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Ultrasonic wave-field reconstruction of bone fractures: numerical modelling and *ex-vivo* studies

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Background, Motivation and Objective: In recent years, interest of using ultrasound to diagnose bone fractures and monitor fracture healing has been increasing. Compared to other diagnostic imaging modalities, such as X-ray and CT, ultrasound does not involve ionizing radiation, which is beneficial to pediatric patients because their bony tissues are still in proliferation and more susceptible to the harmful X-rays. Conventional ultrasound scanners are not optimally designed to image hard tissues such as bone. Post-acquisition inversion/imaging algorithms are necessarily developed to reconstruct the geometrical characteristics of the cortical layer. In this work, we applied the split-step Fourier imaging (SSFI) method to image long bone fractures using simulated and *ex-vivo* data sets. The technique is usually known as Kirchoff migration in geophysics.

Statement of Contribution/Methods: We applied the SSFI method to reconstruct internal bone structure using the pulse-echo (zero-offset) time-distance data acquired on the sample's surface. The method requires an estimated slowness model, which is approximated by a depth-dependent term and a first-order spatially-varying perturbation. Since the recorded wave-fields are generated by the underlying scatterers or reflectors, imaging those reflectors can be accomplished by reversing the propagation path of the wave-fields or propagating backwards in time the wave-fields to the source of scatterers. Simulated data sets were used to validate the method. We used a stratified cortical bone model with water to mimic the overlying soft tissue and underlying marrow. The thickness of the soft tissue, cortical bone, and marrow layers were 6 mm, 7 mm, and 7 mm respectively. The model had a 3-mm-wide 45° inclined crack. The *ex-vivo* data were acquired using a 2.25-MHz 64-element Tomoscan Focus LT™ phased array system. The sample used was a bovine tibia with 6 mm thick overlying soft-tissue-mimicking layer. The 3 mm wide irregularly-shaped fracture was manually created to mimic comminuted type of fractures.

Results, Discussion and Conclusions: The reconstructed images show proper mapping of the cortical layer and fracture. The cortical thickness was reasonably determined with less than 10% error. The result also demonstrates reasonable bone image reconstruction even though the input slowness model was rough, indicating the robustness of the proposed method. The split-step imaging method is a promising technique to map the recorded time-distance data to depth-distance images, which provide better bone/fracture geometry information. The method extends the application of conventional medical ultrasound to study bone tissue and has the potential for clinical application.

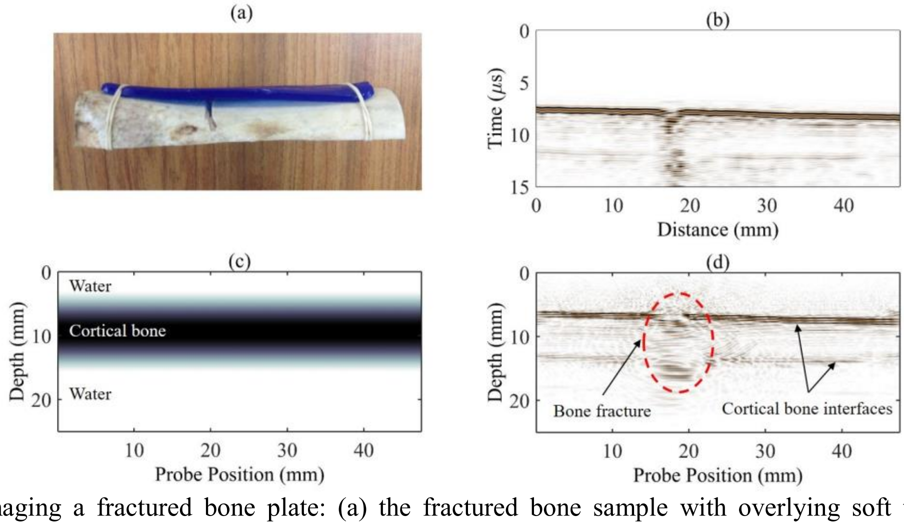

Figure 1. Imaging a fractured bone plate: (a) the fractured bone sample with overlying soft tissue, (b) the acquired ultrasonic time signals after linear gain and normalization, (c) the smoothed velocity model for imaging, and (d) the reconstructed bone image.