Load Sharing of Cancellous and Cortical Bone in Rat Vertebrae Under Uniaxial Compression Determined Using Finite Element Analysis (FEA)

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Motivation

- Rats are often used as an animal model for studying the effects of osteoporosis, a disease associated with reduced bone quality and quantity.
- Recent experimental studies [1] involving combined compression and micro-CT imaging of rat vertebrae, Figure 1, have shown that failure occurs in the vicinity of vascular apertures in the cortical shell.
- The contribution of the cortical shell to the overall mechanical behavior, and the role of the vascular apertures in that behaviour, must be quantified in order to assess how well the rat animal model represents human vertebrae.

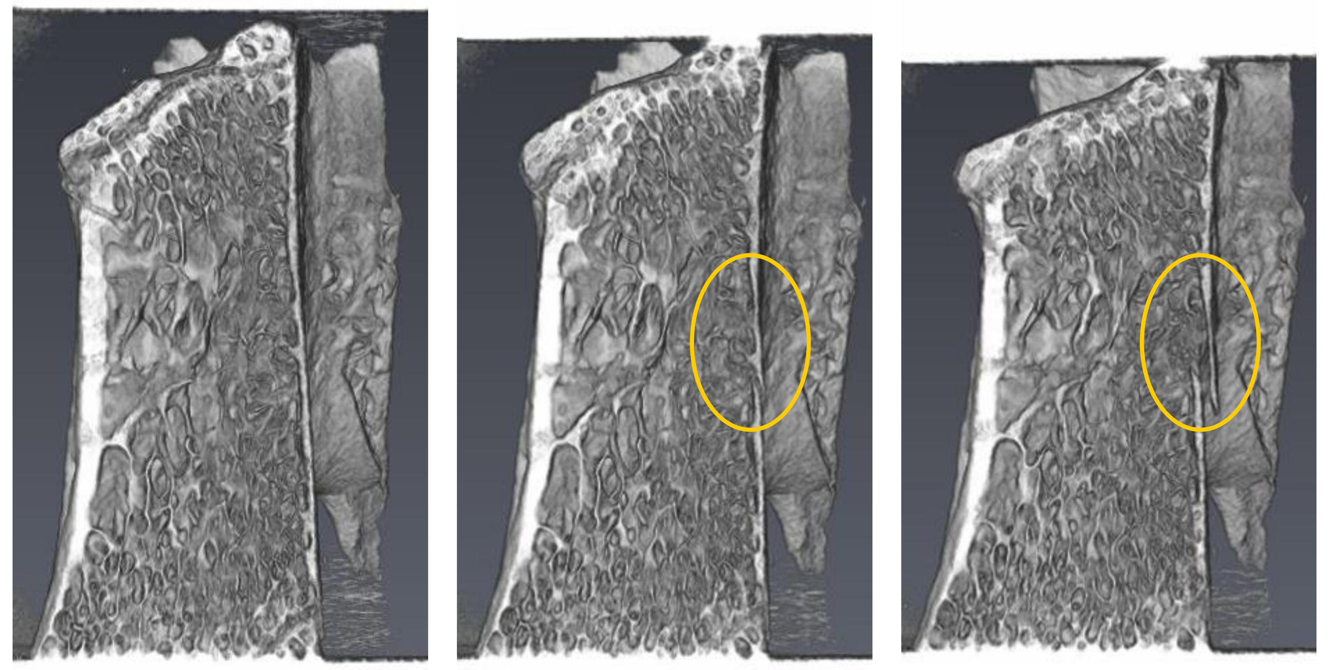

Figure 1: OVX experimental models shown incrementally until failure at 0, 5 and 10% strain [1]. Failure is observed to initiate near the dorsal side of the cortical shell in the vicinity of the vascular apertures.

Objectives

1. Conduct finite element analyses (FEA) on specimen-specific models for three different conditions: healthy (SHAM), osteoporotic (OVX), and osteoporotic + treatment (OVX+E).
2. Determine the load contribution of the cortical shell in uniaxial compression, considering both the presence and absence of vascular apertures.

Methods

- 3D micro-CT images of 30 rat vertebrae [1] (Figure 2a) were segmented (Figure 2b) and converted into a series of hexahedral FEA models (CS+T) (Figure 2c).
- Assuming isotropic linear elastic behaviour, the FEA models were subjected to a 2% uniaxial compressive strain.
- A dual threshold technique [2] was used to remove the trabecular bone, and additional models of just the cortical shell (CS) were created and analyzed (Figure 2d).
- Finally, the vascular apertures were filled in semi-manually to create a third set of vascular aperture filled (VAF) models.
- Contribution to cortical load was calculated as the ratio of CS/CS+T.

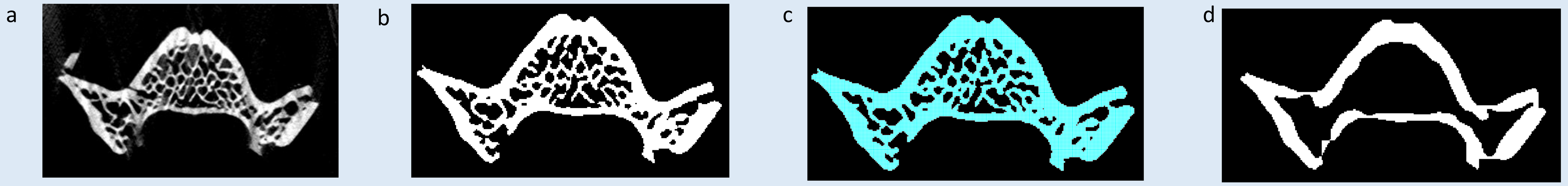

Figure 2: A single micro-CT slice at various image processing steps.

