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Original Article

Non-invasive photo acoustic approach for human bone diagnosis

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ABSTRACT

The existing modalities of bone diagnosis including X-ray and ultrasound may cite drawback in some cases related to health issues and penetration depth, while the ultrasound modality may lack image quality. Photo acoustic approach however, provides light energy to the acoustic wave, enabling it to activate and respond according to the propagating media (which is type of bones in this case). At the same time, a differential temperature change may result in the bio heat response, resulting from the heat absorbed across the multiple materials under study. In this work, we have demonstrated the features of using photo acoustic modality in order to non-invasively diagnose the type of human bones based on their electrical, thermal, and acoustic properties that differentiate the output response of each type. COMSOL software was utilized to combine both acoustic equations and bio heat equations, in order to study both the thermal and acoustic responses through which the differential diagnosis can be obtained. In this study, we solved both the acoustic equation and bio heat equations for four types of bones, bone (cancellous), bone (cortical), bone marrow (red), and bone marrow (yellow). 1 MHz acoustic source frequency was chosen and 10^5 W/m^2 power source was used in the simulation. The simulation tested the dynamic response of the wave over a distance of 5 cm from each side for the source. Near 2.4 cm was detected from simulation from each side of the source with a temperature change of within 0.5 K for various types of bones, citing a promising technique for a practical model to detect the type of bones via the differential temperature as well as the acoustic was response via the multiple materials associated with the human bones (skin and blood).

The simulation results suggest that the PA technique may be applied to non-invasive diagnosis for the different types of bones, including cancerous bones. A practical model for detecting both the temperature change via IR sensors, and acoustic wave signals may be detected via sensitive pressure transducer, which is reserved for future realization.

1. Introduction

There are two categories for the PA techniques when utilizing light sources; broadband sources such as that in lamps using wavelengths from ultraviolet to infrared spectrum, and narrow-band sources such as that of the laser sources. The first is generally inexpensive and compact in size, but have limited spectrum brightness, in addition to its requirement to use monochromators and filters. Furthermore, this has an issue with low source modulated frequencies, resulting in low optical efficiencies. Lasers on the other hand feature large spectrum brightness and is easy to modulate. Pulsed excitation light source will enable laser tunability. Applying higher modulation frequencies will enhance acoustic amplifications, resulting in improved signal to noise ratio (SNR). When the acoustic resonance frequency equal the modulation frequency the acoustic mode of the cells can be excited, resulting in high amplification of the acoustic signals. Pressure sensors may detect the acoustic waves generated from the PA cell as a result of the absorption of radiation by a sample. PA sensor could be a microphone with a lock in amplifier that is capable of detecting a small voltage generated by the microphone. Recently, capacitive microphone with a cantilever type pressure sensor made out of silicon has achieved high efficiency. Laser operating at 0.6 mm to generate acoustic wave pulses at the skin was reported. Piezoelectric material was used to detect acoustic wave rising from

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thermoelastic expansion. The concept of conservation of energy from thermal energy to acoustic energy is the basic concept of this approach. The drop in thermal energy as the heat travel via the multiple layers leads to the generation of acoustic waves. The photo acoustic imaging to better visualize and differentiate various orthopedic pathologies, including, but not limited to: microscopic fractures, degeneration, and neoplastic activity, was studied using computer simulation modeling. The COMSOL multi-physics software was utilized to simulate acoustic wave propagation through various anatomical layers within human bone. The simulation is based on combining Helmholtz equation in 2D, and the Penne's bio heat transfer equation. More specifically, the simulation for healthy density of bone was presented elsewhere.[1] In that work the control parameters for the photoacoustic wave was elaborated on. This work continues to include a comparative study for distinguish various type of bones for possible future diagnosis.

