QUANTITATIVE ASSESSMENT OF TUBES AND RODS: COMPARISON OF EMPIRICAL AND COMPUTATIONAL RESULTS

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Abstract: Abstract: The primary objectives of this study were to establish an understanding of how ultrasound propagates through cylindrical rods and tubes. Another objective was to provide validation data for a computational ultrasonics software package. The long range objective of our work is to develop an ultrasound method to quantitatively assess the radial bone (the forearm) as a means for assessing osteoporosis.

Key words: computational ultrasonics, bone mineral density, cortical bone, net time delay, ultrasound velocity, osteoporosis

1. INTRODUCTION

The long range objective of this research is to develop an ultrasonic method for estimating bone mineral density (BMD) at the forearm. Estimation of BMD is an important component in diagnosing and managing osteoporosis. The use of BMD is based on the well-established thesis that bone strength is strongly related to the amount of bone material present and that a stronger bone in a given individual is associated generally with a lower fracture risk (Siffert and Kaufman, 2001). Radiological densitometry (e.g., DXA), which measures the BMD at a given site is currently the accepted indicator of fracture risk. Because of its expense, inconvenience, and associated x-ray exposure, ultrasound has been proposed as an alternative to DXA. (Siffert and Kaufman, 2007). As part of this project, a study of ultrasound propagation through rods and tubes was carried out.

2. MATERIALS AND METHODS

This study used both empirical ultrasound measurements and data generated in computer simulations. Bench-top measurements were conducted on a set of 6 plastic rods and 7 plastic tubes. A 3.5 MHz 12.7 mm diameter source and 1.5 mm diameter receiver in a through-transmission configuration were used within a water tank, between which the plastic or bone samples were placed. The received waveform was stored for subsequent processing. This configuration, as shown in Fig. 1, is similar to the one described by Robinson and Greenleaf (1984). A set of 2D ultrasound simulations of analogous models was also carried out using a finite difference time domain method (*Wave2000 Pro*, CyberLogic, Inc., NY).

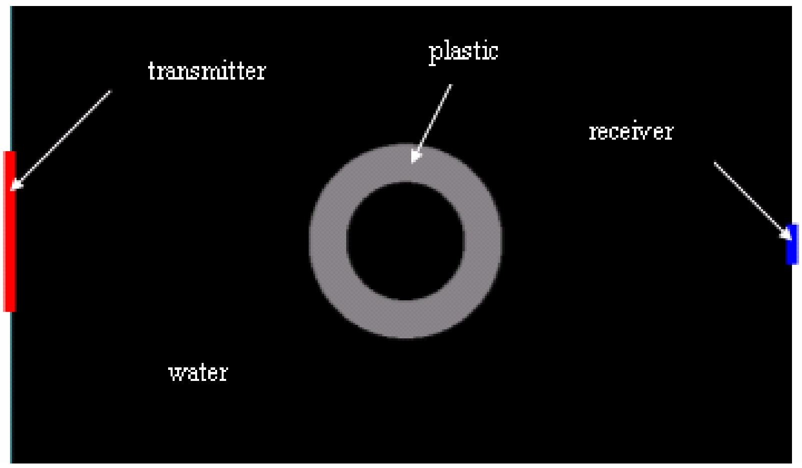

Figure 1. A typical image associated with an ultrasound simulation of propagation through a tube.

The ultrasound data obtained from both the bench-top experiments and the computer simulations were processed to obtain an ultrasound parameter known as *net time delay* (NTD), associated with each sample. The NTD is the difference between the times of travel of waveforms with and without the rod or tube in the path, *i.e.*, with water only or with water and sample (Kaufman *et al.*, 2007).

3. RESULTS

Results obtained show extremely close correspondence between the simulated and empirical results. Moreover, both the empirical and simulated results demonstrate correlations of NTD with overall rod diameter or tube wall thickness greater than 0.99. The simulated and empirical data demonstrate two primary paths of propagation for the tubes. The first is termed the circumferential wave (CW) and travels largely within the wall of the tube. The second is termed the direct wave (DW) and travels through the wall of the tube, into the water within the tube, and then through the wall of the tube as it travels to the receiver (Fig. 2). The estimation of plastic thickness using the NTD is based on the arrival time of the direct wave.

