VISCOELASTIC PROPERTIES OF BONES: NANOINDENTATION TESTING ON TUMOR-INDUCED OSTEOLYTIC RAT MODEL

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INTRODUCTION

Bone metastases are devastating diseases which result in increased morbidity and mortality [1]. Bone metastasis plays a key role contributing to fracture in bones weakened by the metastases. Bone mineral density (BMD), quantified using standard screening method such as DXA, is the current gold standard to predict fracture risk [2]. However, there may be possible changes in bone tissue not visible to X-ray methods that could alter bone quality and still at risk of fracture [3]. Therefore, we proposed viscoelasticity as a new parameter of bone quality that has never been assessed. The purpose of this study is to evaluate the changes in viscoelastic properties of tumor-induced rat femurs, measured in indentation modulus and indentation viscosity, by using nanoindentation technique.

METHODS

Specimens of rat femurs were obtained from four SD female rats. Rat breast cancer cell, Walker Carcinosarcoma 256 was surgically injected into the distal right femur through the intercondylar notch while another group was injected with saline solution to serve as the sham-operated control using the same procedure. The rats were sacrificed 30 days after surgery. After the bone was mounted in epoxy resin and metallographically polished, nanoindentation tests were conducted to measure elastic modulus and the viscosity of rat femoral cortical bone. Using a pyramidal Berkovich tip, indents were performed at least 30µm away from an adjacent indent surrounding ostoecytes in the rat bone structure. Creep phenomena were observed as an increase in depth while holding the maximum load. Non-linear regression model was chosen to best fit the creep displacement-time curve using the equation: $h^2(t) = (\pi/2)P_o \cot \alpha\ [(1-\exp(-tE/\eta))\ /E]$ [4], allowing the values of viscosity to be determined. Student's *t*-tests were used to compare values of elastic modulus and viscosity between cancer-induced and sham-operated groups. Significance was $p<0.05$.

Table 1: Mean values of Elastic Modulus and Viscosity of rat femur bones.

	Femur specimen	Elastic Modulus (GPa)	Viscosity (GPaS)
Sham-Operated	**3**	14.42	86940.99
	4	18.85	112720.90
	6	20.22	129440.80
	Mean	17.83	109700.90
	ST DEV	3.03	21410.25
Cancer-Induced	**3**	11.39	77462.23
	4	14.16	82634.94
	6	12.87	80611.96
	Mean	12.81	80236.38
	ST DEV	1.39	2606.73

RESULTS AND DISCUSSION

As hypothesized, both indentation modulus (E) and indentation viscosity (η) were significantly lower in tumor-induced rat bones as compared to the sham-operated group ($p<0.05$). Results showed that there were significant positive correlations between indentation modulus and indentation viscosity in tumor-induced and sham-operated rat femurs ($p<0.05$), both still followed the general similar trend of linear progression. Therefore, the positive viscosity-modulus relationship found in the current study can be interpreted as an increase in viscosity is associated with an increase in the degree of mineralization of the bone matrix.

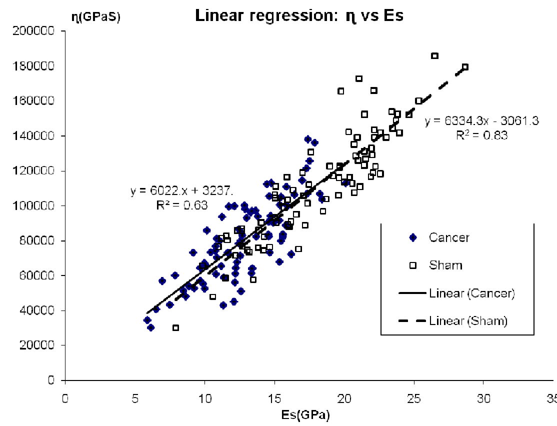

Figure 1: Linear relationship between indentation viscosity (η) versus indentation modulus (Es).

CONCLUSIONS

This new approach to investigate viscoelastic properties could be used directly to determine the quality of bone matrix, and also combined with imaging techniques and mechanical model to extrapolate the material and mechanical properties of bones. Current results would be used to further evaluate the response of tumor-induced metastasis to anti-cancer and/or anti-resorptive treatments for predicting risk of fractures in bone metastasis patients.

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