Results

Table 1: Cortical shell load contribution and apparent stiffness values for the different types of models studied. The contribution of the cortical shell was not found to be significantly different between the three groups, with an overall average of 70.1 ± 4.5%.

Model Type	n	Cortical Load Contribution ± SD (%)	Average Apparent Stiffness ± SD (MPa)	Average % Increase in Apparent Stiffness of VAF Models ± SD (%)
SHAM	10	71.0 ± 4.3	1589 ± 182	0.46 ± 0.1
OVX	10	68.5 ± 5.8	1325 ± 152	0.49 ± 0.1
OVX+E	10	70.7 ± 2.2	1671 ± 197	0.43 ± 0.1
All Models	**30**	**70.1 ± 4.5**	**1528 ± 231**	**0.46 ± 0.1**

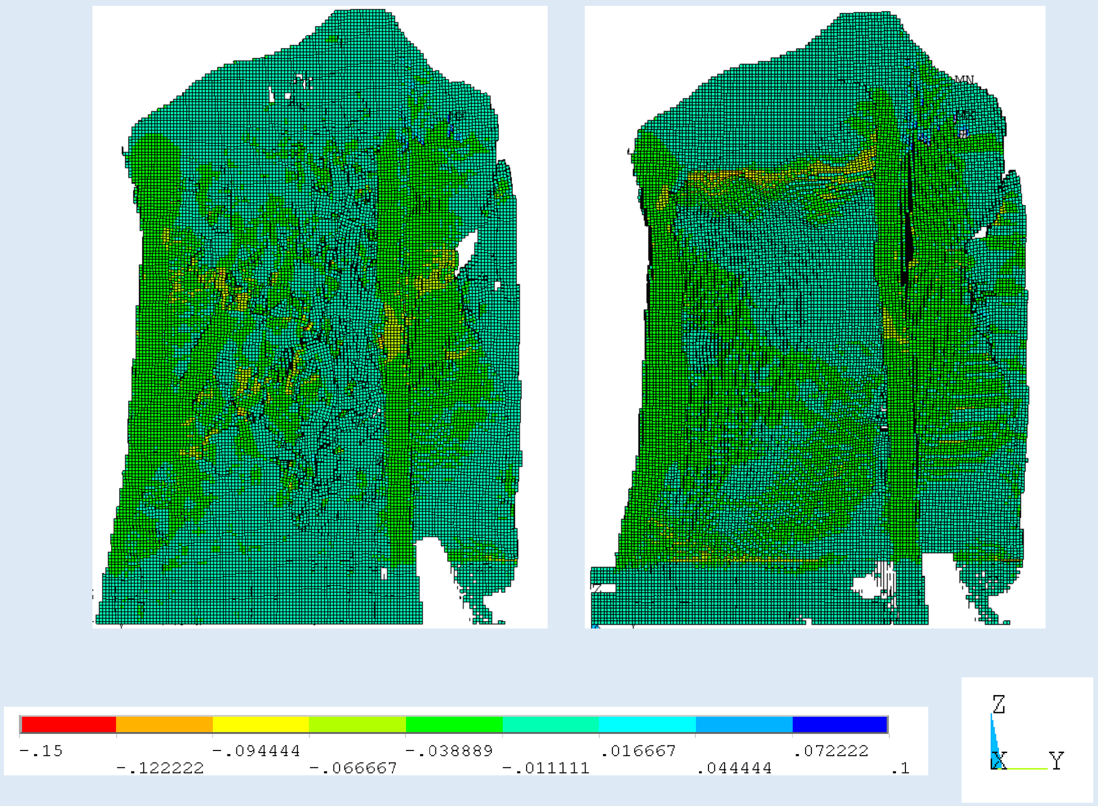

Figure 3: Sagittal plane contour plots of compressive axial strain for the cortical shell (CS) (left) and total vertebral body (CS+T) (right).

Discussion

- The cortical shell of rat vertebrae carries roughly 70% of the axial load, which is statistically different ($p < 0.01$) than the 52% found in human vertebrae [3]. This value was unaffected by disease state.
- Despite the lower cortical shell thickness in the OVX models, the relative contribution was similar because there was also a lower density of bone in the trabecular centrum.
- The small difference in load sharing and apparent stiffness with the vascular aperture filled (VAF) FEA models suggests that the role of these features in failure must occur at a much more local level.

Conclusions

- Linear elastic specimen-specific FEA models of 30 rat vertebrae were loaded under uniaxial compression.
- The relative load contribution of the cortical shell was found to be statistically-signficantly higher than in human vertebrae.
- More insight into the local behaviour of the vascular apertures and trabecular centrum relationship is needed to determine their role in the initiation of local failure.

Acknowledgements

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References

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