Integrating Second Moment of Area with Osteohistology to Identify Limitations in Weight-Bearing Limb Bones

MISERICORDIA UNIVERSITY

Justin Kramer, Jeffrey Stephens, PhD., Mateusz Wosik, PhD.

Departments of Biology and Physics, Misericordia University, Dallas, PA 18612

Introduction

Second moment of area is a measure of how well the cross-section of a beam will resist bending because of its shape. Previous research used second moment of area to calculate gait shifts in *Maiasaura peeblesorum* but failed to incorporate consistent sampling. In this study, we use osteohistological sections from the diaphysis of long bones from *Edmontosaurus annectens* in order to establish a method of calculation for the strength of bone

Computer vision is an area of AI that seeks to enable computers to derive information from images and other visual materials. In this work we make use of OpenCV, an open source package available for python, to create a workflow to extract important physical aspects of the shape and distribution of bone within the image from a histological slice.

Edmontosaurus annectens

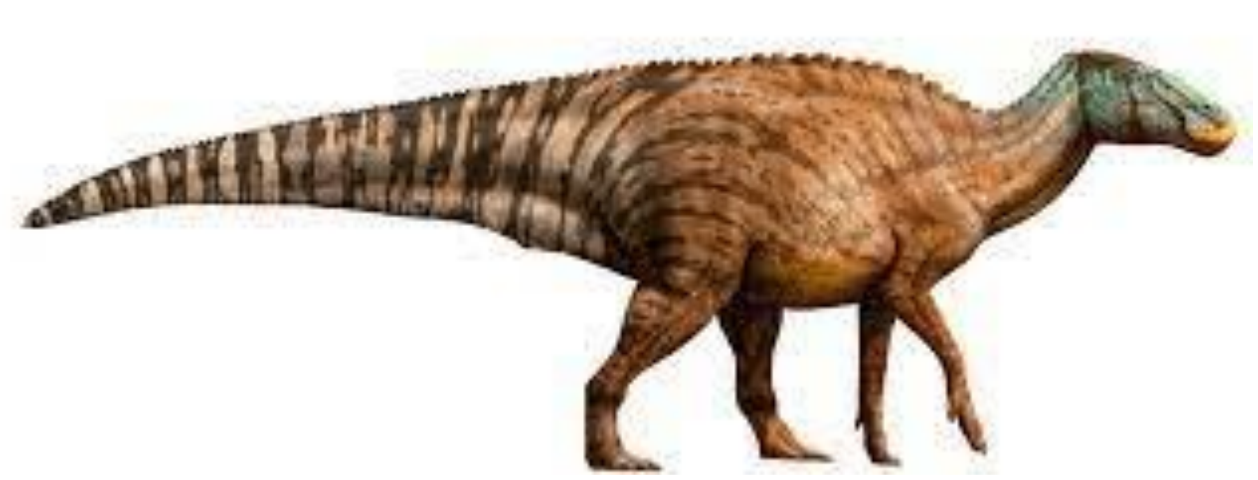

Figure 1. Image of *Edmontosaurus annectens* credited to Julius Csotonyi

Retrodeformation

Figure 2. While some bones are well-preserved, others are distorted from fossilization over time. These specimens require retrodeformation, a digital reconstruction of the image to recover an accurate size and shape of the specimen.

Materials and Methods

Samples were taken from a set of pre-published osteohistological sections of *Edmontosaurus annectens,* which were age-calibrated and sectioned from the minimum circumference of the diaphysis.

To make osteohistological sections, bone specimens are photographed, cast in epoxy resin, cut at the thinnest part of the shaft, and sanded down to the appropriate thickness.

Once the slides are photographed, the image can be processed in OpenCV and python. Once the image is loaded, we task OpenCV with identifying the boundaries of the medullary cavity and cortical bone based on the outline in the image. The final mask allows us to select only the pixels we want in our final image. OpenCV provides a moments method to calculate moments from images using the following calculation:

$$m_{ji} = \sum_{x,y} (image(x,y) \cdot x^j \cdot y^i)$$

The results of the moments function were converted to real units and combined with averaged values for ultimate strength and elastic modulus of bone. These values were then used in the following calculations for the maximum weight of compression and the maximum weight for bucking on the X and Y axes:

Compression

$$\sigma_{ult} = F \div A$$

Buckling

$$P_{cr} = \pi^2 EI / L^2$$

Figure 3. Original image of the osteohistological slide

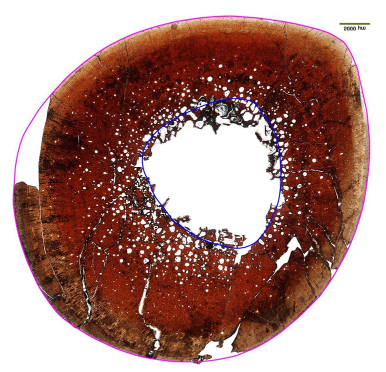

Figure 4. Outlined cortical bone and medullary cavity

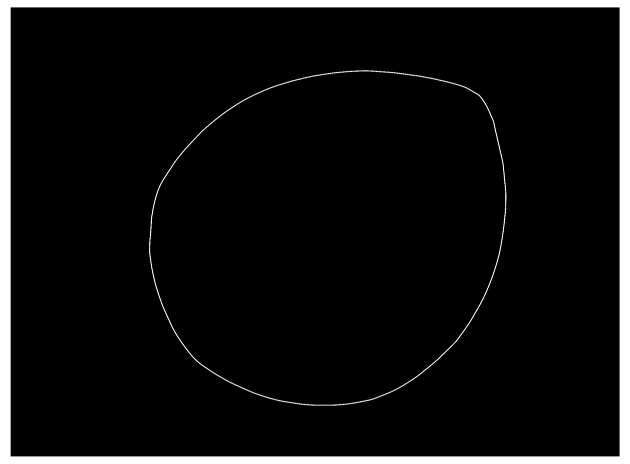

Figure 5. Outlined cortical bone processed by OpenCV

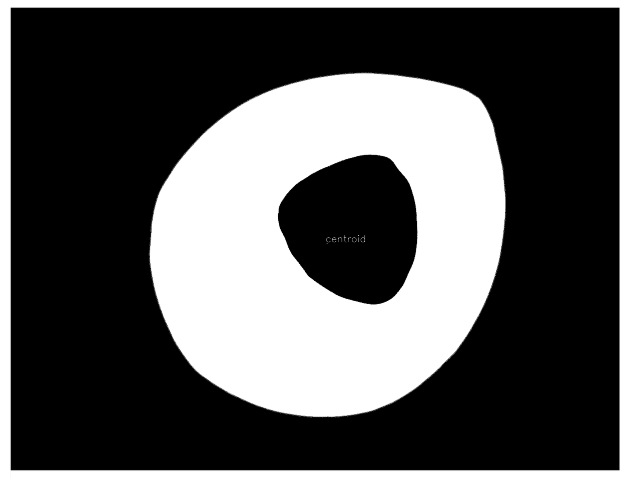

Figure 6. Final mask of the medullary cavity with centroid

Figure 7. Final image produced in OpenCV

Results

Bone ID	Bone Type	Max Weight for Compression	Max Weight for Buckling	
			X-axis	Y-axis
67603	Tibia	112,968 lbs	4.95E+04 kN	4.95E+04 kN
67793	Tibia	214,096 lbs	1.33E+05 kN	1.21E+05 kN
67794	Humerus	153,314 lbs	1.31E+05 kN	8.74E+04 kN
67796	Humerus	76,305 lbs	5.04E+04 kN	3.86E+04 kN
67798	Femur	165,670 lbs	1.41E+05 kN	1.04E+05 kN
73853	Tibia	359,732 lbs	2.66E+06 kN	3.24E+06 kN

*Compression values were calculated using 21.9 GPa and 19.34 GPa for the average ultimate strength of bone in compression and tension, respectively.

**Buckling values were calculated using 0.225875 GPa and 0.14725 GPa for the average elastic modulus of bone for compression and tension, respectively.

Discussion and Conclusions

The purpose of this research was to establish a viable method for calculating the strength of bone. We knew these values would be dramatic over-estimations because we assumed a static creatures, as these calculations do not account for the dynamic load on the bone for a moving dinosaur. However, we were able to confirm that buckling would be a more likely failure point compared to compression, which is consistent with expectations.

Future Research

Future research will incorporate second moment of area calculations to determine the strength of bone. We plan to make use of bending moments, adding another possible failure point for a bone, as well as getting better approximations for the ultimate strength and elastic modulus. This method will also be employed to determine the strength of bone at different growth marks and ages of the specimen.

Acknowledgements

I would like to thank Dr. Wosik and Dr. Stephens for providing the knowledge, resources, and guidance required to complete this project. I would also like to thank the Royal Ontario Museum for providing our specimens.

References

Currey, J. (2002). *Bones: Structure and Mechanics*. Princeton University Press

Gosline, J. (2018). *Mechanical Design of Structural Materials in Animals.* Princeton University Press

Wainwright, J.D., et al. (1982). *Mechanical Design in Organisms.* Princeton University Press