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Measuring strain distributions in tendon using confocal microscopy and finite elements

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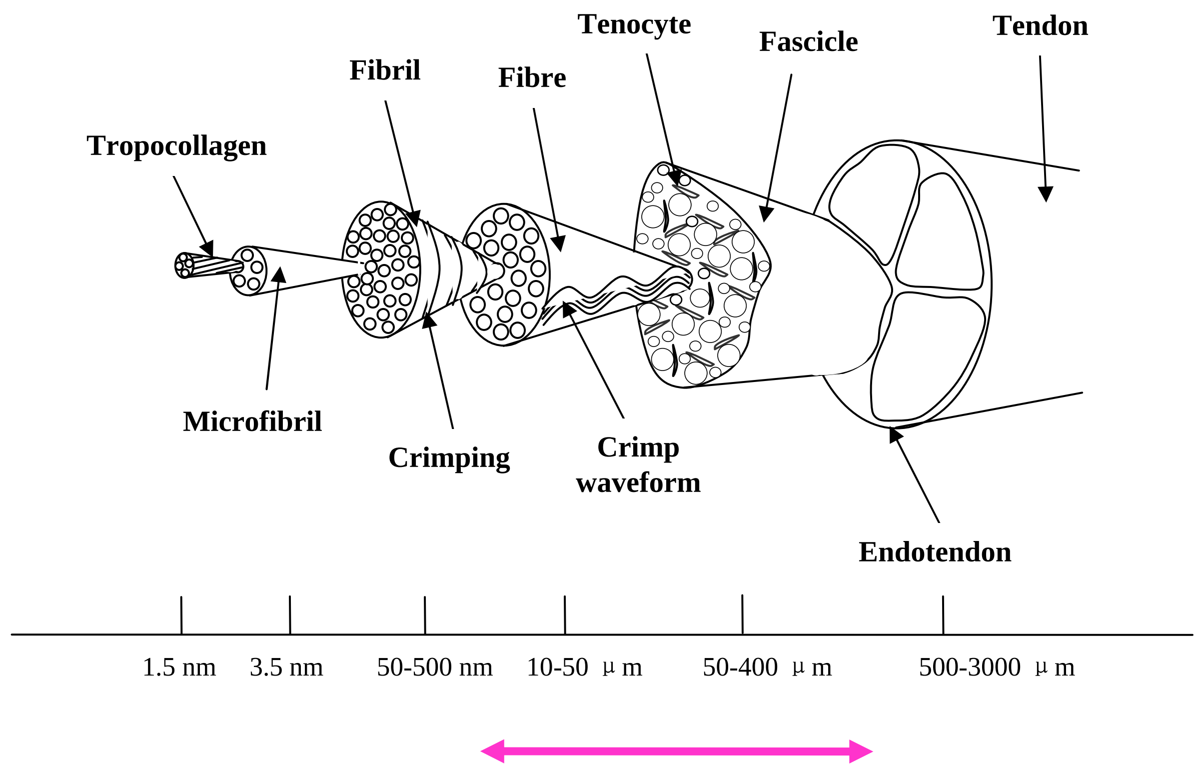
Introduction

- Tendon has a complex fibre structure
- Highly viscoelastic with sliding of fibres
- Tenocytes attached to the fibre bundles are responsible for mechanotransduction
- What strains do the tenocytes “see” during loading/relaxation?

