Predicting Vertebral Strength: A finite element study

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INTRODUCTION & OBEJECTIVES

Activities of daily living with loads exceeding the vertebral strength result in vertebral fractures. The most common are Vertebral wedge fractures that have been associated with uniaxial compressive and forward bending loading. Understanding vertebral strength under different loading conditions experienced during activities of daily living is important [1].

The aims and objectives of this project are to set up a finite element model of a single T12 Vertebrae from clinical CT scans to simulate axial and bending loads to assess their effect on the mechanical stress and strain response of the vertebrae.

MATERIALS & METHODOLOGY

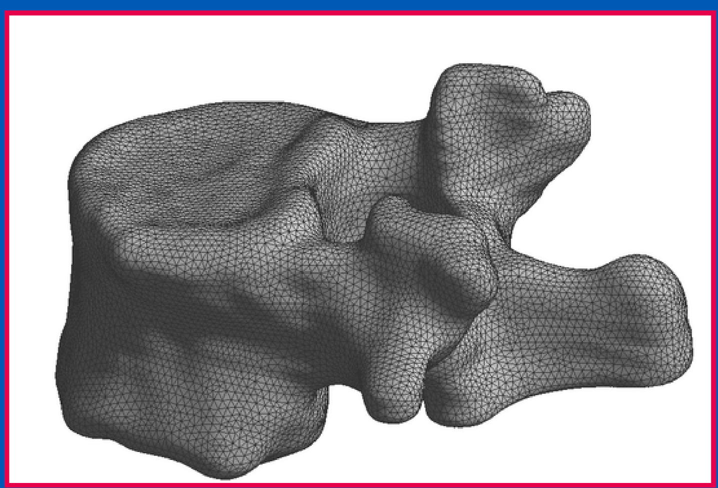


Figure 1: 1mm quadratic tetrahedral mesh

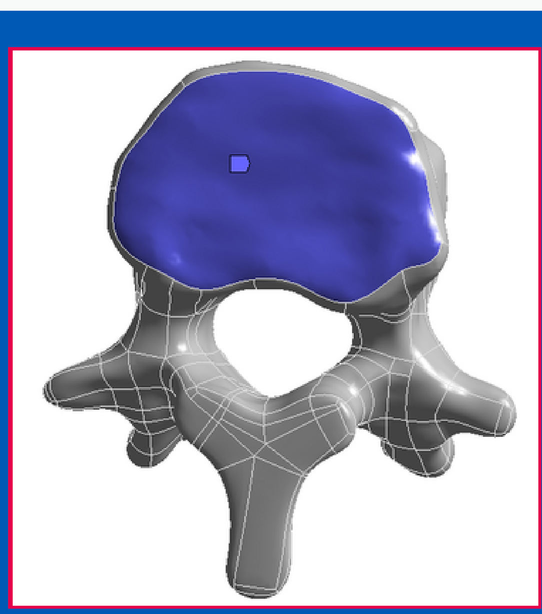


Figure 2: Fixed Support applied to endplate

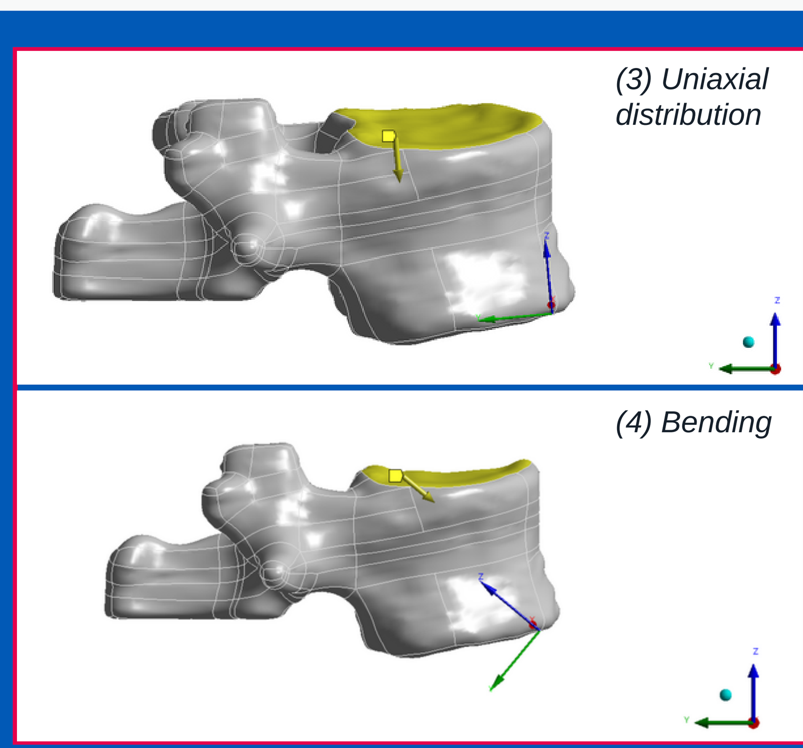


Figure 3 & 4: Coordinate System: (uniaxial loading perpendicular to endplate, simulated bending at 45 degree angle to the endplate)

$$\rho_{QCT} = \rho_{app} \times 0.6\ [g/cm^3] \quad \text{Eq. 1}$$

$$E = 4730 \times \rho_{app}^{1.56} \times 0.6\ [MPa] \quad \text{Eq. 2}$$

$$\sigma_{y1} = 21.7 \times \rho_{app}^{1.52} [MPa] \quad \text{Eq. 3}$$

$$E_{py} = 0.05 \times 4730\ \rho_{app}^{1.56} [MPa] \quad \text{Eq. 4}$$

Mechanical behaviour and Bone material property equations

Four healthy participants T12 Vertebrae models created from QCT images were used:

- Equation 1 and 2 shows the patient specific densitometry calibration and relationships used in assigning the bone heterogenous, linear material properties on Bonemat [2, 3].
- Equation 3 shows yield stress criterion based on the density strength relationship used in modelling the isotropic plastic behaviour of bone on Ansys workbench using an Ansys APDL command [4]. Equation 4 shows the 95% reduction applied in the post yield elastic modulus [3, 5].

The thoracic angle of forward bending of 45 degrees used in figure 4 is consistent with the 20-60 degrees moderate trunk inclination angle range in literature [8].

A fixed support was added to the inferior endplate as shown in figure 2, wiith a 1mm quadratic tetrahedral mesh shown in figure 2. For the displacement control, a strain rate of 1.9% was used.

