Too Much Stress Will Strain Your Brain

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Introduction

- Millions of people sustain **traumatic brain injuries (TBIs)** every year, which can lead to long-term disabilities [1]
- Injury is caused by brain compression after it hits the skull, leading to deformation; no head contact is needed [2]
- **Unconfined compression tests (UCTs)** are performed to understand the mechanical properties of brain tissue [3] and to extract material properties that can be used to understand the tissue deformation in various loading conditions [4]
- The brain's mechanical behaviour under rapid-rate compression is not well understood [1]

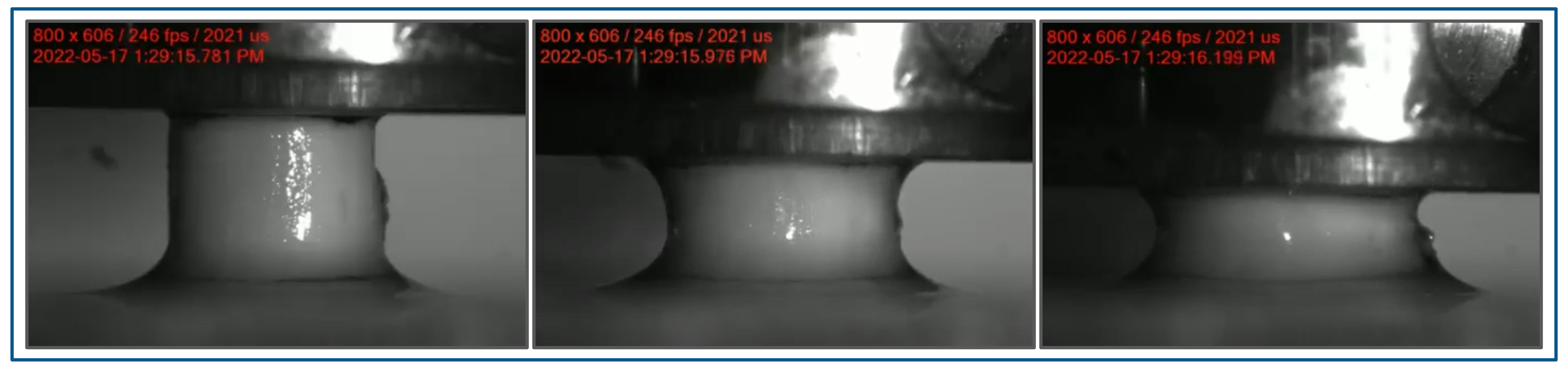

Figure 1. Images captured during compression experiment of temporal lobe tissue sample [3]

Figure 2. The Mach-1 used in compression experiment [3]

Terminology used in this study:
UCTs use compression to study the sample and are considered unconfined as they allow the sample to expand perpendicularly to the force • **Stress** is a measure of the internal forces developed when a body is subjected to external forces • **Strain** is a measure of the deformation of a body • **Young's modulus** is a measure of a material's stiffness calculated using stress over strain • **Poisson's ratio** is a measure of a material's compressibility calculated using lateral over longitudinal strain and can be seen as a measure of the change in volume

Objective

- Seek to determine the best Hookean material model parameters for describing the experimental rapid-rate compression of temporal lobe tissue
- Produce an accurate computer model — can help predict the brain's response to injuries, allowing for the development of improved protective equipment and treatment [1]

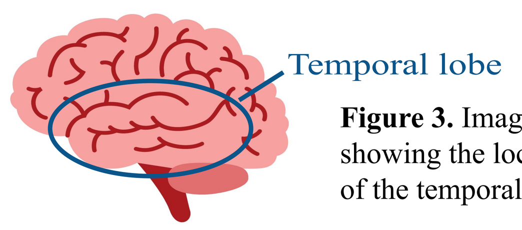

Figure 3. Image showing the location of the temporal lobe

Methods

EXPERIMENT SETUP

This study's reference data was acquired from previous experiments [3] — UCTs were performed on two temporal lobe tissue samples (6 mm diameter, 4 mm height) at a rapid rate (2 mm/s) for a displacement of 1.6 mm (40% strain) using the Mach-1. A 3D mesh model was created in FEBio Studio [5] to simulate the temporal lobe tissue samples and used to run the model experiments.

