Effects of Aging on Nanomechanics of Osteopontin-Deficient Mouse Bone

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Introduction

➢ Osteopontin (OPN), a phosphorylated glycoprotein, is among the most abundant non-collageneous bone matrix proteins produced by osteoblasts and osteoclasts (Figure 1). OPN has been implicated in bone formation, resorption and remodeling[1].
➢ Mechanical properties of bone material are not fixed, but change during life time. In very young stages the bone is growing very fast, during maturation, the properties change significantly mainly as a result of an increase in mineralization[2].
➢ This study has used nanoindentation to identify and compare local variations in elastic modulus and hardness of osteopontin deficient (OPN -/-) and wild-type (OPN+/+) control mouse bones.
➢ Specifically the study has looked at the effects of aging on hardness and elastic modulus and the variations of these properties across the radial axis of cortical femur of mouse bone.

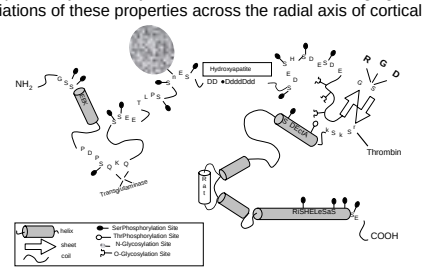
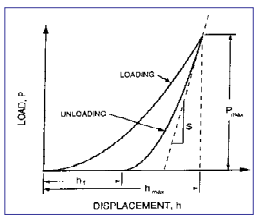


Figure 1. The Osteopontin (OPN) molecule

Method : Nanoindentation

➢ Nanoindentation tests were conducted by using Hysitron TriboIndenter ®, in load control mode (Figure 2,3)
➢ The hardness and elastic modulus for each indentation were determined by using the method of Oliver and Pharr[3]. Indentation modulus for the bone sample is calculated using the below equation for reduced modulus from the measured quantities.
➢ The mechanical properties and variations were examined and compared as a function of distance in cortical sections of femurs of mouse bones from age of 3 weeks to 58 weeks.



$$S = \left(\frac{dP}{dh}\right)_{unloading}$$

$$E_r = \frac{1}{2}\left(\frac{\pi}{A_c}\right)^{\frac{1}{2}} S$$

$$E_r = \left(\frac{1-\upsilon_s^2}{E_s} + \frac{1-\upsilon_i^2}{E_i}\right)^{-1}$$

S = Contact Stiffnes
E_r = Reduced Modulus for the indenter specimen combination

Figure 2. A schematic representation of load vs. indenter displacement showing quantities used in the analysis as well as graphical interpretation of the contact depth.

Figure 3 Typical nanoindentation image using Hysitron (image is 2μm wide)

Results and Discussion

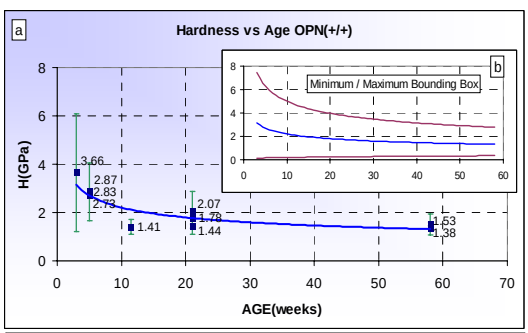


Figure 4 (a) Changes in mean Hardness as a function of age for wild type mouse femur. The error bars are standard deviations. (b) The bounding curve for the minimum and maximum values of Hardness for all age groups.

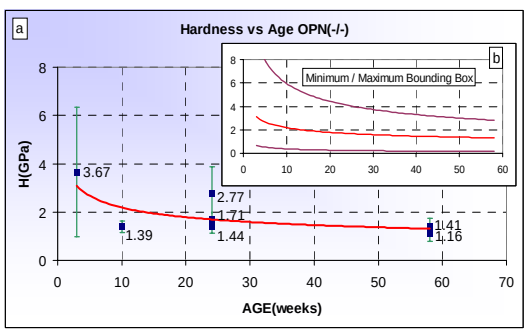


Figure 6 (a) Changes in mean Hardness as a function of age for osteopontin- deficient mouse femur. The error bars are standard deviations. (b) The bounding curve for the minimum and maximum values of Hardness for all age groups.