RESULTS & DISCUSSION

Figure 5: Patient 1 results

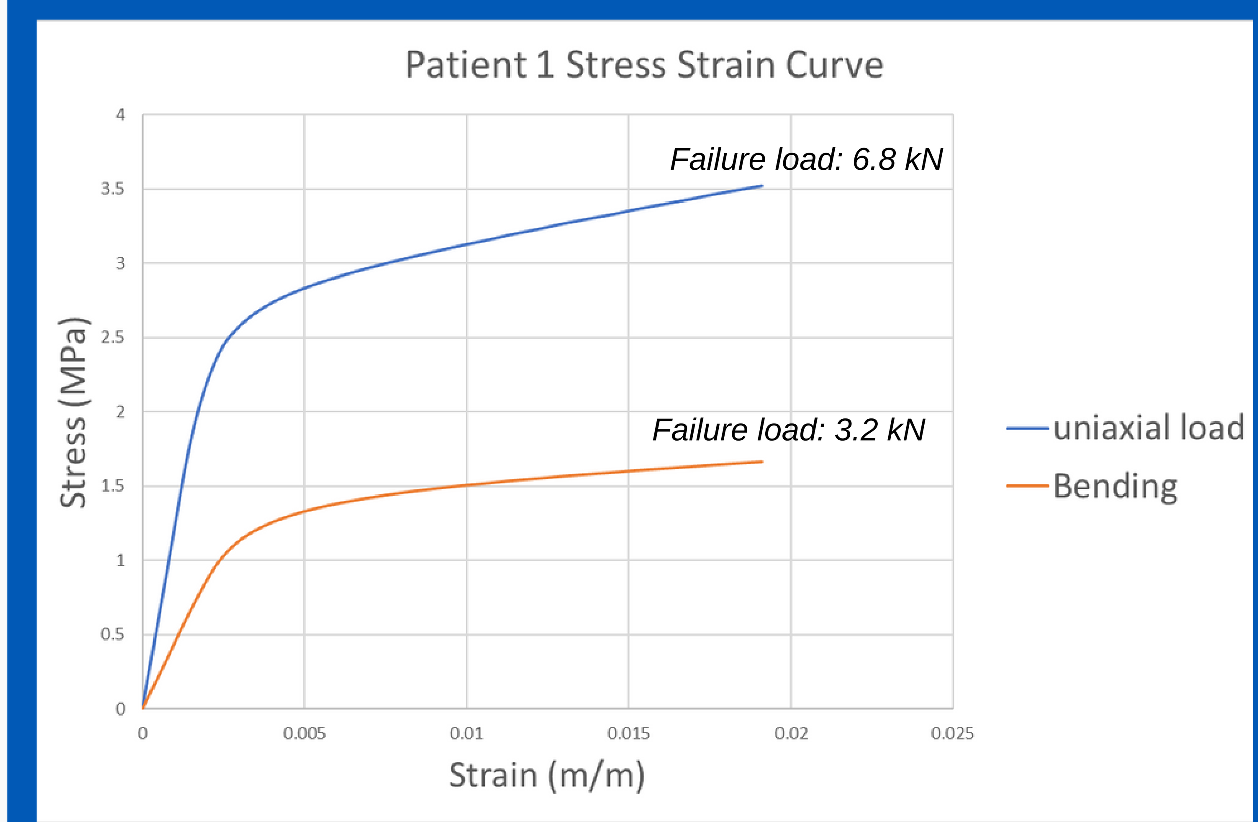