THE REFERENCE DATA

To keep it in the same range as the experiment results, the strain values closest to the averaged experimental strain values were used for all the x-axes. The corresponding stress values of the reference strain values were used for graphing

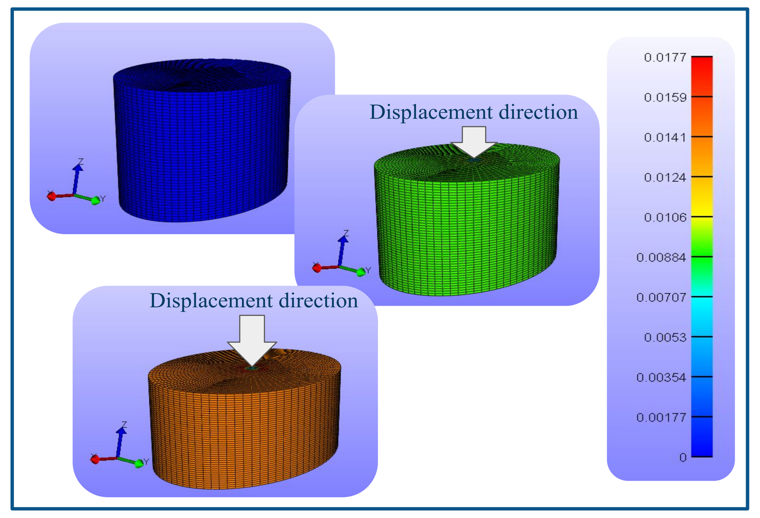

Figure 4. Images showing the effective stress during a simulated experiment in FEBio Studio (the scale is in MPa).

HOOKEAN MATERIAL MODEL

Chosen because it is commonly used when starting to model brain tissue [6]. Assigned to the mesh model, allowing for the modification of Young's modulus, Poisson's ratio, and density

GOOGLE SHEETS

Used to record and graph the experiment results, to average the data for choosing the x-axis, and to graph the reference data for easy comparison.

MODEL PARAMETERS

Modified to observe their effect on the model.

In practice, Poisson's ratio ranges from 0.30 to 0.50 [6], but FEBio Studio would not run the experiment with Poisson's ratio at 0.50, so the range was changed to 0.30 to 0.49

When not specified, Young's modulus, Poisson's ratio, and density were set to 0.10 MPa, 0.45 and 1.081E-06 kg/mm^3, respectively — these parameters were acquired from referencing literature and used as the default [6]

This study focused on results from modifying Young's modulus and Poisson's ratio because changing the density offered little variance and density is easier to measure directly, meaning that the values in literature are less based on assumptions

