Temperature- and frequency-dependent dielectric properties of biological tissues for intense heating during MRI

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Introduction: Due to the strong dependence of tissue electrical properties on temperature, it is important to consider the potential effects of intense heating on the electromagnetic fields during MRI, as in MR-guided Focused UltraSound (MRgFUS). Changes in tissue electrical properties during an exam may affect, for example, both efficacy of pulses designed with knowledge of B1 field distributions and the SAR pattern.[1] During MRgFUS treatment, targeted tissues can be heated to a temperature of 60 °C and thus generate a temperature gradient centered at the ultrasound focus and extending into the surrounding tissues. However, temperature- and frequency-dependent electric properties of tissues within the temperature and frequency ranges typically used in the MRgFUS treatment have been seldom reported. Here the temperature- and frequency-dependent electric properties of porcine uterus, liver, kidney, urinary bladder, skeletal muscle, and fat were measured *ex vivo* over a temperature range from 36 °C to 60 °C and at frequencies of 43, 64, 128, 170, 298, 400, and 468 MHz. The open-ended coaxial probe method was used to measure the reflection coefficient; the conductivity and dielectric constants of the tissues were calculated accordingly[2]. The obtained data can be used to calculate the electromagnetic field and SAR distribution in tissues in and around a region of heating in the MR environment.

Materials and Methods: The open-ended coaxial probe method was used to determine the electrical properties of porcine tissues at frequencies of 43, 64, 128, 170, 298, 400, and 468 MHz[3]. All measurements were completed within 30 minutes after excision of tissue and within 60 minutes from sacrifice. The reflection coefficient Γ was measured and used to calculate the electric properties according to $\Gamma = (Z_L - Z_0)/(Z_L + Z_0)$, $Z_L = (j\omega(C_f + C_0\varepsilon^*))^{-1}$, and $\varepsilon^* = \varepsilon' - jK(\omega)/\varepsilon_0\omega$, where Z_L is the load impedance, Z_0 is the characteristic impedance of the coaxial line, ε^* is complex relative permittivity, ε' is the dielectric constant, $K(\omega)$ is the conductivity, C_f is the equivalent capacitor corresponding to the fringing field in Teflon, C_0 is the capacitance accounting for the fringing field in air. Using the calibration scheme proposed by Bao et al., we can determine ε' and $K(\omega)$ without requiring specific knowledge of C_f and C_0.

Results: The temperature-dependent dielectric constant and conductivity in terms of mean values and corresponding standard uncertainties[4], *U*, for which a coverage factor *K*=2 was applied to obtain a confidence interval (CI) of 95%, of different porcine tissues at various discrete frequencies subjected to MRI are determined. For example, the temperature-dependent dielectric constant and electric conductivity of porcine tissues at 128 MHz with mean values and uncertainty margins are shown in Fig 1. The maxima of uncertainties of the dielectric constant and conductivity of the measured porcine tissues are determined. The standard uncertainties of temperature measurements are less than 4.81%, while the standard uncertainties of conductivity and dielectric constant are less than 10.62% and 11.28%, respectively. In this measurement, the accuracy of the dielectric probe is ± 5%, thus the combined standard uncertainties of conductivity and dielectric constant are less than 16% and 17% respectively.

Discussion and conclusions: We have measured electrical properties of several tissues as a function of temperature for several tissues at frequencies pertinent to MRI. Measurements were made quickly after excision to avoid confounding results with post-mortem changes. The results of this study are in agreement with previously reported values, where available. The obtained results showed that the temperature-dependent dielectric constants of the tissues except fat at 42.6 and 64 MHz were higher than those at higher frequencies, maybe due to the low amounts of water and protein in fat[5]. As temperature increases, dielectric properties change dramatically. This result occurs because the dielectric properties of tissues depend on the water content of tissues, state of water, ionic conductivity, dielectric relaxation of protein, and Maxwell-Wagner relaxation. In future work, the data obtained here can be used to calculate RF electromagnetic field and SAR distribution in tissues subjected to heating in the MR environment.

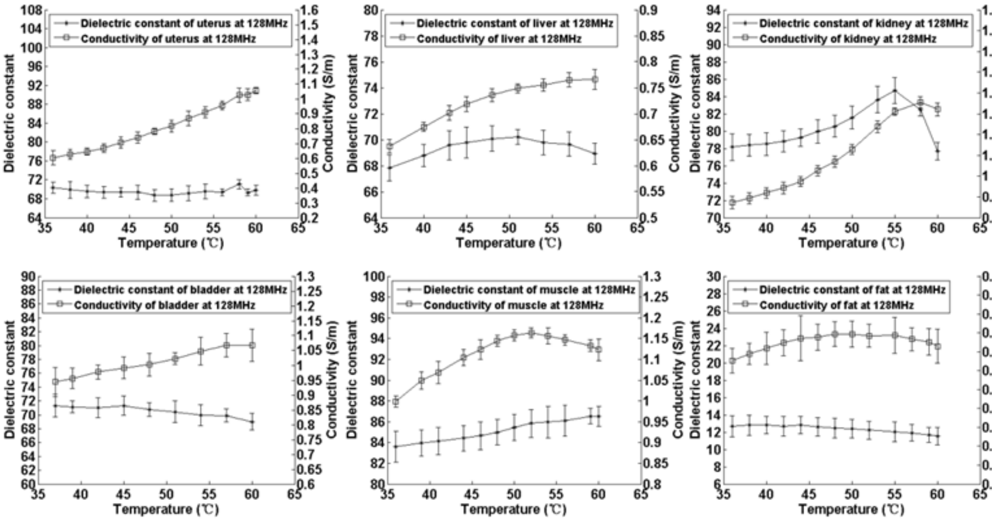

Fig 1. Temperature-dependent dielectric properties of porcine tissues at 128 MHz.

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