VARIATION OF ACOUSTIC AND ELASTIC PROPERTIES OF HUMAN CORTICAL IN RELATION WITH POROSITY

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ABSTRACT

At the macroscopic level, ultrasonic technique in transmission with contact transducers at high frequency (2.25MHz) allows to determine the longitudinal elastic constant on cubic cortical samples [1]. Another technique in reflection such as the scanning acoustic microscope with a frequency between 20MHz and 50MHz allow to have a mapping of the acoustic impedance [2] related to the inhomogeneities of the structure. The purpose of this study is to obtain a spatial distribution of the acoustic velocities on cross femoral sections which will be compared with located bulk longitudinal velocities obtained with another technique in transmission on parallelepiped samples belonging to the same femur. The last step will be to make a correlation between the microstructure and spatial velocities.

INTRODUCTION

Ultrasonic technique is a non-invasive technique, which enables the assessment of acoustic properties (velocity, impedance, attenuation) and elastic properties (Young's modulus, Shear modulus, Poisson's ration) of a solid material. Thus, contact tranducers at 2.25MHz [1] enable to measure the bulk velocities which in the longitudinal direction are about 4000m/s. Furthermore, histological parameters (like porosity or volume fraction, degree of calcium content, density of osteon) were assessed to predict the Young's modulus. The objective of this work is to correlate the spatial distribution of acoustic properties of four Human femoral cross sections with its micro structural properties such as pores diameter and porosity.

METHODS

A cadaveric femur of a man (70 years old) has been cut transversally in order to have four sections between 40% and 70% of the total length. Between the previous slices 12 parallelepiped cortical samples (5*4*13mm) have been cut parallel to the axis of the femur in the lateral, medial and posterior sides (figure (1)). Two ultrasonic transmission techniques have been used: the first one (figure 2) used immersion focused transducers at 5MHz. The cross sections have been laid down into a water container (T=20°C) and the transducer (which is both receptor and emitter) scanned the surface of the sample with a step of 0.5mm. On each point of acquisition two acoustic echos have been recorded, enabling to measure longitudinal bulk velocities calculated by the $V = 2e/t$, e being the thickness (mm) and t (µs) the time delay between the two echos. The second ultrasonic technique (figure 3) used a couple (emitter and receptor) of contact transducers at 2.25MHz. The parallelepiped samples have been disposed between these two transducers and the longitudinal propagated bulk velocities were calculated by $V=L/t$, L being the length of the sample (mm) and t (µs) being the time propagated by the wave. At last, the elastic axial coefficients have been calculated by the relation: $C_{33}=V^2\times\rho$, ρ is the density (kg/m^3) and C_{33} the elastic coefficient (Pa) of the material. The calibration of the two ultrasonic transmission techniques has been performed with different materials (5*5mm): cooper, stainless steel, plexi glass, PVC.

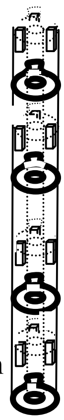

Figure 1 : Samples localisation

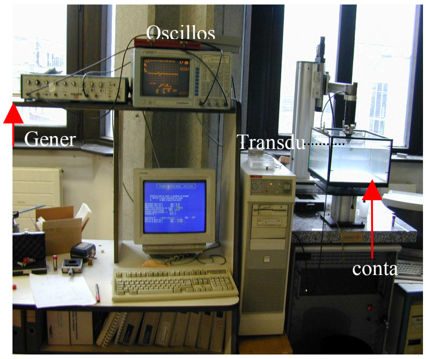

Figure 2: Ultrasonic transmission technique in immersion

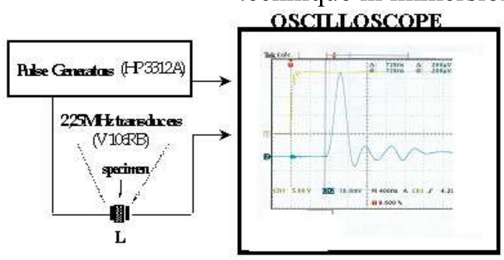

Figure 3: Ultrasonic transmission technique with contact transducer at 2.25MHz.

