A modulated laser–impedance technique for accurate determination of tissue degradation parameters

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The accurate prediction of thermal damage during minimally invasive laser, microwave, and radiofrequency treatments requires precise knowledge of tissue degradation paremeters under extreme thermal conditions. This study presents a novel methodology combining modulated optical heating with real-time electrical impedancemetry to separate reversible (temperature-dependent ionic conductivity) from irreversible (cell lysis, protein coagulation) processes in biological tissue. Liver samples were uniformly heated within an integrating sphere using 970 nm laser radiation, modulated at 0.1 Hz. Simultaneously, the electrical admittance modulus at 10 kHz (sensitive to membrane disruption in the β-dispersion region [1]) and temperature (via highly sensitive fiber Bragg gratings) were recorded. We extracted the temperature coefficient of admittance via Hilbert transform, revealing its dependence on temperature. The irreversible component was then isolated and fitted by the Arrhenius damage model [2], yielding degradation parameters: a critical temperature $T_{cr} = 101 \pm 2\,^{\circ}C$ and frequency factor $\ln(A) = 48.5 \pm 3.8 \ln(s^{-1})$. These results demonstrate better accuracy compared to non-modulated methods, which overestimate reversible effects. The developed technique provides a robust framework for improving treatment planning.

[1] Raicu V and Feldman Y 2015 *Dielectric relaxation in biological systems* (Oxford university press)

[2] Welch A J and Van Gemert M J 2011 *Optical-Thermal Response of Laser-Irradiated Tissue* (Springer Netherlands)