Mechanical and Thermal Effects of Focused Ultrasound on a Biological Tissue using COMSOL Multiphysics®, Three Different Approaches

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INTRODUCTION: Presbyopia, a vision disorder, is characterized by the stiffening of the crystalline lens of the eye. The use of focused ultrasound into the lens region, is the aim of future ophthalmological anti-aging treatment. Three approaches have been implemented to simulate the wave propagation, and quantify the thermal and mechanical effects of such procedure. Figure 1 shows the 2D axisymmetric full parametric eye and acoustic transducer constructed in COMSOL Multiphysics® [1,2]. In the following simulations, the acoustic transducer is driven at the frequency of 5 MHz that is turned on for one second and then turned off to let the tissues cool down.

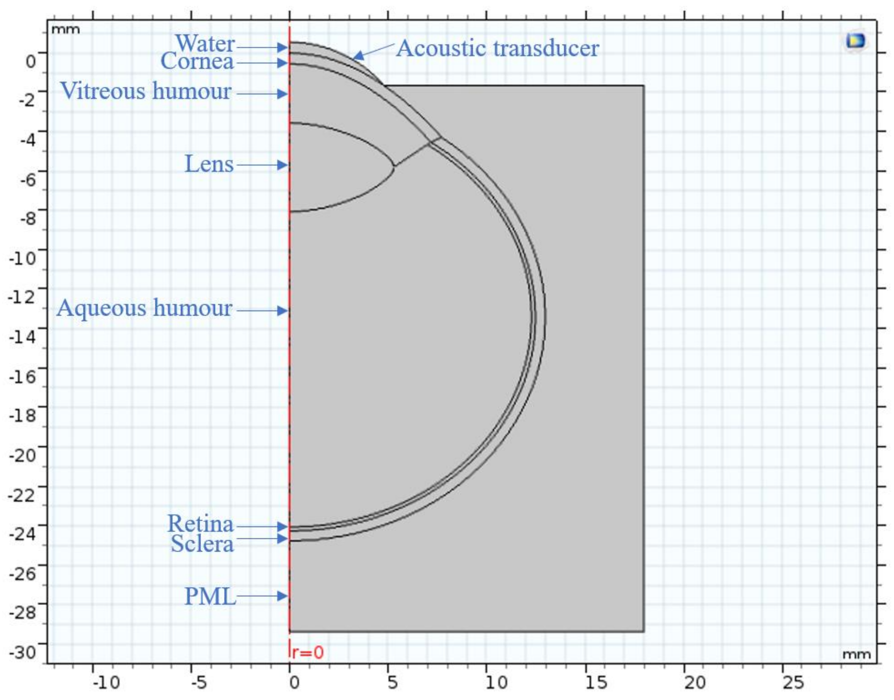

Figure 1. Model geometry. The different domains of the human eye are shown in addition to the PML (Perfectly Matched Layer).

COMPUTATIONAL METHODS:

- The first approach gives us information about the pattern of the focalized pressure field using a fluid equivalent model defining all the domains (See Figure 2).

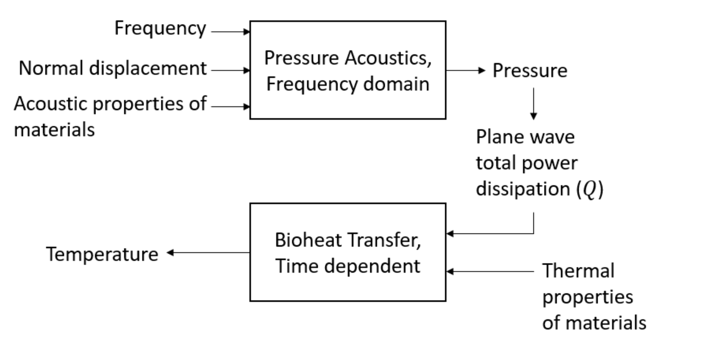

Figure 2. Schematic representing the first approach.

- The second approach's main goal is to quantify the induced mechanical effects mainly in the lens region. Therefore, some domains are defined using hyperelastic material model (See Figure 3).

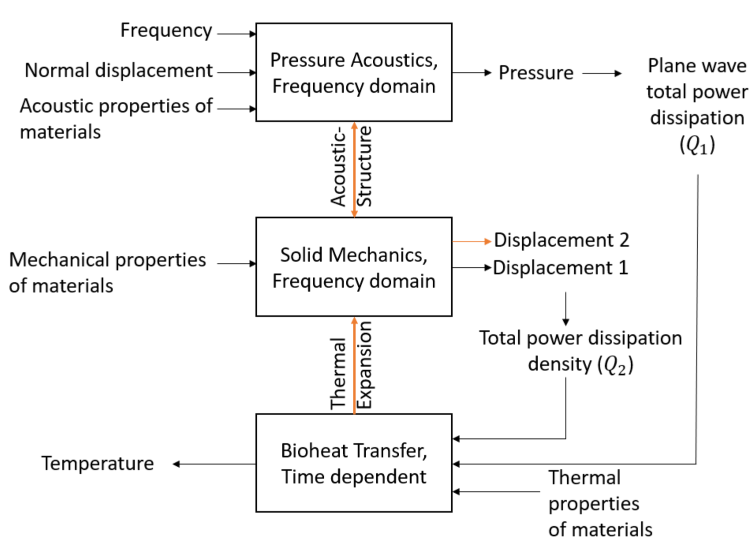

Figure 3. Schematic representing the second approach.

