A Finite Element Model of Shear Wave Propagation Induced by an Acoustic Radiation Force Impulse

R. De Luca[1,2], J. Fromageau[1], H. W. Chan[1], F. Marinozzi[2], J. Bamber[1]
1Institute of Cancer Research and Royal Marsden Hospital, Sutton, England, UK.
2Sapienza University of Rome, Dept. of Mechanical and Aerospace Engineering, Rome, ITALY.

Introduction: Shear wave elastography is an innovative technique that employs one conventional focused ultrasound beam to induce shear waves and another to detect them. The final quantitative elasticity image is presented as a colour map overlaying the B-mode image [1].(Figure 1)

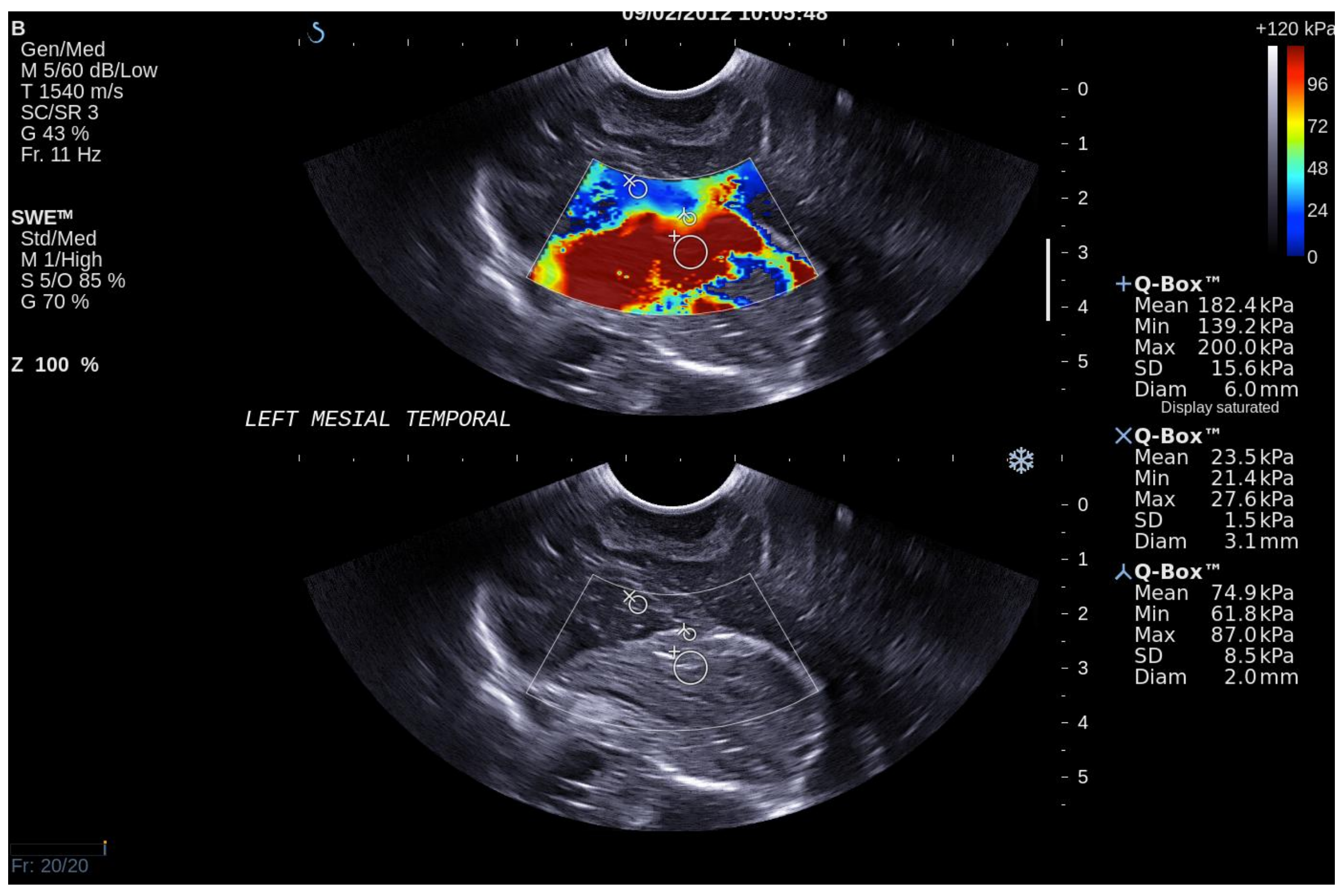


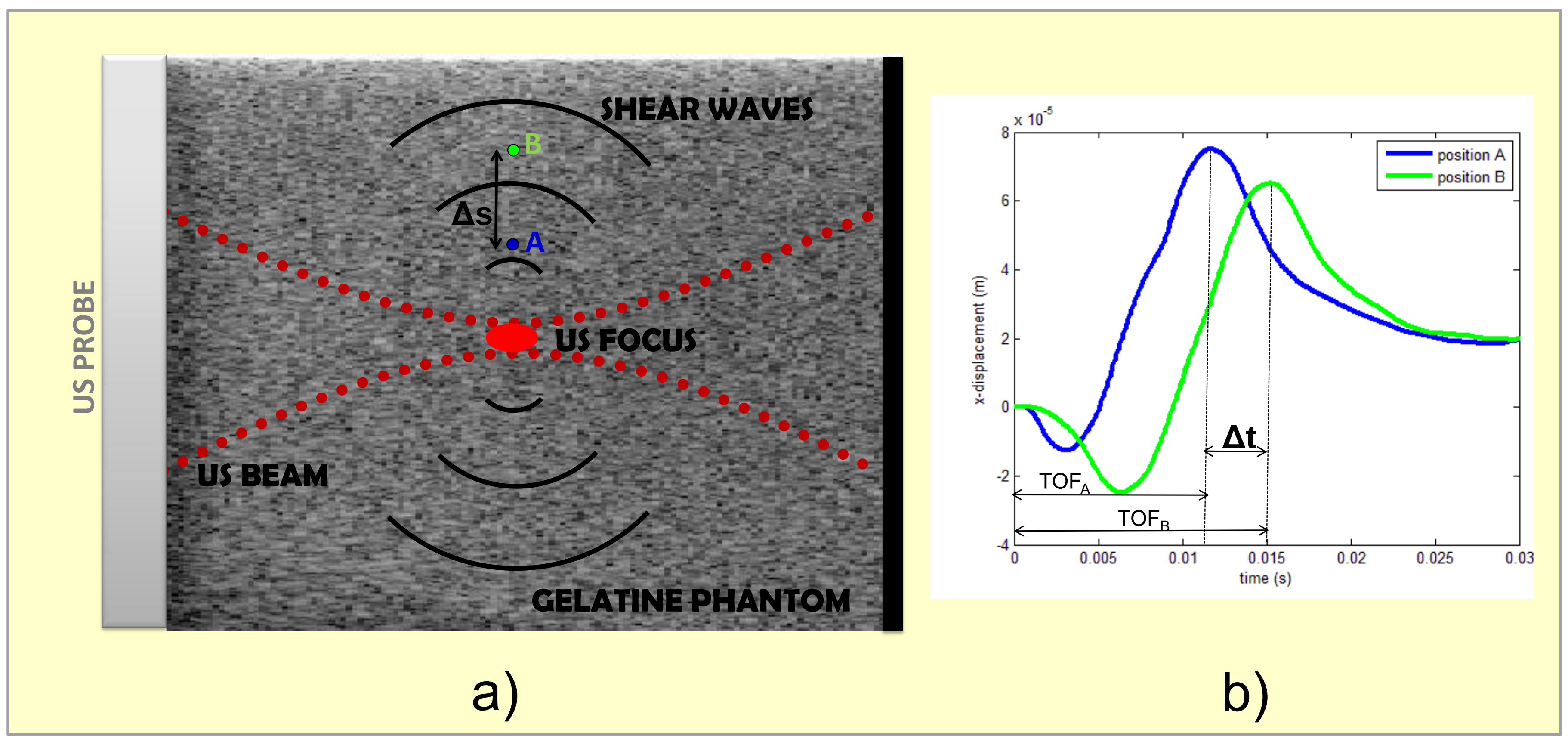
Figure 1. Example of the application of shear wave elastography on a patient. The top image is a shear wave elastogram superimposed on a B-mode sonogram and the bottom one is the B-mode sonogram on its own. The elastogram demonstrates clearly the stiff lesion (intracranial epidermoid cyst) with good margins (red) while the B-mode shows the lesion as hyperechoic.

Computational Methods: A two-dimensional finite element model (FEM) was developed in Comsol Multiphysics® to simulate the propagation of shear waves induced by an acoustic radiation force impulse (ARFI) in various media. (Figure 2a)

When the ARFI is applied, transient shear waves are generated. The relationship between shear wave speed and Young's modulus for a linear isotropic medium is

$$c_t = \sqrt{\frac{E}{2(1+\nu)\rho}},$$

where c_t is shear wave speed, E is Young's modulus, ν is Poisson's ratio and ρ is density. [2]



a) b)

Figure 2. a) Diagram of the 2D FE model, composed of realistic boundary conditions. The medium was assumed to be isotropic, homogeneous, linear elastic and quasi-incompressible. b) Time-varying transversal displacements recorded in the region of interest. The time-to peak method is used to calculate the shear wave speed: the average velocity between A and B can be obtained finding the ratio of Δs and Δt.