Figure 6: Patient 2 results

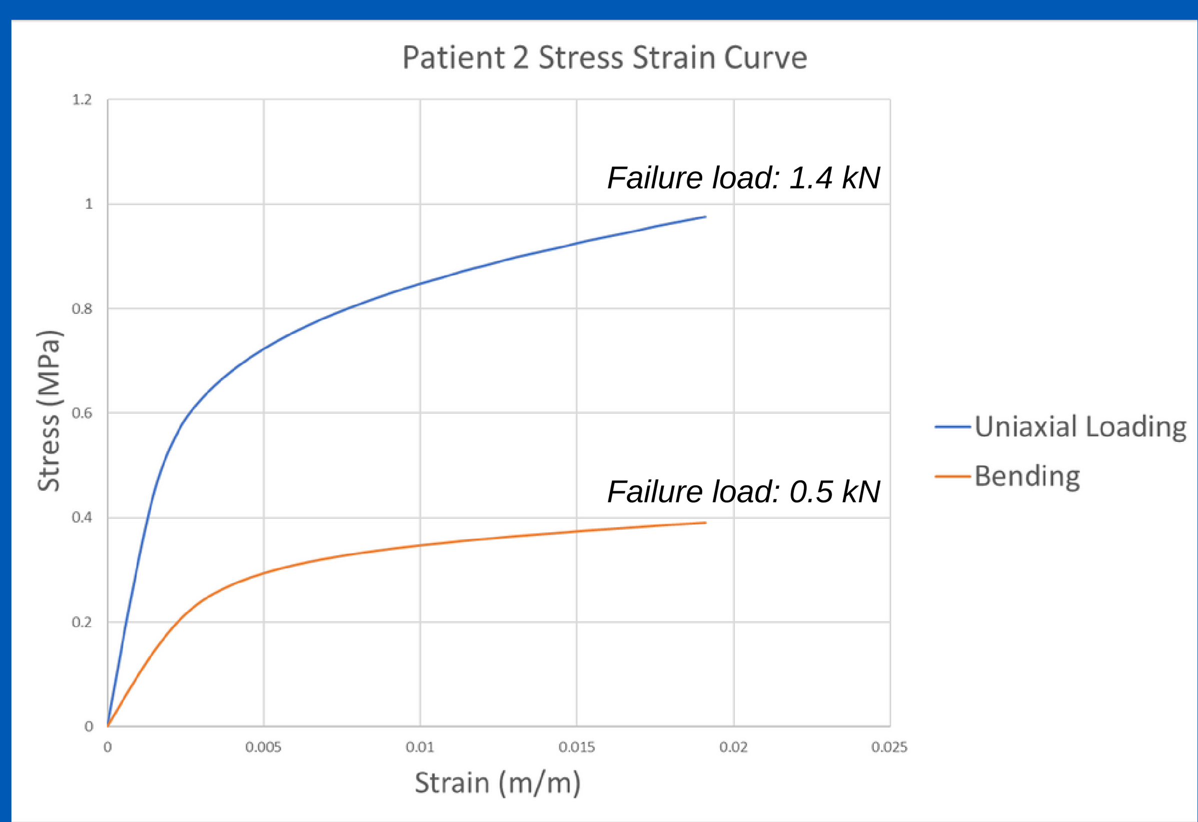


Figure 7: Patient 3 results