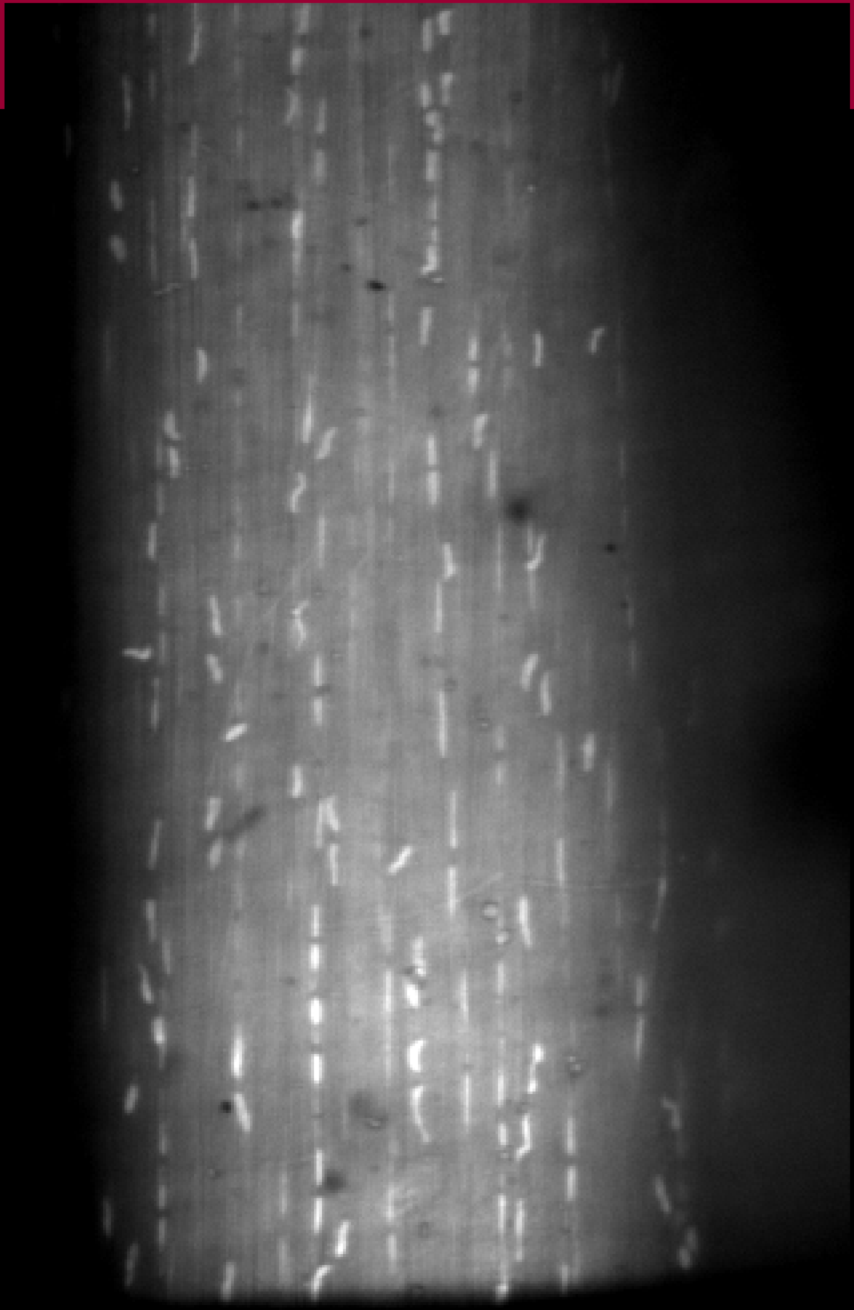
Tendon structure



Length scales visualised using confocal microscopy

Methods - experimental

- Rat tail tendon samples stained with acridine orange and loaded on the confocal microscope
- Held at constant strain (6%) and stress relaxation monitored
- Images of cells recorded during relaxation