- The third approach adds to the first one, the solid mechanics interface to perform a thermal expansion analysis on the solid lens (See Figure 4).

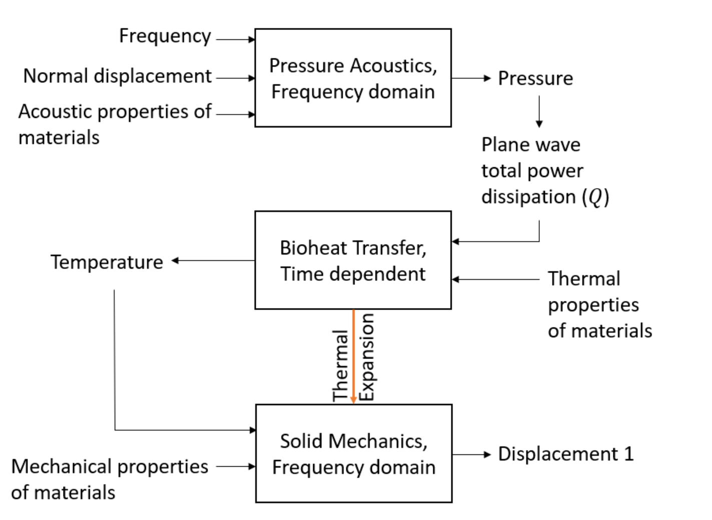

Figure 4. Schematic representing the third approach.

The purpose of this fluid equivalent model is to mimic a behavior of damping by solving the Helmholtz equation (1) [3]:

$$\nabla.\left(\frac{-1}{\rho_c}(\nabla p)\right)-\left(\frac{\omega}{c_c}\right)^2\frac{p}{\rho_c}=0 \qquad (1)$$

This heat generated (Q) due to focused ultrasound is given by equation (2):

$$Q=2\alpha I=2\alpha\left|Re(\frac{1}{2}pv)\right| \qquad (2)$$

Then, in order to describe the heat transfer by conduction as function of time, equation (3) is solved:

$$\rho C_p\frac{\partial T}{\partial t}=\nabla.(k\nabla T)+Q \qquad (3)$$

The thermal strain caused by the variation in temperature is given by equation (4):

$$\varepsilon_{th}=\alpha\left(T-T_{ref}\right) \qquad (4)$$

RESULTS: The simulation results of the third approach are presented in the following figures. As we can see, the beam converges into a focal zone, which generates heat and negligible thermal expansion in the lens region.

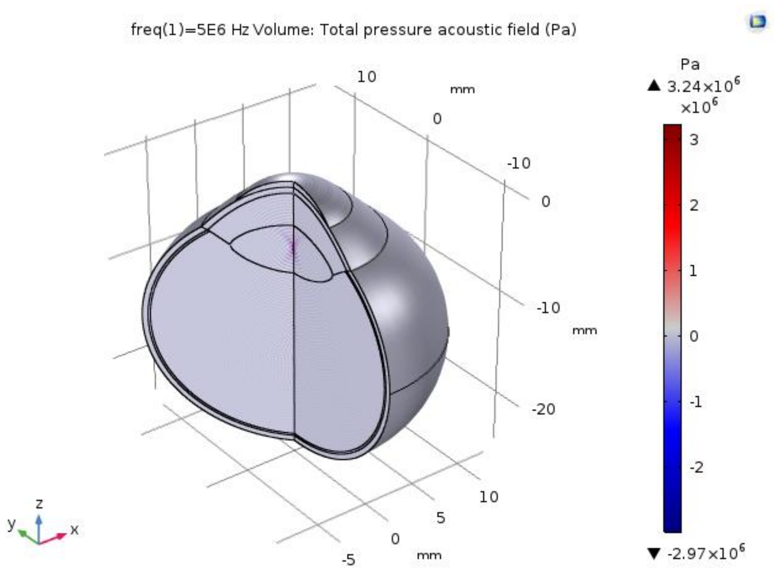

Figure 5. Acoustic pressure field in the eye without the PML.

