THERAPEUTIC APPLICATIONS OF MIDDLE INTENSITY FOCUSED ULTRASOUND. THERMAL EFFECTS.

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Introduction

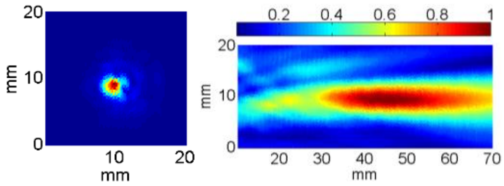
Therapeutic ultrasounds (US) of intensities of $0.125 - 3\ W/cm^2$ at frequencies of $1 - 3\ MHz$ have been used in the past 50 years to stimulate the physiological process in tissue healing. The interaction mechanisms of the US with cells and tissues are divided into thermal and non-thermal. The non-thermal effects are induced by acoustic cavitation, micro streaming or due to radiation force. Thermal effects results from the absorption of energy by the tissue, which increases with the protein content. Accurate temperature distribution measurements to prevent damage and to correlate US dose and therapeutic effect are crucial. In this work two non-invasive methods to measure the heating produced with a new designed focused US transducer are presented. Middle Intensity Focused Ultrasound (MIFU) heating rate is measured in a tissue-thermal mockup using the time shift pulse-echo signals method (PES) and, also, for the first time, with an Optoacoustic (OA) method. Results are corroborated with thermocouple registers and simulation models using Finite Element Method (FEM).

Transducer array

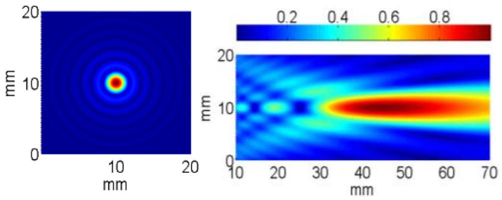
2 MHz array made of eight equiareal coaxial PZT-4 rings

Each element is connected to an individual pulser, so that piston like or focused beam at an arbitrary point along axial direction can be emitted. Time delays laws are calculated to produce constructive interference at the focus.

Focused beam emitted



Experimental focused acoustic beam at a distance of 60 mm measured with a needle hydrophone (DAPCO 54389). Transversal (2 MHz) and axial view (640 kHz).



Acoustic beam of a 60 mm radius concave transducer simulated with COMSOL Multiphysics ®. Transversal (2 MHz) and axial view (640 kHz).

Heating rate

Assuming that all energy removed during the propagation of US in a tissue is due to absorption, the rate of heat deposition is given by:

$$Q\ (x) = \alpha\ I(x)$$

Where α is the attenuation coefficient and $I(x)$ is the intensity of the acoustic wave at a distance x. Using heat diffusion equations, it is possible to calculate the temperature rise that would expect a tissue by:

$$\rho_t C_t \frac{dT}{dt} = Q + Q_{met} + \nabla(k\nabla T) - \rho_b C_b w_b (T - T_b)$$

Where ρ denotes density, C specific heat, w perfusion rate, k thermal conductivity and de sub-indices t are for tissue and b for blood parameters. It has been considered that there is also a metabolic heat source (Q_{met}).

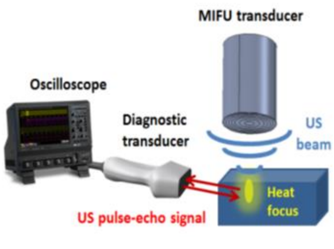
Non-invasive measurements of the heat produced with US

Pulse-echo shift method (PES)

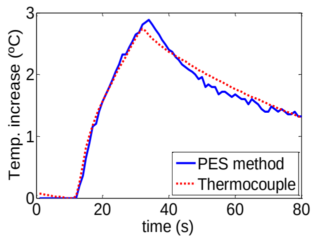
The temperature is calculated from the shift of a backscattered signal obtained with a diagnostic device due to the change of sound velocity, c, with temperature, given in water by the simplified Lubbers and Graaf equation:

$$\Delta c = \int_{T_0}^{T_0+\Delta T} 4.624 - 0.0766T\ dT$$

Temperature rise due to MIFU on an agar based mockup is measured. Simultaneously readings with a thermocouple certified the method.



Experimental set up.



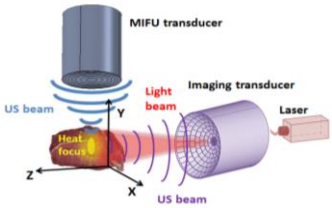
Temperature increase in the agar based mockup.

Four-dimensional Optoacoustic (OA) Tomography

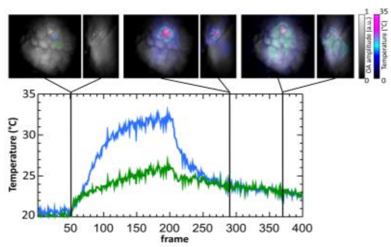
Short pulsed (< 10ns) tunable laser generates a pressure increase, p_0, in the medium due to thermoelastic conversion. Subsequent waves are registered with a 256 elements piezoelectric array. The amplitude of the OA signal is expected to depend with the increase of medium temperature T_0 by:

$$\frac{\Delta p_0}{p_0} = \frac{0.0053\ \Delta T}{0.0043 + 0.0053\ T_0}$$

Heating is produced with MIFU transducer in an ex-vivo bovine sample. Time sequences of 3D images of the heating zone can be obtained.



Experimental set up.



Temperature increase in the ex-vivo bovine tissue.

Conclusion

Two non-invasive methods have been used to calculate the heating rate in a medium due to MIFU. OA imaging has been used for the first time to show the complete 3D distribution of T and its evolution. However, this technique is limited by the low depth penetration of laser in tissues.