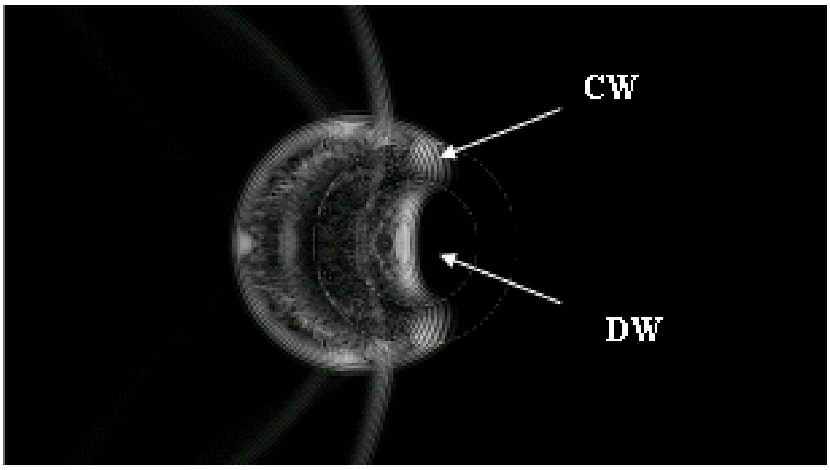

Figure 2. ***The ultrasound wave propagating through a simple tube showing a snapshot of the displacement magnitude at t=30.9 microseconds.***

Fig. 3 displays the NTD for all the rods and tubes (for the direct wave only) as a function of total plastic thickness. In this case, the total plastic thickness is the diameter for the rods and twice the wall thickness for the tubes. As may be seen, the correspondence between the empirical (‘scope’) and simulated (‘wave2000’) data is nothing short of remarkable. Note also the linear relationship between plastic thickness and NTD.

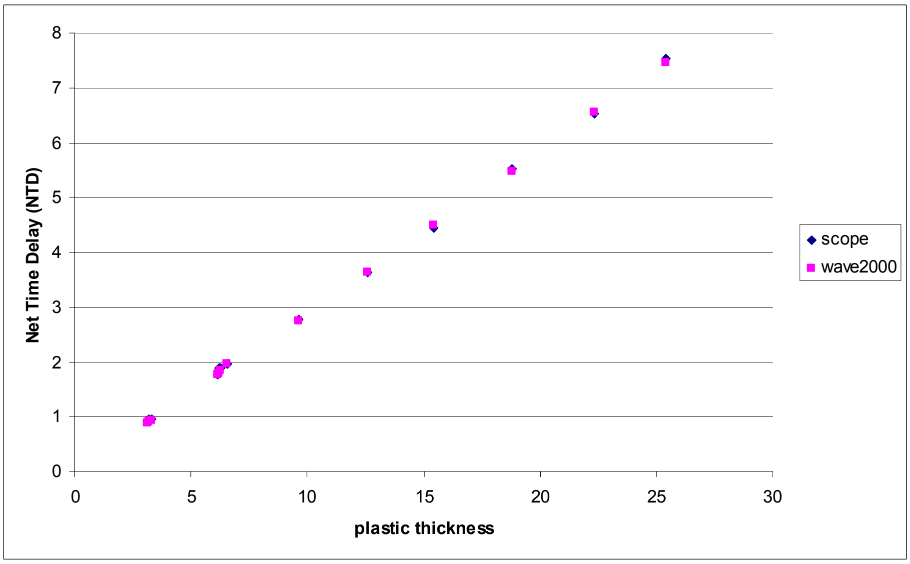

Figure 3. Comparison of the NTD vs. plastic thickness for the simulated ("Wave2000") and empirical ("Scope") data.

4. CONCLUSION

This study demonstrates that the net time delay parameter can be used to determine a thickness of plastic rods and tubes in a through-transmission configuration. It also shows that ultrasound simulation can be a useful tool for modeling ultrasound propagation in tubular structures. Subsequent research on human radial bone, including simulation, *in vitro* and clinical studies, will be carried out to develop a simple non-invasive radiation-free method for diagnosis and management of osteoporosis.

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