Results: In general the results confirmed a number of expectations [3]:

- ✓ displacement amplitude decreases with increasing shear modulus;
- ✓ the maximum amplitude of shear wave displacement is proportional to the duration of the push (Figure 4);
- ✓ the wave amplitude decreases with the increasing radial distance from the pushing focus (Figure 2b);
- ✓ the estimated shear wave speed was found to be in good agreement with theory (Figure 4).

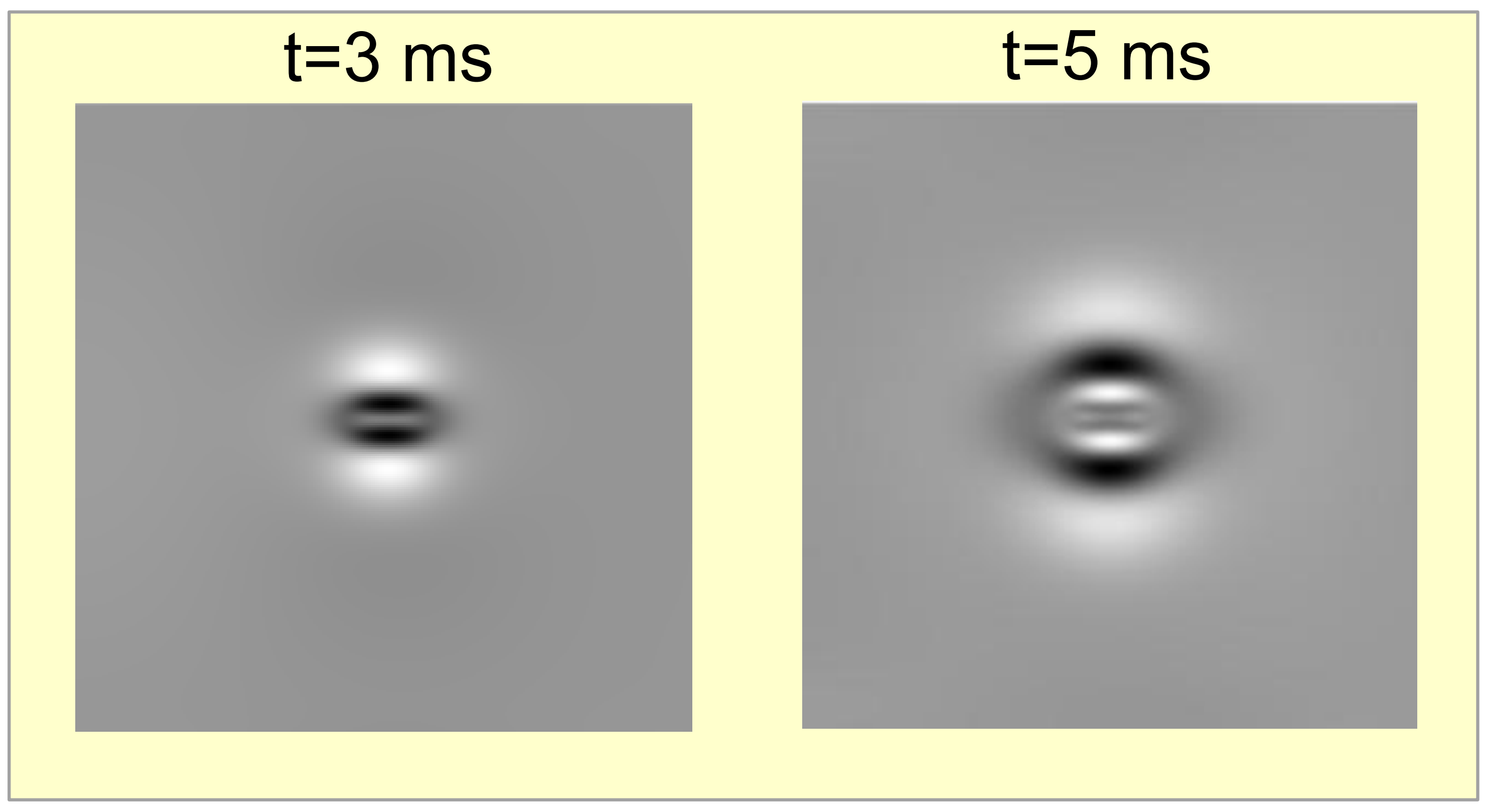


Figure 3 Example of shear wave propagation (E=100kPa, ν=0.49) at different times after the start of the ARFI. The acoustic source is located on the left. The brightness of the greyscale indicates the normalized instantaneous shear wave displacement.

