Influence of Bone Microarchitecture on the Stressed Volume of Equine Subchondral Bone

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I. Introduction

Musculoskeletal injuries are a significant source of lost training time and morbidity in racehorses. The metacarpophalangeal (MCP) joint is the most frequently injured site and there is a consensus that injuries at this location are a mechanical fatigue phenomenon. The fatigue life of bone is strongly determined by bone microarchitecture and the resulting stress concentration volume [1]. In equine subchondral bone, fatigue life was positively associated with bone volume fraction (BV/TV) in the deep trabecular region [2]. BV/TV is a function of both trabecular number and thickness, suggesting that trabecular bone geometry plays an important role in the fatigue resistance of equine subchondral bone. The objective of this work was to quantify the influence of bone microarchitecture on stress concentration volume in the trabecular region of equine MCP joint subchondral bone.

II. Methods

Twelve cylindrical bone samples measuring 6 mm in length and diameter were cut from the MCP joints of three equine forelimbs (4 samples/limb). Samples were scanned using µCT (Scanco Medical AG, Bassersdorf, Switzerland) with an isotropic voxel size of 6 µm and acquisition settings of 55 KVp and 145 µA. Microarchitecture measurements for the deep trabecular region (proximal most 2 mm of sample) were quantified using Fiji (NIH, USA) software. Measurements included BV/TV, trabecular number, trabecular thickness, and ellipsoid factor (the proportion of plate and rod-like trabecular structures). Finite element models were developed from the µCT images to quantify stress concentration volume for each sample using FAIM software (Numerics88 Solutions Ltd., Canada). Elements were assigned homogeneous, linear-elastic material properties. A uniform compressive load of 65 MPa was applied to the subchondral surface and the trabecular surface nodes were fixed. Stressed volume was defined as the volume of material experiencing a stress greater than the yield strength of equine subchondral bone (Fig. 1).

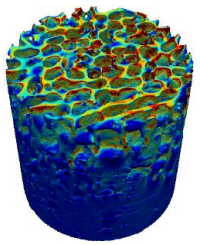

Fig. 1 Finite element predicted stress distribution of an equine subchondral bone sample loaded in compression.

III. Results

BV/TV was strongly correlated with stressed volume (Table 1). Mean trabecular thickness correlated more strongly with stress concentration volume than the number of trabeculae. There was no significant relationship between stressed volume and the proportion of trabecular rods and plates.

Table 1 Relationships between microstructure and stressed volume

	Correlation Coefficient	R-Squared	P-Value
Bone Volume Fraction	0.95	0.91	< 0.001
Trabecular Number	0.83	0.68	< 0.001
Trabecular Thickness	0.98	0.95	< 0.001
Ellipsoid Factor	0.31	0.10	0.32

IV. Conclusion

Stress concentration volume is a known determinant of bone fatigue strength that correlates with BV/TV. This work suggests that trabecular thickness is more important than trabecular number for the fatigue strength of equine subchondral bone.

References

1. L.L. Loundagin, A.J. Pohl, W.B. Edwards, “Stressed volume estimated by finite element analysis predicts the fatigue life of human cortical bone: The role of vascular canals as stress concentrators,” Bone, 143 (115647), 2001.
2. S. Martig, P.L. Hitchens, P.V.S. Lee, R.C. Whitton, “The relationship between microstructure, stiffness and compressive fatigue life of equine subchondral bone,” J Mech Behav Biomed Mater, 101 (103439), 2020.