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Guided ultrasound wave propagation in cortical bone with microstructure using the gradient elasticity theory

Maria Vavva[a], Vasilios Protopappas[a], Leonidas Gergidis[b], Antonios Charalambopoulos[b], Dimitrios Fotiadis[a] and Demos Polyzos[c]
[a]University of Ioannina, Unit of Medical Technology and Intelligent Information Systems, Department of Computer Science and Department of Material Science and Engineering, GR 45110 Ioannina, Greece
[b]University of Ioannina, Department of Material Science and Engineering, GR 45110 Ioannina, Greece
[c]University of Patras, Department of Mechanical Engineering and Aeronautics, GR 26500 Patras, Greece

Ultrasonic characterization of bone has been largely based on the linear theory of classical elasticity. However, the classical theory cannot adequately describe the mechanical behavior of materials with microstructure. In such materials, the stress state has to be defined in a nonlocal manner by employing theories, such as those proposed by Cosserat brothers, Mindlin (gradient elastic theory) and Eringen. In this study, we adopt the simplest form of gradient theory (Mindlin FormII) to model the cortical bone's microstructural effects in a macroscopic framework. The frequency characteristic equations are analytically derived for a bone plate (4mm thick, density 1.5 g/cm^3, bulk longitudinal velocity 4107 m/s). The plate is assumed free of stresses, as in the classical Lamb problem, and free of double stresses. The volumetric strain gradient energy coefficient, g (a measure of internal length), is equal to 10^{-4} and 10^{-5} m, i.e. of the order of the osteons size. The velocity dispersion curves of guided waves are numerically obtained using root-finding techniques and compared with those of the Lamb waves. It is shown that microstructure affects mode dispersion by inducing both material and geometrical dispersion. In conclusion, bone models with microstructure can contribute to the interpretation of in vivo measurements.
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