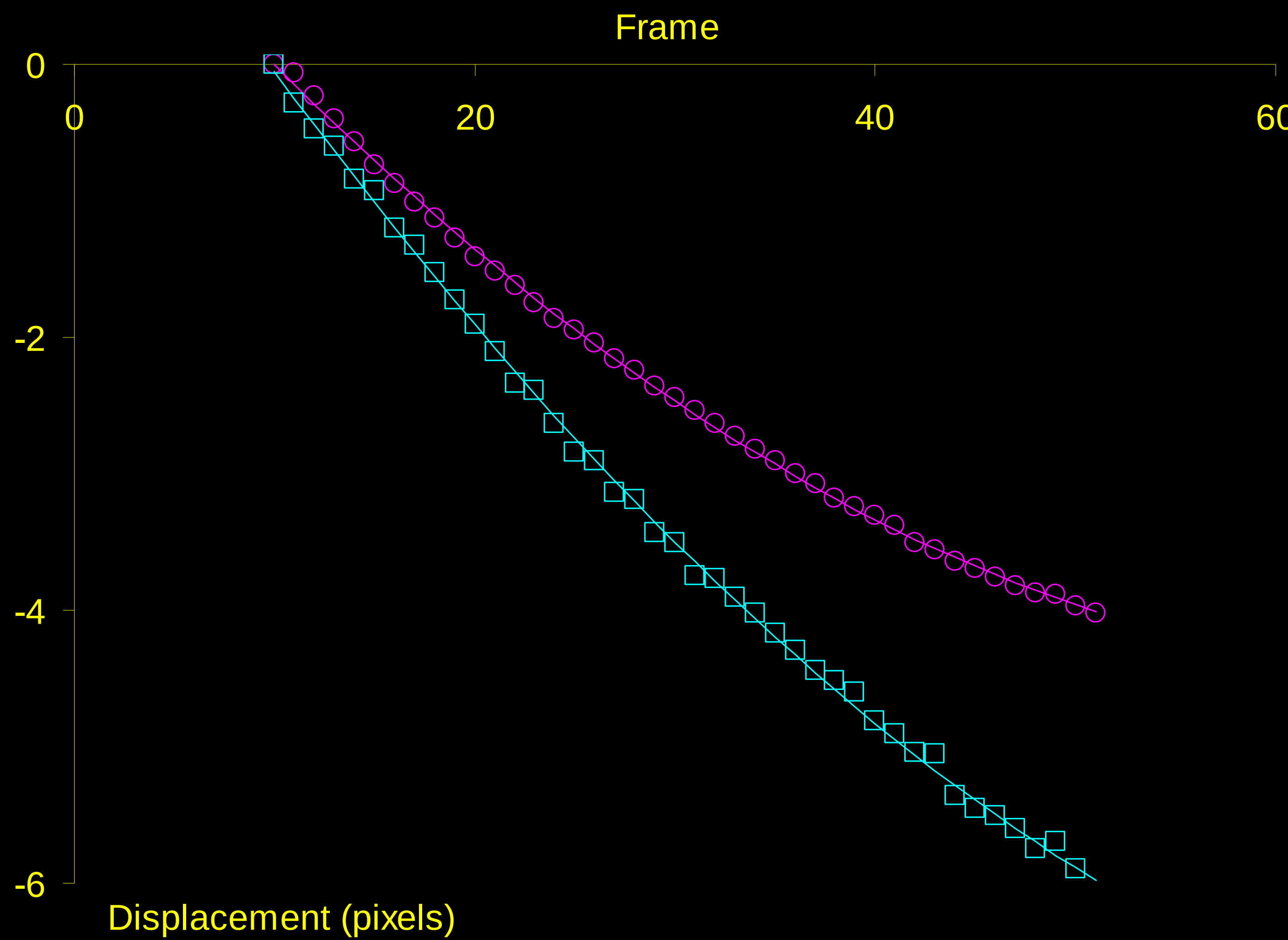


- **Cells and fibres visualised during stress relaxation at constant 6% strain**

Methods – image analysis

- Cells thresholded out and tracked using IMARIS (Bitplane, Zurich)
- Cell coordinates exported to Matlab and incomplete tracks discarded
- Tracks smoothed by fitting a second order polynomial through the data points