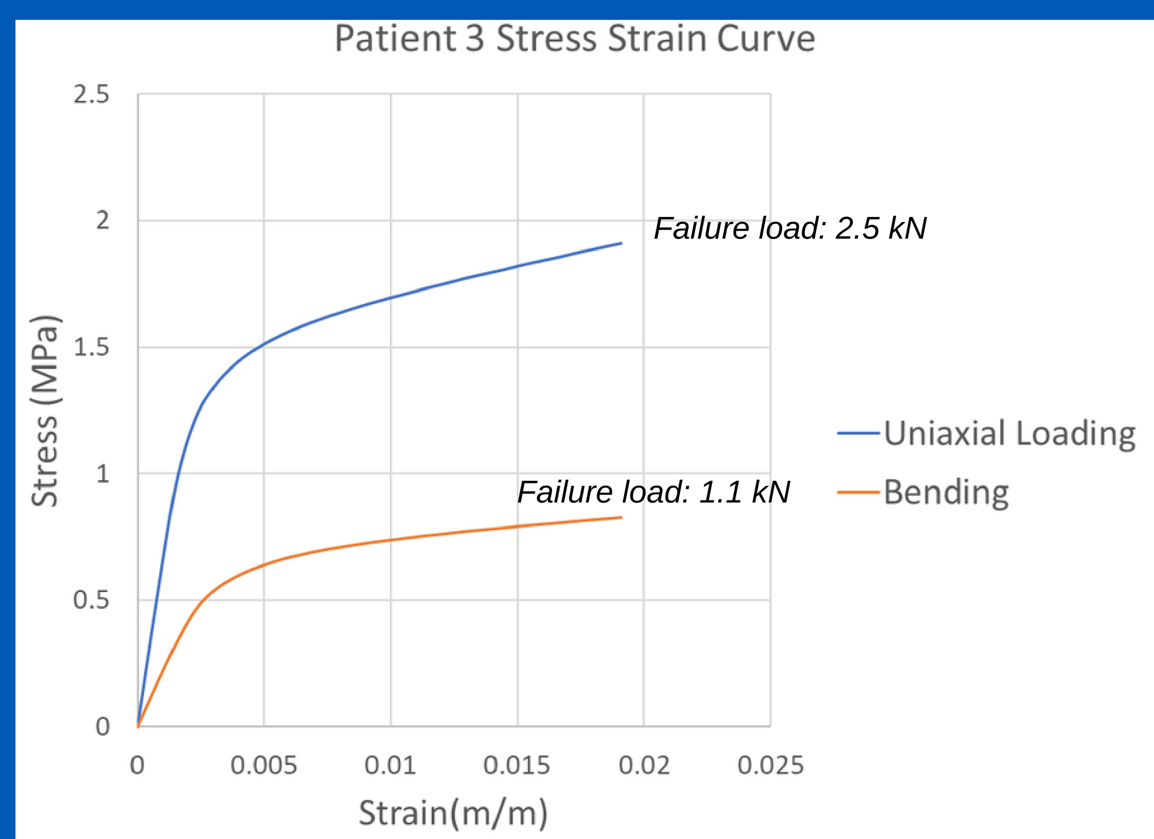
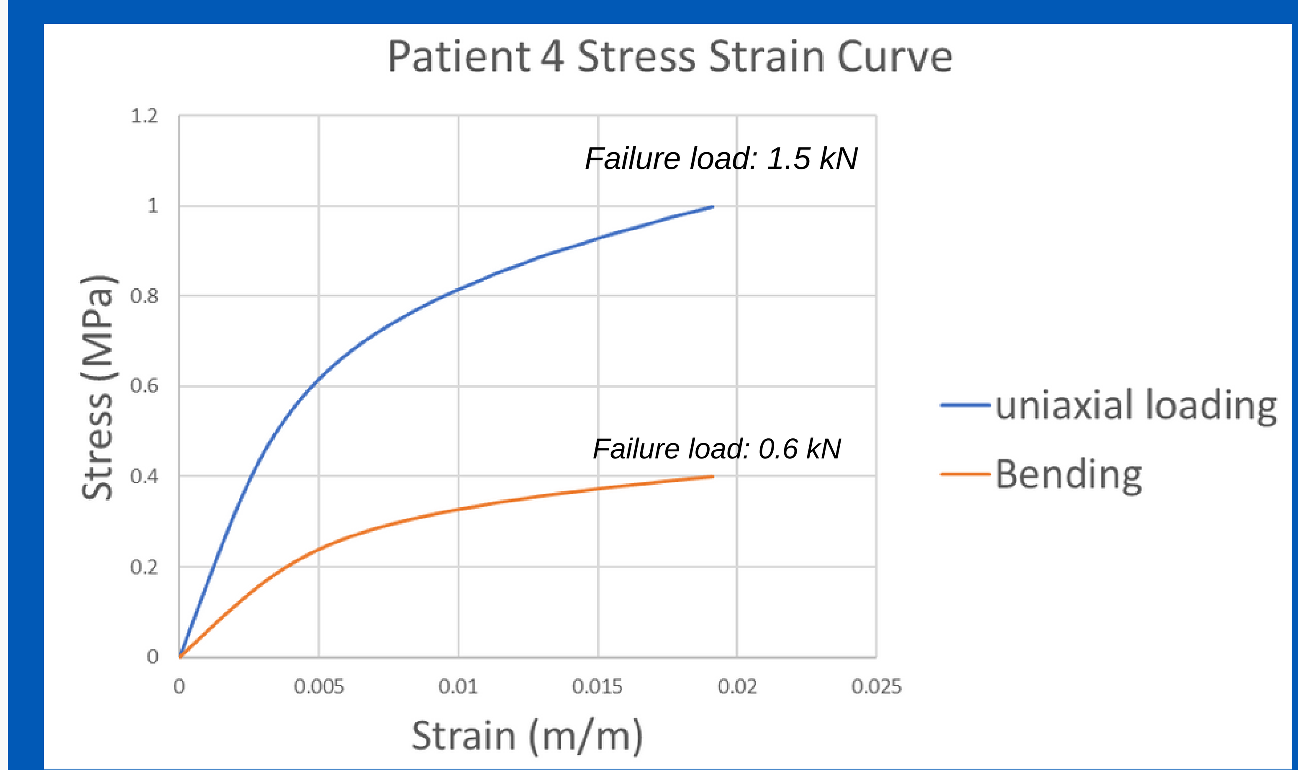


