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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 277-278
8-10 November, 2011

Quantitative Analysis of Soft-Tissue Displacement Generated by Acoustic Radiation Force
音響放射力による生体組織の変位量に関する定量解析

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1. Introduction

Acoustic radiation force (ARF) elastography is potentially useful for quantitatively imaging the elasticity of human tissue. A focused beam is used to produce an ARF, which induces a shear wave, and Young's modulus is estimated from the shear velocity of the wave's propagation [1].

Our group investigated the attenuation characteristics of the shear wave propagation and the limitation of the measurement distance [2]. In this paper, we describe our quantitative investigation of the optimal focal distance to obtain sufficient displacement with a conventional ultrasound scanner by finite element method (FEM) simulation.

2. Tissue Displacement by Acoustic Radiation Force

The radiation body force F_x [N/m^3] under a linear approximation takes the following form [3]

$$F_x = \frac{2\alpha I}{\rho c}\frac{\varphi^2(\Omega t)}{f^2(x)}\exp\left(-2\alpha x - \frac{2r^2}{a^2 f^2(x)}\right), \qquad (1)$$

where $f(x)$ is the Gaussian beam used and x_d is the Rayleigh distance:

$$f(x) = \sqrt{\left(1-\frac{x}{d}\right)^2 + \frac{x^2}{x_s^2}}, \quad x_d = \frac{\omega a^2}{2c}. \qquad (2)$$

The I is spatial peak-pulse average intensity, c is the longitudinal sound velocity, ρ is the density, α is the absorption coefficient, d is the curvature radius of a transducer, r is the radial position as shown in **Fig.1**, ω is the driving frequency, Ω is the modulation frequency, and a is the aperture radius of the transducer.

The displacement s_x at the focal point is as follows [1]

$$s_x = \frac{\sqrt{\pi}}{2}\frac{\alpha a^2 I_0}{c\sqrt{\rho\mu}}e^{-2\alpha d}\left(\frac{t_0}{aD}\right) \times \frac{\left(\frac{\sqrt{\mu/\rho}}{aD}\right)t}{1+\frac{4\nu t}{(aD)^2}+\left(\frac{\sqrt{\mu/\rho}}{aD}\right)^2 t^2}, \qquad (3)$$

where ν is the kinematic shear viscosity, D is d/x_d, and t_0 is the time duration of oscillation of the focus beam.

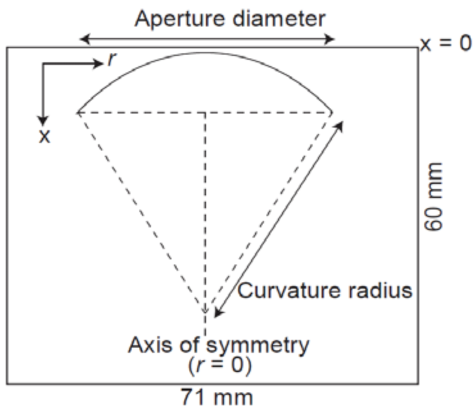

Fig. 1 FEM simulation model.

3. FEM Simulation Model

The time-averaged radiation force and generated shear wave were simulated with the PZFlex FEM package [4][5]. The geometry of the simulation is shown in **Fig. 1**. The wave propagation was simulated using cylindrical coordinates and axis of symmetry was r = 0. The parameters were ρ = 1000 kg/m^3, c = 1540 m/s. The time step and grid space were 4.5 μs and 50 μm, respectively.

4. Simulation Results and discussion

Figure 2 shows the calculated acoustic radiation stress field for a = 19 mm, d = 35 mm, t_0 = 1 ms, I= 1 kW/cm^2, and a driving frequency of 2 MHz. The absolute maximum stress was about 62 N/m^2, and the corresponding ARF was estimated to be 8.6 kN/m^3, where the axial beam width at the focal area was 7.2 mm. This value agrees roughly with the theoretical value of 3.5 kN/m^3 given by eq. (2) as shown in **Fig. 3**. Displacements of simulation results are shown in **Fig. 4**. The simulated values were about several times smaller than the experimental results [2]. We assume this is because the simulation model did not include viscous and scattering effects.

Realizing an accurate shear wave measurement requires a large displacement at the focal area.

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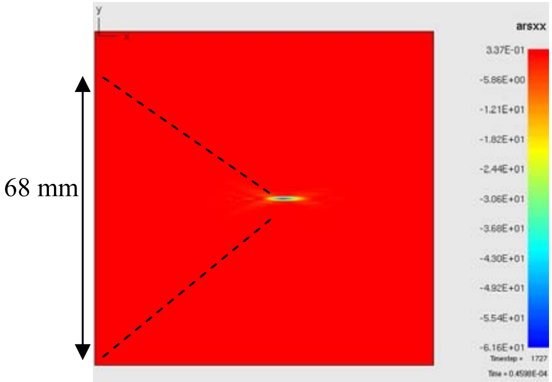

Fig. 2 Calculated ARF field.