The research community is pursuing characterization by degenerative changes in the bones, cartilage, menisci, ligaments, and synovial tissue. In addition, osteoarthritis (OA) has evolved to

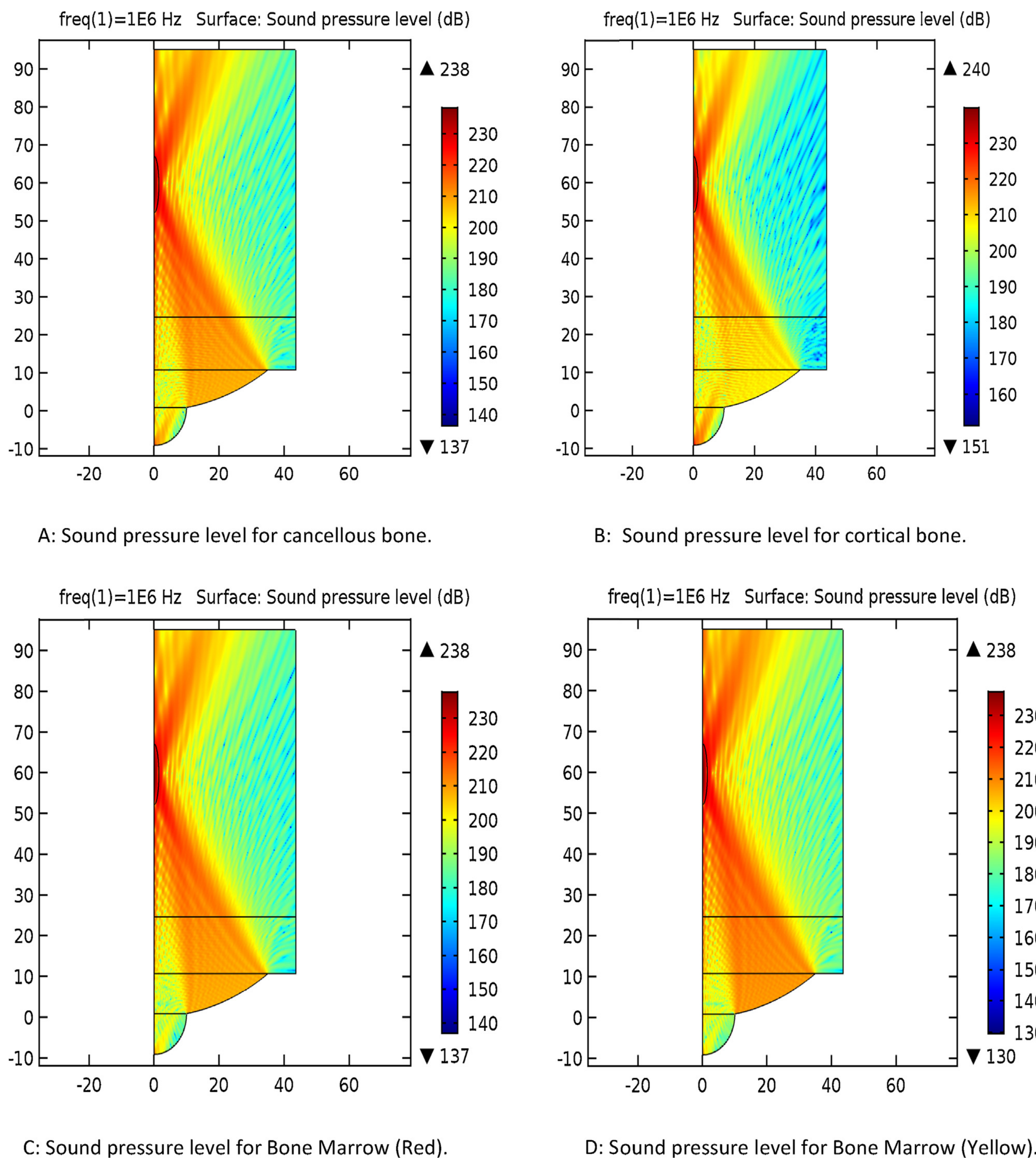

Fig. 1. Simulation of the sound pressure in 2D and 3D planes. (A) Sound pressure level for cancellous bone. (B) Sound pressure level for cortical bone. (C) Sound pressure level for bone marrow (red). (D) Sound pressure level for bone marrow (yellow). (E) Sound pressure level, 3D for cancellous bone. (F) Sound pressure level, 3D for cortical bone. (G) Sound pressure level, 3D for bone marrow (red). (H) Sound pressure level, 3D for bone marrow (yellow).