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Recent developments in modeling and measuring scattering from trabecular bone

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Previously, scattering measurements from single nylon cylinders were used to compare to measurements from cancellous bone. The comparison required the assumption of incoherent scattering to extrapolate scattering from a single cylinder to a network of cylinders. Now, the experimental model has been improved by the use of arrays of parallel-nylon wires, which are better models of cancellous bone. Good agreement between theory and experiment was found.

1 Introduction

The investigation of scattering from cancellous bone is important for two reasons. First, backscatter from cancellous bone has been shown in clinical trials to have diagnostic value [1-4]. Backscatter is an attractive clinical measurement because, unlike through-transmission measurements such as broadband ultrasound attenuation (BUA) and speed of sound (SOS), it only requires one transducer and therefore may potentially be applied to important skeletal sites such as hip and spine. Second, scattering is a fundamental mechanism for the interaction between ultrasound and bone. BUA, for example, is the combined result of absorption and scattering. Improved understanding of scattering may lead to development of improved ultrasound-based methods for detection of osteoporosis.

A scattering model based on elastic scattering from a cylinder has previously been reported [5-8]. The model predicts the frequency-dependence of backscatter from human calcaneus samples *in vitro* very well. The model was validated by performing backscatter measurements on individual wires. Cancellous bone was assumed to be comprised of a network of thin cylinders (trabeculae). Echoes from individual cylinders within the network were assumed to add incoherently. This assumption implied that the frequency dependence of backscatter from a network of cylinders is the same as that from a single cylinder [6].

In the present paper, scattering measurements from arrays of nylon wires are reported. Measurements from arrays permit more direct comparison to cancellous bone than the previous measurements from single nylon wires.

2 Methods

Phantoms consisting of parallel nylon wires (simulating trabeculae) in two-dimensional rectangular grid arrays (custom-built by Computerized Imaging Reference Systems, Norfolk, VA) were interrogated. The nylon wire diameter corresponded to trabecular thickness, which in the standard nomenclature for bone histomorphometry is denoted by Tb.Th [9]. Four values for Tb.Th were used: 150 μm, 200 μm, 250 μm, and 300 μm. The spacing between wires was 800 μm. See Reference 10 for details. These phantoms were originally used to explore the relationship between speed of sound and porosity, a topic that has also been investigated by other investigators [11-14].

Scattering was far greater than absorption in these phantoms (for the range of ultrasonic frequencies used). Therefore, through-transmission attenuation measurements could be used to assess scattering. Phantoms were interrogated in a water tank using a Panametrics (Waltham, MA) 5800 pulser/receiver and pairs of coaxially-aligned Panametrics broadband, 19 mm diameter, focused transducers (center frequencies 2.25 and 3.5 MHz). The propagation path between transducers was twice the focal distance (2 X 38 mm = 76 mm). Received radio frequency (RF) signals were digitized (8 bit, 25 MHz) using a LeCroy (Chestnut Ridge, NY) 9310C Dual 400 MHz oscilloscope and stored on computer (via GPIB) for off-line analysis. Five measurements (of ten RF lines each) were obtained on each phantom for each center frequency. Phantoms were removed from the tank and then repositioned between measurements.

Theoretical predictions for scattering were based on Faran's theory for elastic scattering from cylinders [5]. The material properties of nylon were assumed to be longitudinal velocity = 2500 m/s, density = 1.12 g/cm^2, and Poisson's ratio = 0.39. These values may be found at http://www.ultrasonic.com. (The value of velocity was reduced from 2600 to 2500 m/s in order to improve agreement between theory and experiment. It is understood that the values in the tables at http://www.ultrasonic.com are only approximate and not all nylon samples have identical material properties.) The material properties of water were assumed to be longitudinal velocity = 1480 m/s (at room temperature of about 20 degrees C) and density = 1 g/cm^2. The total scattering coefficient was estimated by averaging the angular-dependent scattering coefficient over all angles from 0 to 360 degrees.

3 Results

Figure 1 shows measurements and theoretical predictions of attenuation coefficient versus frequency for all four parallel-nylon-wire arrays. Recall that, in this experiment, nearly all attenuation was due to scattering. Theoretical functions were scaled by a frequency-independent factor in order to match measurements. Good agreement in frequency-dependence of measurements and theory may be seen over the range from 1.5 to 3.5 MHz. Agreement for Tb.Th = 200 μm, however, was not quite as good as in the other three cases.

4 Conclusion

Previously, scattering measurements from single nylon cylinders were used to compare to measurements from cancellous bone [6-8]. The comparison required the assumption of incoherent scattering. Now, the experimental model has been improved by the use of arrays of parallel-nylon wires, which are better models of cancellous bone. Good agreement between theory and experiment was found.

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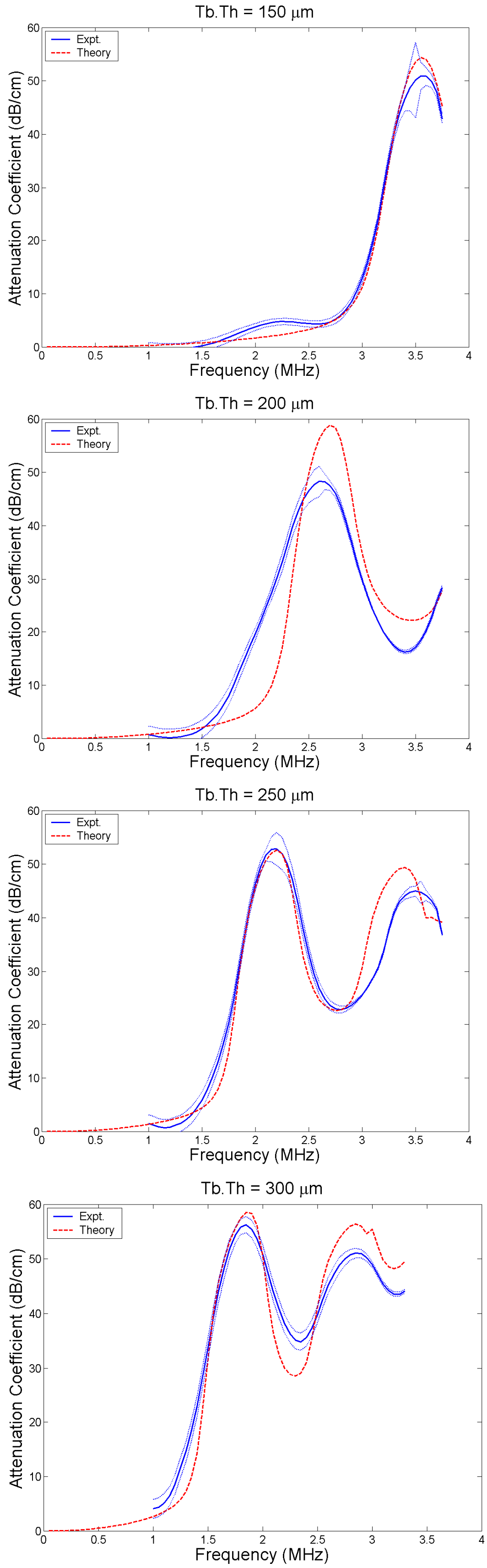

Figure 1. Dashed lines: theory. Solid lines: experiment. Dotted lines: plus or minus one standard deviation.

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