Ultrasound Spectroscopy of Cortical Bone: Insights from In-Silico Modeling to In-Vivo Detection of Fragility Fractures

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Abstract

Cortical ultrasound spectroscopy (CortBS) offers a non-ionizing method for assessing viscoelastic properties and intracortical pore morphology, showing promise in detecting fragility fractures. This study integrates in-silico modeling and in-vivo evaluation to establish the sensitivity of ultrasound metrics to cortical bone properties and their utility in fracture discrimination.
In-silico simulations using a finite-difference time-domain (FDTD) model analyzed cortical bone with varying pore morphologies and tissue absorption (αabs). A heterogeneous pore size distribution (Ct.PoDm.D) was modeled through an erosion procedure, which gradually increased pore sizes from the outer to the inner bone boundaries. While material properties remained constant (c11=c22=23.7 GPa, c12=9.5 GPa, c66=6.6 GPa, ρ=1.93 kg/m^3), thickness, αabs, and Ct.PoDm.D were varied. Results demonstrated distinct shapes and amplitudes of backscatter and attenuation coefficients BSC(f) and α(f) with respect to pore density, morphology and tissue absorption, reflection bone deteriorations caused by reduced turnover, unbalanced remodeling and viscoelastic matrix alterations (Fig. 1).

Building on these insights, an in-vivo study evaluated 177 participants (144 women and 33 men, aged 30–86 years). DXA scans were performed at the lumbar spine and femoral sites, while CortBS measurements were performed at the anteromedial tibia midshaft. Multivariate analyses examined the effects of gender, age, and anthropometric factors, while partial least squares discriminant analysis (PLS-DA) compared fracture detection performance. CortBS scores, influenced by age, sex, and fracture status, demonstrated superior fracture discrimination for vertebral and non-vertebral fractures compared to DXA (AUC: 0.68–0.74 for CortBS vs. 0.60–0.63 for DXA).
CortBS reflects gender-specific alterations in cortical pore morphology and viscoelastic properties, providing a robust tool for assessing fracture risk in both women and men. The in-silico findings underscore the sensitivity of ultrasound metrics to pore morphology and viscoelastic matrix properties, offering a foundation for interpreting in-vivo results and advancing the understanding of bone quality and fracture risk with respect to ageing and bone pathologies.

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