Effect of Duty Cycle Variation on Acoustic Pressure Field Simulation in an Ultrasound Bioreactor

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Abstract

Daily application of a low intensity pulsed ultrasound (LIPUS) regimen has been shown to have positive effects on bone fracture healing. Although LIPUS treatment can induce cellular responses supporting bone repair, the underlying mechanisms are not well understood. Further in vitro experiments are needed to investigate the bioeffects of the US pulsed protocol under well-controlled conditions in ultrasound bioreactors. Complications like the presence of standing waves demonstrate the need for computational studies to investigate such effects and improve US bioreactor designs. In this study, the acoustic pressure in an US bioreactor was simulated by developing a finite element model in the COMSOL Multiphysics® software. The model was built by coupling Solid Mechanics, Electrostatics, and Pressure Acoustics interfaces. To evaluate effects of duty cycle variation on the generated pressure field, simulations were run with 10%, 20%, and 50% duty cycles for the US pulsed protocol (Figure 1). Complete wave reflection at the air interface resulted in wave interference and, thereby, standing wave formation. A summation of the acoustic pressure delivered to the dish surface for the 20% and 50% duty cycle protocols was 1.6 times and 3.7 times higher, respectively, than the 10% duty cycle protocol over the 1 ms pulse period. These differences were smaller than theoretically predicted and resulted from the delayed drop in pressure after the cessation of US. In a subset of simulations, an acoustic absorbent was added to the top surface of the culture medium to eliminate the air interface and explore its effect on the pressure field. In this modified bioreactor configuration, the pressure increase to the maximum value in the active period and the pressure drop after signal cessation occurred more quickly. Overall, the acoustic pressure pattern at the dish surface followed the applied US signal more closely. However, the acoustic pressure amplitude at the dish surface when the acoustic absorbent was present was 83% lower than the maximum value for the original configuration. The difference in the maximum average values between the original and modified configurations demonstrated that standing waves created by reflections at the air-dish interface substantially increased the magnitude of the generated pressure field.

Figures used in the abstract

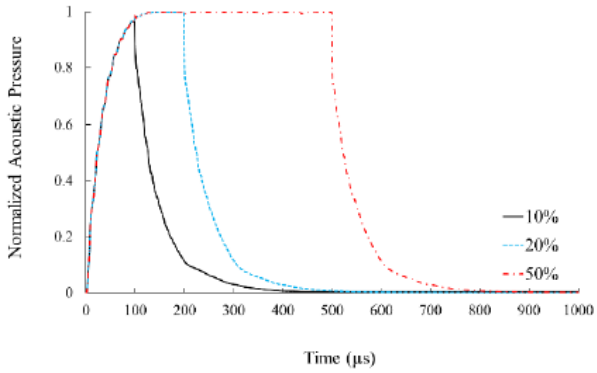

Figure 1: Using a time-dependent simulation, the acoustic pressure at the dish surface of an US bioreactor was analyzed over 1 ms in response to varying the duty cycle of the pulsed US signal from 10% to 20% to 50%.