Results

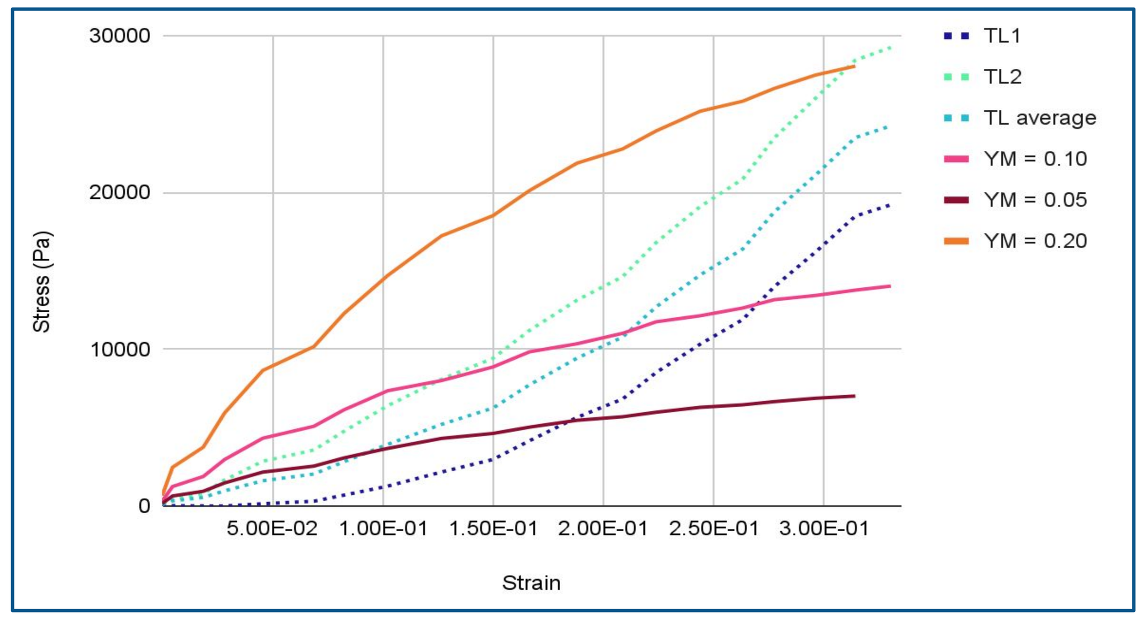

Figure 5. Stress-strain graph comparing results of 0.05, 0.10, and 0.20 MPa Young's modulus values (YM) with the reference data (TL1, TL2, TL average).

- Increased stress results in increased strain, meaning that the stiffness increases — this applies to **Figure 5**, **Figure 6**, and **Figure 7**
- A higher Young's modulus value results in a curve that is more steep, and the change in slope is relatively proportional to the change in the Young's modulus value — this applies to **Figure 5** and **Figure 6**
- YM = 0.10 follows TL2 for more values than YM = 0.05 follows TL average, then they both deviate
- The endpoint of YM = 0.20 coincides with TL2's

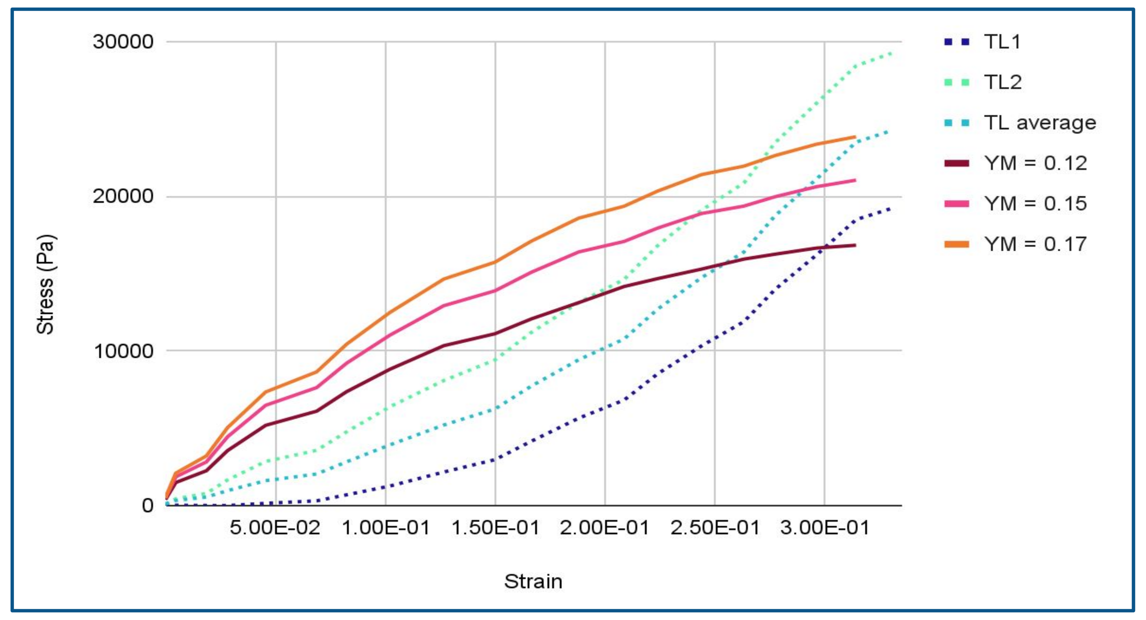

Figure 6. Stress-strain graph comparing results of 0.12, 0.15, and 0.17 MPa Young's modulus values (YM) with the reference data (TL1, TL2, TL average).

