Study on the effective ultrasonic wave convergence in bone for fracture healing

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Background, Motivation and Objective

The healing time of bone fracture can be reduced by using Low Intensity Pulsed Ultrasound (LIPUS). In the LIPUS system, ultrasonic waves are radiated from a transducer on the fracture site without considering the complex wave propagation in human body. The effective ultrasound radiation to the fracture site covered with a cast is useful for actual application of ultrasound. In this study, a 3D simulation for optimum ultrasound radiation from transducer arrays was performed to achieve wave convergence to the fracture site.

Methods

A 3D elastic Finite-Difference Time-Domain (FDTD) method was used for wave propagation simulation. A 3D human bone model was made from High Resolution - peripheral Quantitative Computerized Tomography (HR-pQCT) data of a 66 years old female's radius. Spatial and time resolutions were 61 μm and 8.3 ns respectively. In this simulation, the bone model was set in the water mimicking the soft tissue. In the first simulation, one cycle of sinusoidal wave at 1 MHz with Hann window was radiated from a virtual fracture site. This site will be the convergent point in the second simulation. Receiver arrays (16 elements) were set around the bone model as shown in Fig.1 (a). In the second simulation, one cycle of sinusoidal wave was transmitted from each transducer in the arrays with different radiation time, which was decided by the arrival time of sound in the first simulation. (Figs.1 (b) and (c)) The stress distribution in this simulation was investigated at the cross section of the first emission point (fracture site). A simple cylindrical bone model was also investigated for comparison.

Results, Discussion and Conclusions

Figure 1 (d) shows the stress distribution at the cross section of the fracture site. We can find high stress near the fracture site. The shape of converged area was almost elliptical. The major axis was longer in the circumferential direction than that obtained using the cylindrical bone model. Figure 1 (e) shows the contribution of each radiated wave to the stress at the fracture site. The total of these stress values is the converged stress. The degree of contributions of all transducers were similar. This technique, using the simple transducer arrays outside of a cast and simple radiated waves, allows an effective ultrasound convergence to the fracture site.

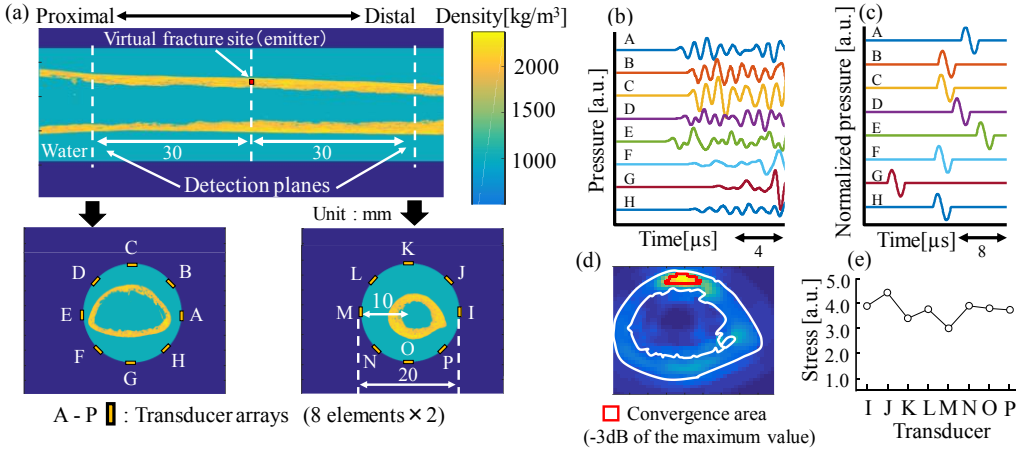

Fig.1 (a)Simulation condition in the human bone model. (b) Observed waveforms. (c) Radiated simple waveforms from arrays. (d) Stress distribution at the cross section of the first emission point in the human bone model. (e) Contribution of each radiated wave to the stress value at the fracture site.