Cell displacements



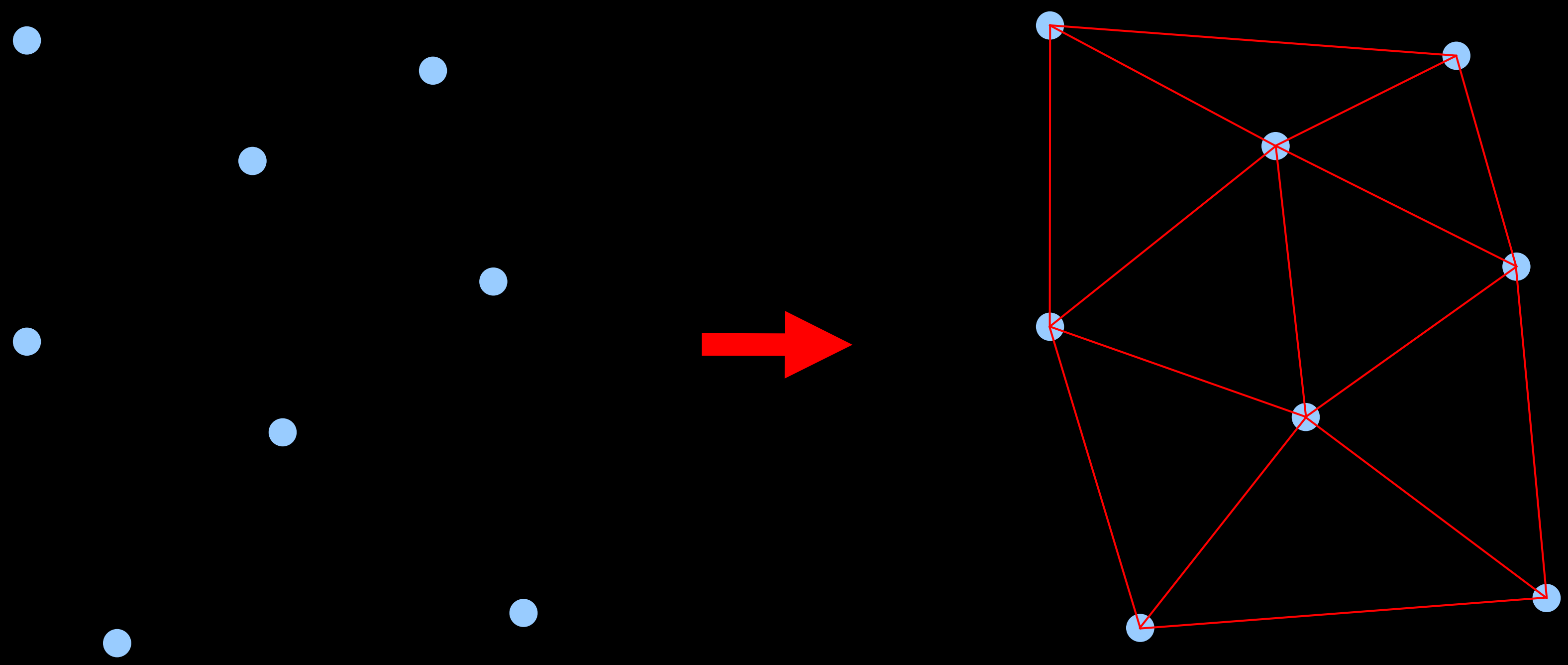
Strain calculation

- We have displacement measurements at discrete points
- Strain is the rate of change of displacement with position
- Need to interpolate the displacements between the measurement points and find the gradients