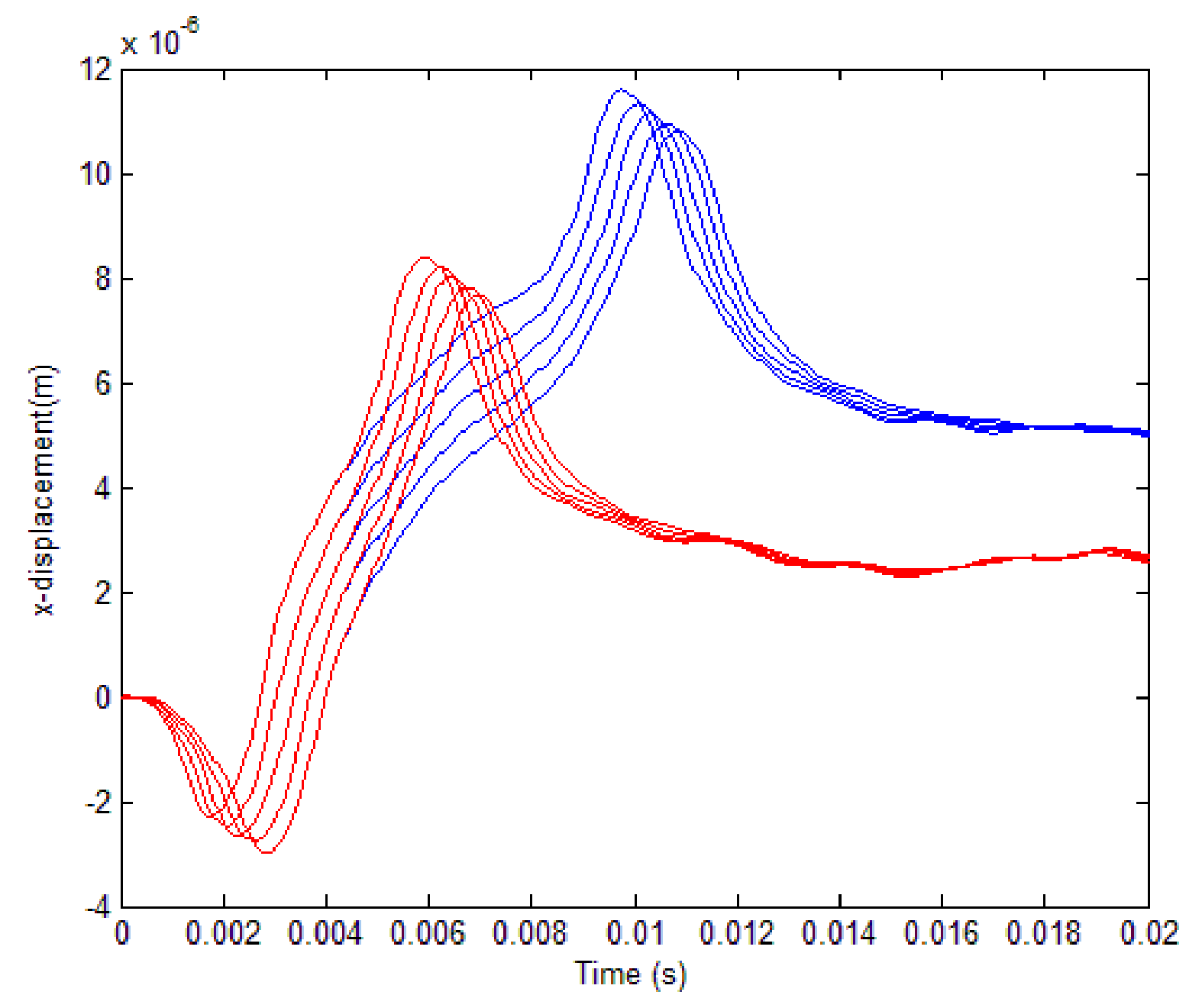


Figure 4 Example of FE time-varying transversal displacements recorded in a FE model phantom with E=10 kPa (c_t=1.83 m/s). The red and blue lines correspond to a push length of 4 ms and 8 ms respectively. For each group of curves, the displacement is recorded at different distance from the acoustic source. The estimated shear speed is 1.849±0.111 m/s.

Conclusions: The results show that Comsol Multiphysics provided a reliable model of shear wave generation and propagation in biological soft tissues.

References:

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ICR The Institute of Cancer Research

SAPIENZA UNIVERSITÀ DI ROMA

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