THREE PHASES IN BONE TISSUE PROPERTIES FROM MICROMECHANICAL TESTING AT THE MATERIAL LEVEL

Andrea Bonicelli (1), Elena F. Kranioti (2), Bledar Xhemali (3), Peter Zioupos(4)*

1. School of Natural Sciences, University of Central Lancashire, Preston, UK; 2. Dept of Forensic Sciences, University of Crete, Heraklion, Greece; 3 Institute of Forensic Medicine, Tirana, Albania. 4. Biomedical Engineering, School of Engineering, University of Hull, Kingston Upon Hull, UK.

Introduction

In ontogeny the properties and structure/composition of bone alter continuously according to demands placed upon it. Structural changes are concomitant to composition, architecture and physicochemical changes at the microscale which reflect at properties at the macroscale. We present here the pattern of properties at the osteon and interstitial lamellar level of a large collection of samples of human ribs [1] and clavicles [2] across a wide age range. Understanding of these pattens at the micro level may enable us to understand bone physiology in healthy ontogeny, in disease, as well as the developmental pressures placed upon it.

Methods

Sternal ends of the fourth and fifth ribs from 85 individuals (12-85 yrs) from the Forensic Institute in Tirana were employed in this study. The material was stored at -20°C and exposed to temperature variation for the least amount of time possible during testing. Experimental procedure involved nanomechanical tests on osteons and nearby interstitial lamellae by a CSM-NHT (CSM Switzerland) instrument, composition analysis (TGA) and physicochemistry (DSC, FTIR, XRD). Statistical analysis was carried out using the open-source software R 3.6.0.

Results & Discussion

The micromechanical data and most of the physicochemical data showed that there was a two-phase behaviour of bone tissue with age. A rise to a maximum value by the age of 35 and a decline thereafter. This behaviour, as expected, was related to the underlying chemistry and composition of the tissue [1]. However, the data has also raised some unanswered questions among which is the following conundrum: why do the interstitial lamellae decline after maturity? Do we really understand the osteon mediated remodelling of bone and its maturation in-situ? The prevailing wisdom [3] is that in the remodelling process old material is removed by newly laid down material and the older the material is the denser, harder and stiffer it becomes, by ageing in situ in ontogeny. We examined therefore, the relative magnitude (difference) of values of interstitial and osteonal lamellae across the full age range. There was no noticeable inflection at 35 and up to the age of 57yrs old and then it showed significant decline in the difference for both Hardness and Stiffness values. This means that in later life, the interstitial lamellae do not become even harder and stiffer than the osteonal ones; to the contrary the difference tends to decrease rather than increase!

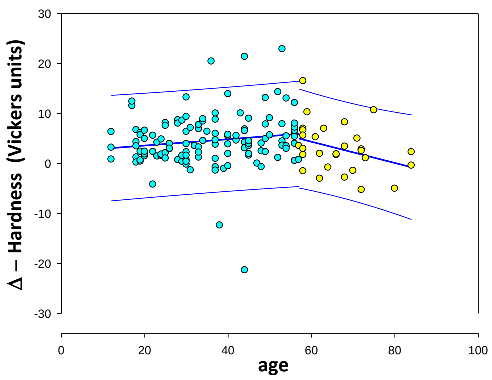

Figure 1: Difference in hardness of osteonal and interstitial lamellae across a wide age range.

Conclusions

A combined examination of the material, compositional, and mechanical properties of bone tissue showed that it goes through 3 phases in ontogeny with cross over points at ~35 and ~57yrs old. The 1st phase is driven by modelling and maturing of the tissue up to age 35; the 2nd phase up to 57yrs is a phase for maintaining equilibrium with a very gradual deterioration of properties but equal weakening of both osteonal and interstitial lamellae, which nevertheless maintain their relative differences; the 3rd phase post-57yrs does not appear to be physicochemical in its make or origin, but simply a change in the relative ratios of bone resorption-vs-formation, removal-vs-addition of osteons.

References

1. Bonicelli A. *et al*., Bone, vol 155, 116265 (2022)
2. McGivern H. *et al*., Front. Bioeng. Biotechnol. Vol 7:467 (2020)
3. Burr DB, & Allen MR (eds) Basic and Applied Bone Biology, Academic Press, (2019

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