial component of the electrical field and the local SAR calculated from electrical conductivity, mass density and the measured electric field values inside (1) a liquid phantom filled with a solution of 1.25 g NiSO₄ × 6H₂O + 5 g NaCl per liter of distilled water to mimic the patient, (2) a resonant circuit was put at 2 cm from the liquid-filled phantom, (3) an orange and (4) a veal muscle.

Discussion/Conclusion: This study exhibits the SAR-values for different samples by measuring directly the E-field using an optical-based probe. The E-field values depend strongly on the dielectric properties of the sample to be imaged and our measurements have shown the sensitivity of the optical probe to this variation. Finally, we have demonstrated that this probe could be used for different B₀-field strengths and different coil geometries with very low disturbance to the EM field.

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