EFFECT OF FRACTURE CALLUS SCATTERING ON WAVE DISPERSION AND ATTENUATION IN HEALING BONES

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Introduction

The role of quantitative ultrasound as a diagnostic tool of the bone healing process has been widely investigated experimentally and numerically. The velocity of the first arriving signal, the estimation of the attenuation as well as guided wave analysis are considered as the main indicators of the gradual change of the material properties during the healing stages. However, for waves propagating in composite media, the phase velocity and attenuation are affected by material and structural properties.

Methods

In this study, we make use of an iterative effective medium approximation (IEMA) [Aggelis *et al*, 2004] in order to conduct wave dispersion and attenuation predictions in two callus segments of a healing bone. The geometry and the material properties of the examined specimens were derived from the tibia of a Merino sheep using scanning acoustic microscopy (SAM) and correspond to the ninth postoperative week [Preininger *et al*, 2011]. We examined two regions within the callus tissue measured 2.3 mm in width and 4.6 mm in length each characterized by different particle distributions and sizes.

The osseous tissue was considered as the matrix and blood as the material of the spherical particles. The average diameter of the inclusions was calculated as 0.11 mm for the first segment (denoted as segment I1) and 0.30 mm for the second one (denoted as segment I2), while the volume concentrations were estimated 12.7% and 28.7%, respectively. The material properties of the matrix and the inclusions were derived from the calibrated maps of the acoustic impedance using empirical relations [Preininger et al, 2011].

Results

Examining the attenuation coefficient within the frequency range of 24 kHz – 1.2 MHz, we observed a significant increase regarding the specimen I2, while for the specimen I1 the calculated values remained almost constant. The maximum attenuation values at 1.2 MHz for segments I1, I2 were found 0.56 m^{-1} and 61.84 m^{-1}, respectively.

Moreover, the phase velocity for the first specimen was found to slightly decrease when the frequency increases, obtaining values from 3359 at 24 kHz down to 3353 m/s at 1.2 MHz. A more significant negative dispersion is observed for the segment I2 with the phase velocity to decrease from 2994 m/s at 24 kHz down to 2912 m/s at 1.2 MHz.

Discussion

In this work, we demonstrated that negative dispersion is theoretically predicted for wave propagation in fracture callus by using an iterative methodology. This phase velocity behavior is attributed to the linear increase of attenuation with frequency. The results indicate that the variation of both the attenuation coefficient and the phase velocity depends on the volume concentration as well as on the size of the blood inclusions. In our future study, IEMA predictions will be conducted for serial SAM images derived from successive healing stages in order to investigate how these wave propagation phenomena evolve during the healing process.

References

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