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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 447-448
8-10 November, 2011

Elastic characterization of human jaw bone using scanning acoustic microscopy

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1. Introduction

The mammalian tooth is a biological functionally graded composite hard tissue comprising of calcified dentin capped by hard mineral enamel enclosing a soft core of pulp cavity providing mechanical stiffness and protecting against wear, fracture and ablation. Dentine comprised of 70 % hydroxylapatite and 30% of organic matter and water. The quantification of anisotropic physo-mechanical properties of enamel and dentine is of great importance for the clinical treatment and facial reconstruction. The emphasis is being laid towards fabrication of biomaterials which are mechanically, chemically and physiologically similar to the natural dental structure.

Ultrasonic scanning microscopy and pulse laser acoustic microscopy have been utilized to determine the anisotropic mechanical property. Ultrasound with long wavelength penetrates deep inside the hard tissue and provides high temporal and spatial resolution. The ultrasonic wave penetrates in the thickness of the hard tissue and helps in detection of discontinuity, micro-cracks and pathoses such as carious lesions. Major fractured or cracks are traditionally detected using micro computer tomography (μCT) [1]. However, μ-CT is costly and time consuming and has poor lateral resolution to detect pathoses.

Ultrasonic imaging provides a fast and accurate method for early detection of tooth defects in the patients. Ng *et. al* [2] and Ghorayeb *et. al* [3] have performed C scan imaging of enamel and characterized the mechanical properties of the tooth. Thijssen *et. al* [4] have quantified thickness revealing tooth topography using acoustic imaging. However, no accurate acoustic imaging of the entire jaw bone including enamel, dentine and pulpa has been done so far. The objective of the present study is to characterize the mechanical properties of the human jaw bone surrounding in the center of a canine tooth using scanning acoustic microscopy. The ultrasonic waves are excited at 30 MHz and operated in reflection mode. Speed of sound and elastic constants are quantified using material signature curves.

2. Experimental Investigation

The scanning acoustic microscope (PVA TePla Analytical systems GmbH, Aalen, Germany) was equipped with a broadband spherical acoustic transducer. The surface of the specimen was scanned and the entire pulse echo was stored in form of the radio frequency signal, 1280×1024 pixels, 8 bit raw data files. The low energy mode was used as standard for imaging at 30 db. The signal acquisition was sampled with a resolution of 8 bit at 500 MS/s. The lateral resolution of the imaging scanner was in the range of 10 μm depending on the scan length. The speed of scanning of the imaging was 8 to 1000 mm/s. **Fig. 1** shows a schematic diagram of the acoustic lens with the focal point (F) placed at negative defocus. The scanning area was 20×30 mm^2. The acoustic material signature curves were generated for the change in depth of focus of the lens with an increment of 30 μm for the focal penetration depth of 900 μm within the sample. Skimming longitudinal acoustic waves were excited in the central incisor jaw bone during scanning.

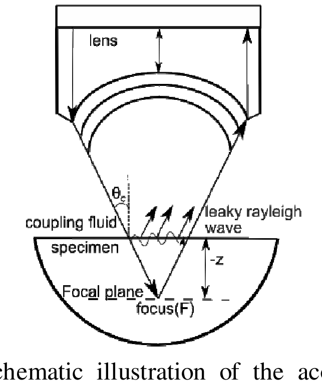

Fig. 1 Schematic illustration of the acoustic lens with a focal point defocused to the depth of z.

3. Results and discussions

The human caninus was scanned using acoustic microscopy at 30 MHz and the false color acoustic micrograph is shown in **Fig. 2**. In **Fig. 2**, pulpa and spongiosa is indicates with brighter contrast and enamel, jaw bone and dentine with relatively dark contrast. The acoustical micrograph represents the manifestation of relatively hard and inhomogeneous and anisotropic material property.

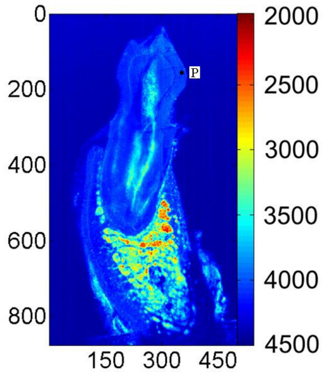

Fig. 2 Acoustic wave velocities (m/s) mapping in central incisor tooth calculated from acoustic material signature curve

The speed of the sound in the jaw bone is evaluated using an acoustic microscope by analyzing the variation of the voltage (V) as the focus of the lens is moved within the surface of the jaw bone also known as acoustic material signature curve (AMS) [5]. The material signature curve is resulting due to interference pattern of specular reflection of normal incident acoustic wave, leaky surface acoustic wave and skimming longitudinal waves [5]. **Fig. 3** shows a typical acoustic material signature curve in the point (P) in enamel marked in **Fig. 2**. The interspacing between the peaks of the AMS curves depicts the interference of the longitudinal waves and surface acoustic waves.

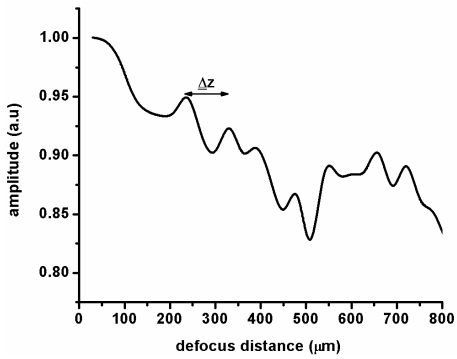

Fig. 3**.** Material signature curve evaluated in enamel of a human caninus tooth at an excitation frequency of 30 MHz.

Considering point focus acoustic beam propagating in an anisotropic solid, the acoustic material signature curve V (z) is given as $V(z) = \int_0^{\theta_m} P(\theta)\overline{R(\theta)} exp\,(-2ikzcos\theta)d\theta$, $P(\theta)$is pupil function of the point focus lens. For a point focus transducer, the reflection coefficient $R(\theta,\varphi)$ is measured from the surface reflection[5]. The corresponding wave velocity of LSAW is given as $C_{LSAW} = \frac{c_f}{\sqrt{\frac{c_f}{\Delta z f} - (\frac{c_f}{2\Delta z f})^2}}$. The variation of speed of sound and of the leaky surface acoustic waves is calculated using this equation for AMS analysis. The results are visualized in **Fig. 2**.

4. Conclusion

Scanning acoustic microscopy at 30 MHz is performed on the central incisor jaw bone for mechanical characterization. Acoustic material signature curve technique was utilized to quantify the anisotropic and in-homogeneity of the mechanical property in the jaw bone. The enamel, dentine, pulpa and spongiosa are distinctly characterizing AMS curves. The AMS curves provide the manifestation of the speed of sound of leaky surface acoustic waves.

Acknowledgements

This research has been performed within the cooperative research project "Preventive Biomechanics–PraeBionics" of the Loewe initiative of the State of Hesse.

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