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Simulation Study of Ultrasonic Wave Convergence in the artificial Human Femoral Neck model by X-ray CT

ヒト大腿骨のCTデータを用いた大腿骨頚部の超音波集束シミュレーション

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1. Introduction

In recent years, as the elderly population increases, fractures of proximal femora tend to increase. This fracture causes bedridden and has a major impact on mortality. Therefore, the ensure of strength of femoral neck leads to improve QOL. In this study, focusing on the preventive medicine, a prevention method of the fracture was investigated.

Clinical studies of Low Intensity Pulsed Ultrasound (LIPU) have reported the reduction of the healing time of bone fracture. From these studies, it was suggested that local ultrasound simulation may promote activation of bone metabolism. In this study, in order to focus the ultrasound wave on the femur, the installation positions of the ultrasound transducers were examined. For this purpose, a two-dimensional simulation of Finite Difference Time Domain (FDTD) simulation was performed to analyze of ultrasound wave propagation inside the thighs[1)].

2. Ultrasonic wave propagation simulation

2.1. Simulation conditions

At first, a proximal model of a human femur was created from the High Resolution-peripheral Quantitative CT (HR-pQCT) data. Figure 1 shows the cross section view of the model. The spacial resolution of the model was 61 µm, and the time resolution was set to 10 ns from the Counrant's stability condition[2)]. For eliminating the reflected waves from the end of the model, Higdon's second order was used as absorbing boundary conditions[3)]. Figure 2 shows the simulation model. The proximal femur model was assumed to be surrounded by the columnar water simulating soft tissue.

Assuming the bone was isotropic, we estimated elastic constants in the model. c_{11} was estimeted following the studies of Yamato et al[4)]. c_{66} was estimated using Poisson's ratio of 0.33. c_{13} was estimeted following the studies of Nakatsuji et al[5)].

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2.2. Virtual Ultrasound radiation from the inside of femoral neck

We performed two simulations. At first, ultrasound was transmitted from the inside of femur and observed at the array transducers as shown in Fig. 2. This transmission point in the femur should be the focal point in the next simulation. Here, the longitudinal wave velocity in water was 1500 m/s and the density was 1000 g/cm^3. The density of femur was 2000 g/cm^3. The radiated wave from the inside of femur was one cycle of 1 MHz sinusoidal wave with a Hann window. Receiving transducers were set along the body surface considering the position of muscles and bones around the femur.

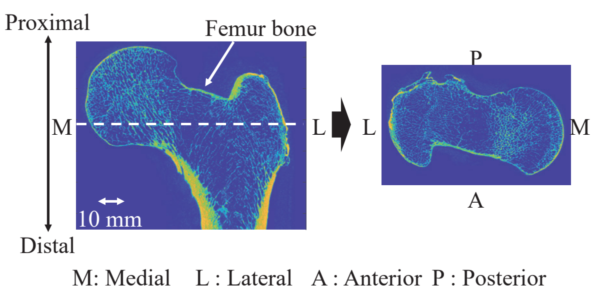

Fig. 1 The femur model obtained from data by HR-pQ CT.

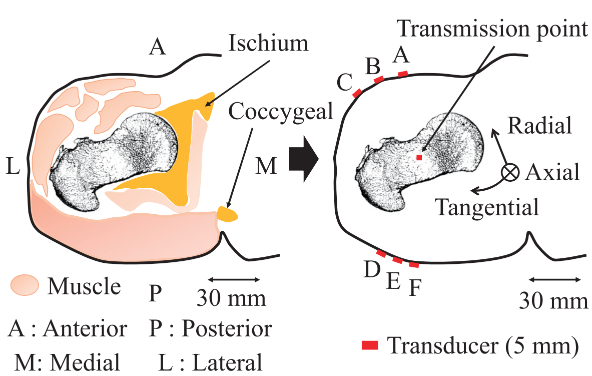

Fig. 2 Simulation conditions of the first step. Transmission of waves from the inside of femur.