Figure 8: Patient 4 results



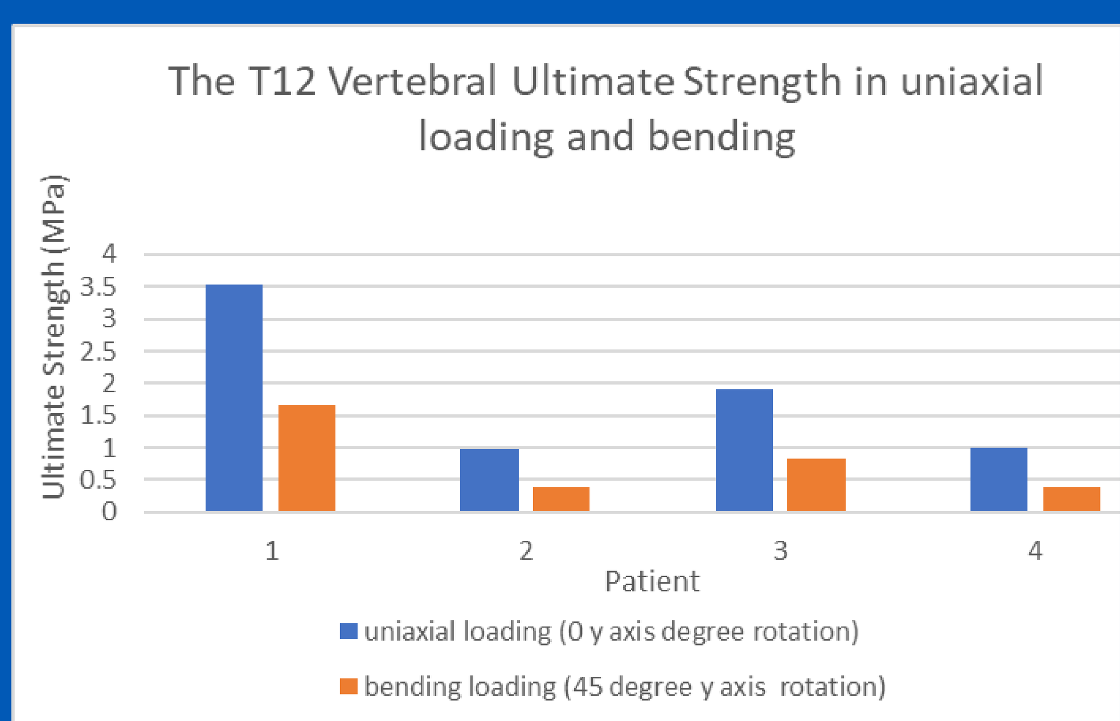


Figure 9: A bar graph showing the decrease in the ultimate compressive strength with a change in the loading conditions on the T12 vertebrae for 4 healthy participants

The ultimate strength bar graph in Figure 9 shows a general decrease in the ultimate compressive strength of the T12 vertebral body for the 4 participants studied from uniaxial compressive loading to forward bending loading. The stress-strain graphs in figure 5 to 8 show that for the same applied load, there are greater strains in bending than uniaxial loading with the maximum stress the vertebrae can withstand before failing being lower in forward bending. The ultimate strength paired t-test for the 4 participants gave a p-value of 0.0408 showing that the change in ultimate strength with a change in the loading condition is statistically significant. This is shown by the lower failure loads in bending for the 4 participants in Figures 5, 6,7 and 8.

CONCLUSION

Based on the 4 participants studied, the vertebrae are weaker in bending which is consistent with what has been reported in the literature[6, 7]. The limitation of this study is that it is a single vertebral model that does not account for the whole spine, muscle force contributions, and fixed support that does not account for intervertebral disk material properties.

REFERENCES

[1] P. McDonnell et al, Medical Engineering & Physics, vol. 32, Jul 2010

[2] E. Schileo et al., Journal of Biomechanics, vol. 41, no. 11, pp. 2483–2491, Aug 2008

[3] E. F. Morgan et al, Journal of Biomechanics, vol. 36, no. 7, pp. 897–904, Jul 2003

[4] E. F. Morgan and T. M. Keaveny et al, Journal of Biomechanics, vol. 34, no. 5, pp. 569–577, May 2001

[5] G. L. Niebur et al et al., J Biomech, 33,(12):1575-83, Dec 2000

[6] A. G. Bruno et al, Journal of Bone and Mineral Research, vol. 32, no. 6, pp. 1282–1290, Mar 2017

[7] A. Rohlmann et al., PLoS ONE, vol. 9, no. 5, p. e98510, May 2014

[8] D. Ignasiak et al, Journal of Biomechanics, vol. 70, pp. 175–184, Mar 2018

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