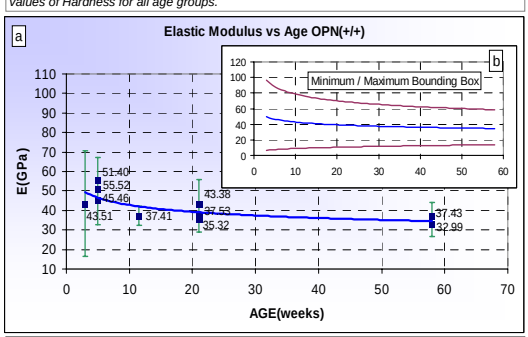


Figure 5 (a). Changes in mean Elastic Modulus as a function of age for wild type mouse femur. The error bars are standard deviations. (b) The bounding curve for the minimum and maximum values of Elastic Modulus for all age groups.

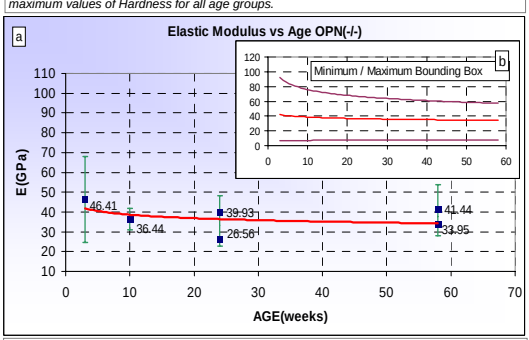


Figure 7 (a) Changes in mean Elastic Modulus as a function of age for osteopontin-deficient mouse femur. The error bars are standard deviations (b) The bounding curve for the minimum and maximum values of Elastic Modulus for all age groups.

➢ Effects of aging on wild type (OPN+/+) mouse bone (Figure 4,5)

✓ 62.3 % decrease in mean Hardness with an 87.3 % decrease in standard deviation

✓ 24.2 % decrease in mean Elastic Modulus with a 76 % decrease in standard deviation

➢ Effects of aging on osteopontin deficient (OPN-/-) mouse bone (Figure 6,7)

✓ 68.4 % decrease in mean Hardness with an 87.7 % decrease in standard deviation

✓ 26.8 % decrease in mean Elastic Modulus with a 72.4 % decrease in standard deviation

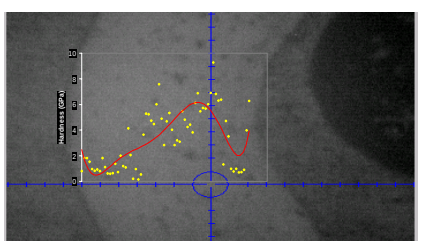


Figure 8. Hardness of 3 weeks old wild type mouse bone across the femur's radial section. A similar distribution of hardness is found for OPN(-/-) mouse bone of same age.

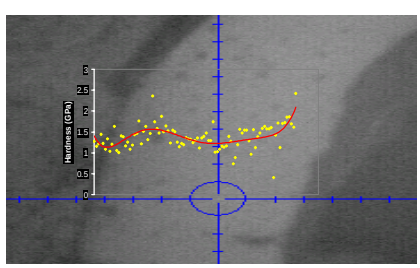


Figure 9. Hardness of 58 weeks old wild type mouse bone across the femur's radial section. A similar distribution of hardness is found for OPN(-/-) mouse bone of same age.

➢ Large, abrupt variations in mechanical properties across the femur's radial section for young mouse bone of both OPN(-/-) and the wild type control (Figure 8).

➢ Quite homogeneous mechanical properties along the radial axis of the adult mouse bone of both OPN (-/-) and the wild type control (Figure 9).

Conclusion

➢ Mechanical properties of the mouse bones decrease substantially with maturity. Statistically hardness and elastic modulus are more homogeneous in mature bones than young ones.

➢ Similar variation in both OPN-/- and OPN+/+ bones is observed, however statistically, no significant difference could be found in the mechanical properties of OPN(-/-) mouse bone and its wild type control.

References

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