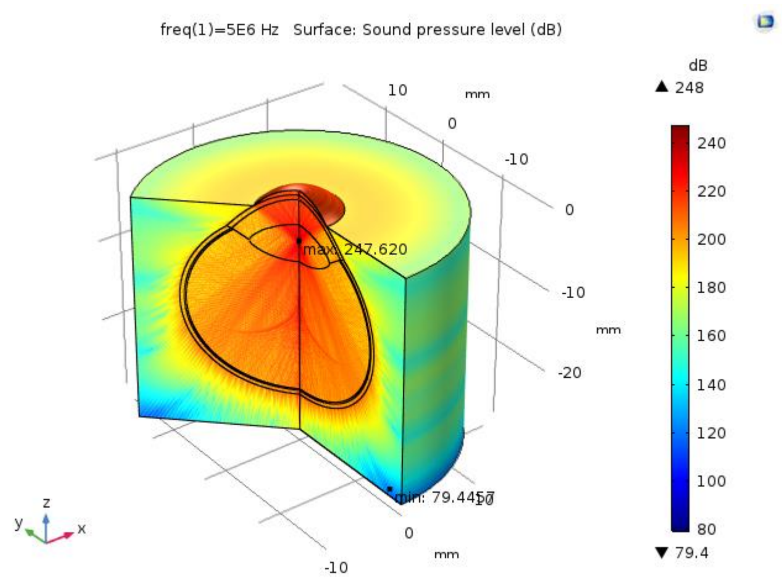

Figure 6. Sound pressure level (SPL) in the eye and PML.

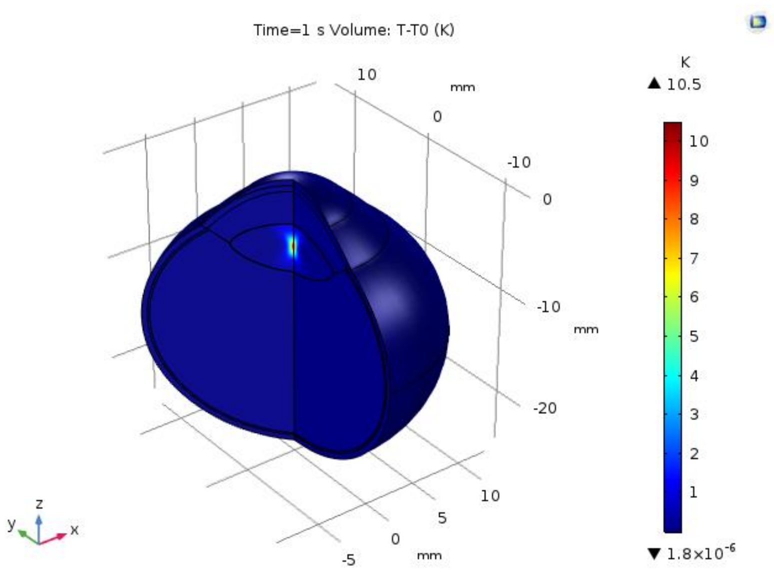

Figure 7. Temperature field in the eye at t=1 s.

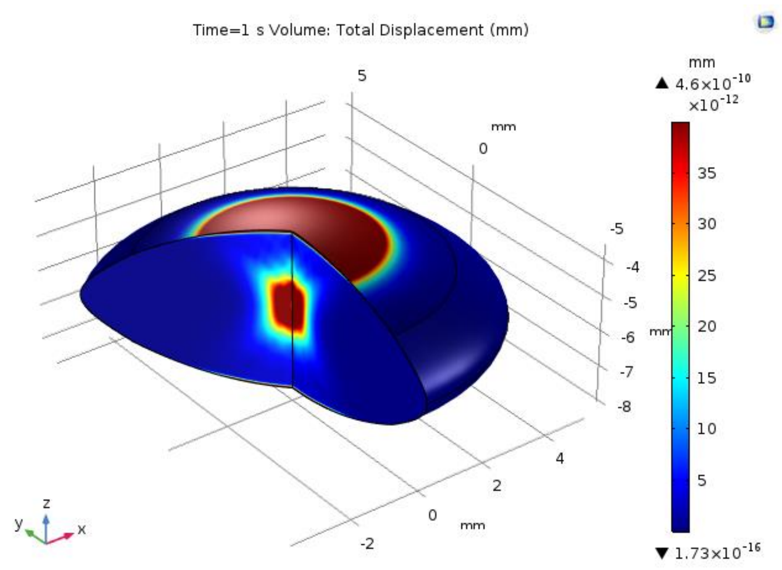

Figure 8. Displacement field in the lens region at t=1 s.

CONCLUSIONS: The third approach has been the most efficient one, in terms of computation time and simulation results. Focused ultrasound has great potential and could be employed in the future, to treat this particular vision disorder.

REFERENCES:

[1] Douglas L. Miller et al., *Overview of therapeutic ultrasound applications and safety considerations*, Journal of Ultrasound in Medicine, 31(4): 623-634, 2012
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[3] Acoustics module users guide, COMSOL Multiphysics® 5.3a, 2017