Delaunay meshing

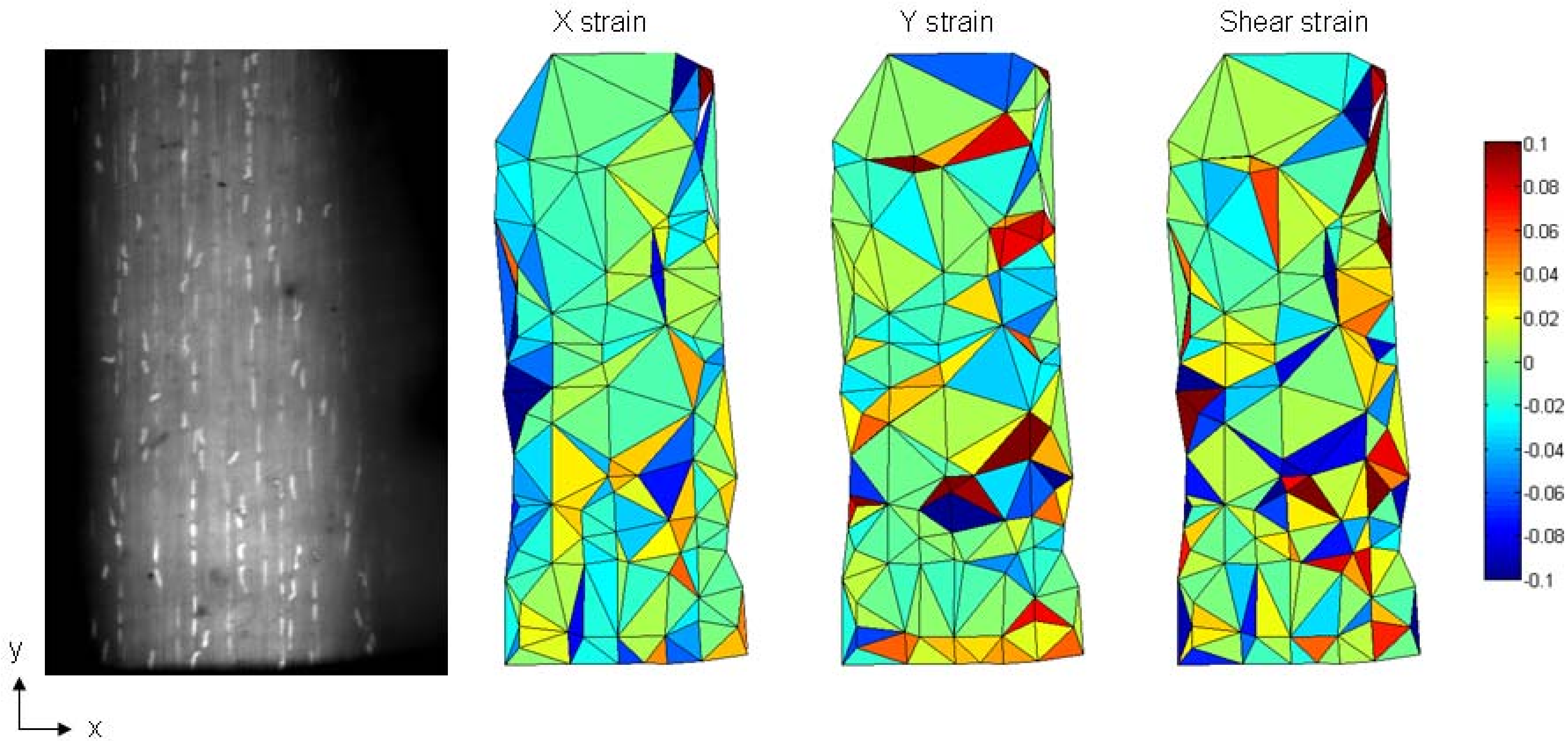
- If we take three measurement points, we can assume a linear variation in displacement between them
- Delaunay meshing always gives the best mesh of triangles joining a set of randomly distributed points
- There are still a few very long, thin triangles – these were discarded