- All experiment trends follow the reference data then deviate
- The difference between YM = 0.12 and the reference data is less than the other two, but YM = 0.17 follows it for more values of stress and strain than the other two
- YM = 0.15 follows the reference data for more values than YM = 0.12, and there is a smaller difference between YM = 0.15 and the data compared to YM = 0.17

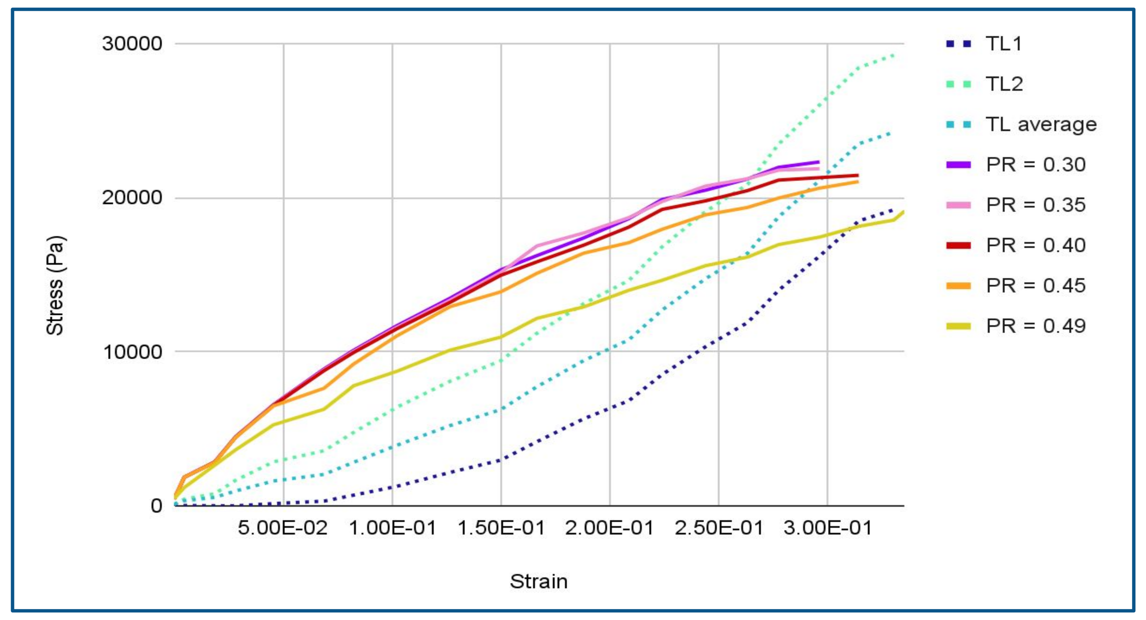

Figure 7. Stress-strain graph comparing results of 0.30, 0.35, 0.40, 0.45, and 0.49 Poisson's ratio values (PR) with the reference data (TL1, TL2, TL average). All Young's modulus values are 0.15 MPa.

- An increase in the Poisson's ratio value results in a curve that is less steep, which is the opposite of Young's modulus
- The change in steepness is not proportional to the change in Poisson's ratio. Generally, the steepness decreases by greater steps each time as Poisson's ratio increases in equal steps
- Higher Poisson's ratio values are observed to flatten the curve more than lower values
- The endpoints of the experiment trends are similar to at least one of the reference trends

Conclusion

- Young's modulus values from 0.10 to 0.20 MPa allowed for a more similar trend between the model and the reference data, so values in that range could be chosen depending on the desired simulation results (i.e. smaller difference between the model and the reference values or have similar endpoints)
- A higher Poisson's ratio fit the reference data better because it resulted in a flatter and less steep curve. A higher Poisson's ratio means that the sample is not very compressible
- It is important to note that the models in this study provide for accurate simulations but tend to overpredict the results

LIMITATIONS

- The mechanical behaviour of the brain is non-linear [3], but our models use constant parameters for each experiment
- Brains are heterogeneous and exhibit different properties when measured from different directions [1]. They also vary between individuals, so the results cannot be generalized or applied to different parts of the brain [3]
- The results from this study may not be able to represent other temporal lobe tissue samples. There is evidence for this as most of the models in this study followed TL2 better than TL1 or TL average

FUTURE DIRECTIONS

- More experiments could be performed with different parameter values to improve accuracy
- The models in this study can be applied to other temporal lobe tissue sample experiments to observe whether the same trends apply and if the models fit the data
- The Ogden material model is another commonly used model for brain tissues [6]. Testing the Ogden model would allow for a comparison with the Hookean model to determine which is more accurate

References

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