Back–scattered environmental scanning electron micrographs (XL 30 ESEM - FEG) were produced under high vacuum at 20KV with a magnification of 22 in order to have a mapping of secondary electrons (figure 4), which is related with the composition of the microstructure. Three typical regions of interest were defined by a square size of 3 mm and located at the posterior, lateral and medial regions of each section. Then, a methodology has been developed using custom made program allowing edge detection and geometric modelling into a CAO software. Thus, the detection of the porosity and the pores size were defined (figure 4). The pores size was defined by diameter D of a mean surface S of a pore calculated as: $D^2 = 4S_p/\pi N_p$, D: mean diameter of the pores in µm, S_p: total surface of the pores, N_p: total number of pores. The accuracy of the methodology was assessed by using calibrated geometry. The reproducibility was quantified by repeating all the process three times. Statistical analysis (Anova) has been performed (Statgraphics 5.0) in order to study the variation of the microstructure function of the anatomical localisation.

RESULTS

The accuracy of the acoustic velocities is 137m/s and 60m/s with the first and second ultrasonic techniques. The reproducibility obtained with three measurements is about 140m/s. The significant variation of velocity is represented by a change of the fringe colour (range of 200m/s) (figure 5).

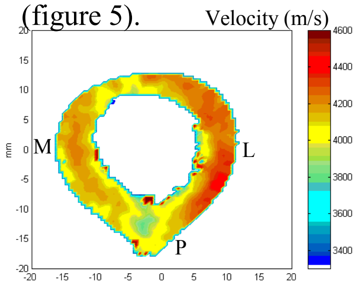

Figure 5: Velocities mapping of the cross section 3

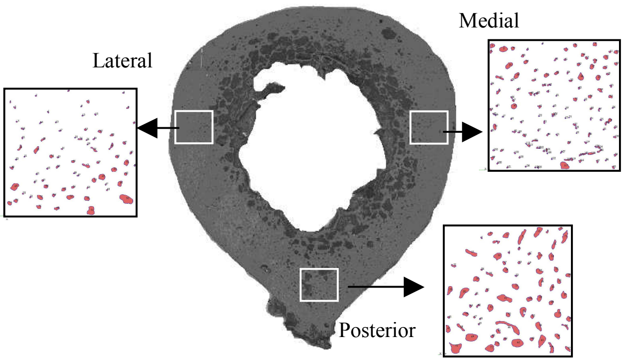

Figure 4: ESEM of the cross section 3 with the porosity

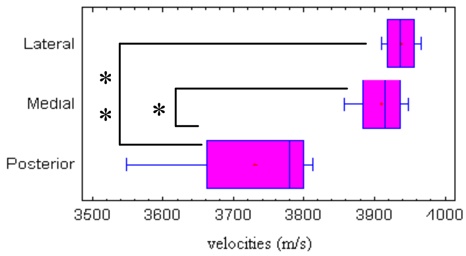

Figure 6. Peripheric variation of velocities

The mapping of the ESEM image for the cross section 3 is illustrated in figure 4. The range of pores size is for the posterior side (112±51µm-253±243µm) and the other sides (47±17µm-83±26µm). The range of the porosity is for the posterior side (9.7%-47%) and the other sides (3%-5%). The range of values varies from 3548m/s to 3967m/s and between 18.5GPa and 33.1GPa for the bulk velocities and axial elastic constants respectively. The accuracy of the technique of measurement of the diameter of the pores is about 10µm. The reproducibility of the measurement of the surfaces and the porosity are about 4% (0.2 – 10%) and 0.011% respectively.

DISCUSSION

The mapping of velocities shows a spatial distribution of velocities which varies as well in periphery (20%) as in the radial direction (11%) and along the length (11%). Bulk velocities were found to be lower at the posterior side with an increase along the length ($p<0.001$). These variations are significantly related with the microarchitecture where SEM pictures exhibit a more important porosity in these areas, which slightly decreases along the length. The medial and lateral sides have higher velocities with a significant radial variation from the endosteal to the periosteal region. This is in agreement with variation of the porosity at that location. Same ranges of velocities (figure 6) were obtained with both techniques. The results showed 1) that small variations of velocity in vitro may reflect high changes in the microstructure of the bone and 2) that immersion technique could be used to assess the spatial distribution of the elastic constant with the knowledge of spatial distribution of densities.

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