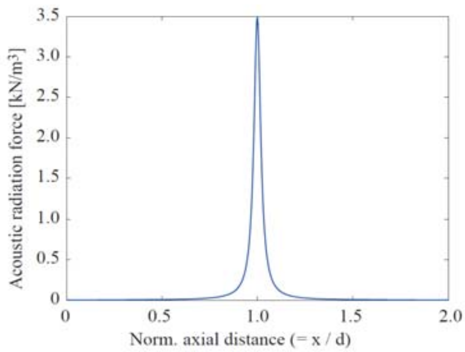

Fig. 3 Theoretical value of ARF.

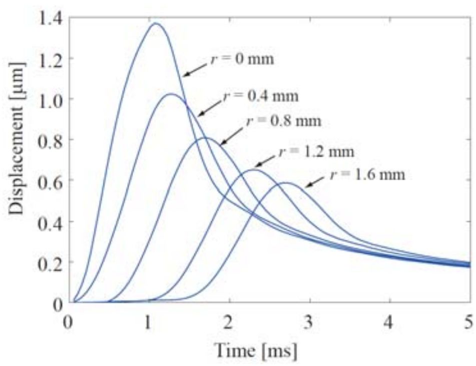

Fig. 4 Simulated displacements.

However, for a typical ultrasound scanner, the acoustic intensity, the driving frequency, the aperture diameter, and the number of burst cycles of the focus beam are usually limited by thermal breakdown and the frequency range of the ultrasonic probe used. Therefore, it is uncertain that which condition of (a) a large intensity and a small beam width or (b) a small intensity and a large beam width, is sufficient to obtain a large displacement. To investigate the condition, we calculated the displacement for a variety of beam shapes. The number of burst cycles was set to 400, the aperture diameter was set to 23 mm.

Figure 5 shows the displacement vs. driving frequency for focal distances: 10, 15, 25, and 35 mm. The figure shows that the displacement decreased as the focal distance and the driving frequency increased, and the condition (a) is preferable, because the intensity increases and the beam width decreases as the focal distance decreases for the same frequency and the aperture diameter.

Supposing the diagnosis of breast tissue with the measurement distance of 4 mm and considering the attenuation characteristics [2], approximately a displacement at the focal point of at least 1 μm is required, where the minimum measurable displacement of a typical scanner is 0.1 μm. **Figure 5** shows that focal distances of less than 15 mm for the frequencies of less than 4 MHz, and less than 10 mm for over 6 MHz, are preferable for the shear wave measurement.

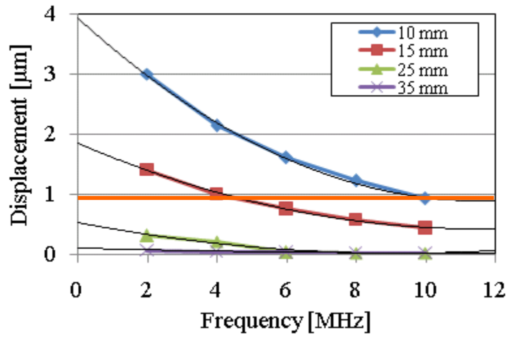

Fig. 5 Displacement vs. driving frequency for four curvature radii.

5. Conclusion and Future Work

The FEM simulation results show that the distances of less than 15 and 10 mm are preferable for the frequencies of less than 4 and 8 MHz to diagnosis of breast tissue, respectively. The results also show that for higher frequencies, the measurement depth of ARF elastography is limited to the area closer to the body surface compared with the area of the B-mode image obtained with the same frequency.

Future work includes the viscous and scattering effects will be included in the simulation model, and the corresponding displacements will be compared with the theoretical value.

6. References

1. A.P. Sarvazyan, O.V. Rudenko, S.D. Swanson, J.B. Fowlkes and S. Y. Emelianov: Ultrasound in Med. & Biol., **24** (1998) p. 1419.
2. M. Tabaru, T. Azuma and K. Hashiba: Jpn. J. Appl. Phys., **49** (2010) 07HF09.
3. O.V. Rudenko, A. P. Sarvazyan and S. Y. Emelianov: J. Acoust. Soc. Am., **99** (1996) p.2791.
4. G.L. Wojcik, D.K. Vaughan, N. Abboud and J. Mould. Jr.: IEEE Ultrason. Symp. Proc. (1993) p.1107.
5. C.P. Lee and T.G. Wang: J. Acoust. Soc. Am. **94** (1993) p.1099.