2.3. Re-radiation from array transducer

As the next step, re-radiating waves were emitted from the outside transducers to focus at the transmission point in the femur. In order to create a practical and simple system for future instrumentation, re-radiated waves were created based on the arrival time of the observed first waves. Figure 3 shows re-radiated waveforms. Transmitted waveform was one cycle of 1 MHz sinusoidal wave with a Hann window. The simulation conditions for transmitting re-radiated waves were same. The stress values of the femur were obtained from the simulation.

3. Results and Discussions

Figure 4 (a) shows stress distribution inside the bone when maximum stress observed at the target. In order to examine the focusing at the femoral neck area, the femoral proximal bone was classified into three areas. Figures 4 (b), (c), and (d) show stress distributions in three areas. The horizontal axis is the stress normalized with the maximum stress. The vertical axis is normalized by the total number of data points because the number of data points is different in each area. From these histograms, it can be seen that the number of low stress data points in Area Ⅱ are smaller than those of other areas. In addition, higher stresses were found in the Area Ⅱ. The ultrasonic wave may be focused near the femoral neck when maximum stress observed at the target.

Figure 5 shows the averaged total stress observed in the areas until 66 μs. The vertical axis represents the total stress observed in the areas. From Fig. 5, it can be seen that high stress was observed in area Ⅱ compared to other areas. These results suggest that stress may be focused on the femoral neck using simple waves radiated from transducers. In the next step, it will be necessary to examine the location of the sensor set along the skin surface.

4. Summary

In this study, a two-dimentional elastic femur model was created from the in vivo HR-pQCT data. Then, the focusing of the ultrasonic waves was challenged using the 2D FDTD method. In this study, in order to focus the ultrasound wave on the femur, transducers were set in consideration of the actual body shape. As a result, the ultrasonic wave seemed to be focused on the femoral neck. Next step is 3D simulation and optimization of transducer conditions.

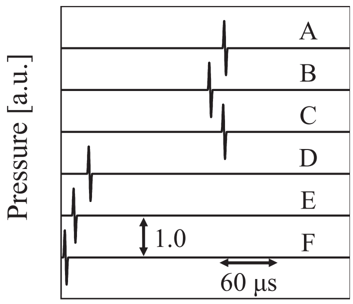

Fig. 3 Re-radiated waves from array transducers.

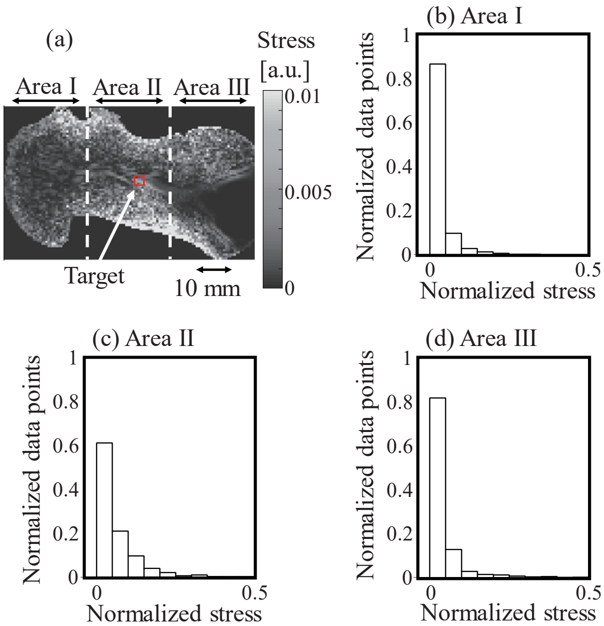

Fig. 4 (a) Stress distributions inside the bone when maximum stress was observed at the transmission point. (b) area Ⅰ, (c) area Ⅱ and (d) area Ⅲ.

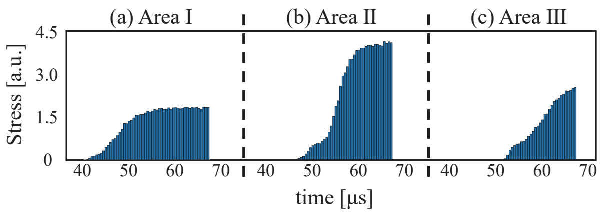

Fig. 5 (a) Total stress in the femur model observed during simulation time in area Ⅰ. (b) is in area Ⅱ and (c) is in area Ⅲ.

References

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