Delaunay meshing

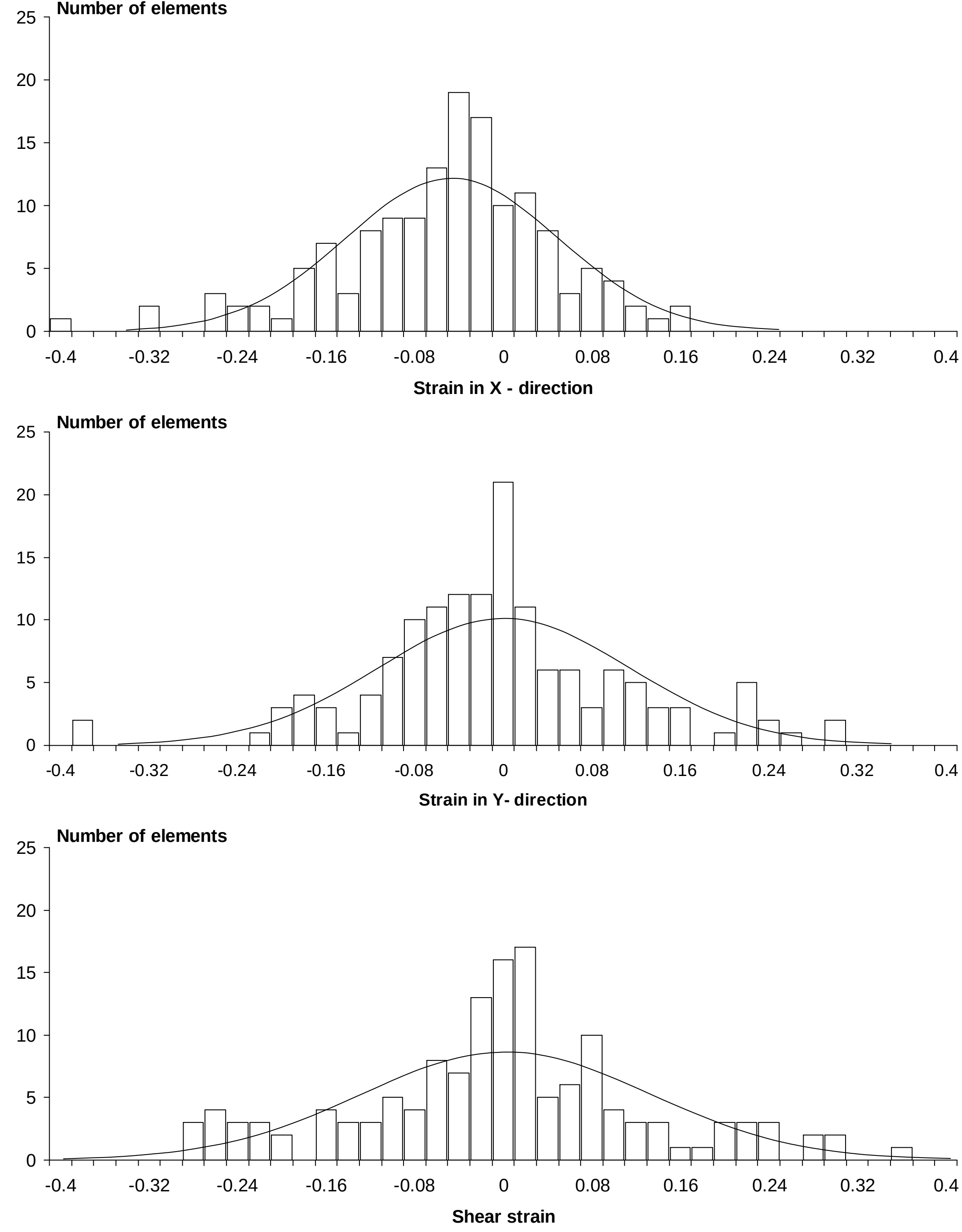


Finite elements

- The finite element method provides us with the necessary maths in a convenient form
- Calculate a B – matrix for each element
- Put the displacements in a matrix and multiply by the B – matrix to get the strains



Change in strain during relaxation



X: -0.051±0.096

Y: -0.0033 ±0.114

XY: -0.0014 ±0.131

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Discussion

- There are very large strains within the tendon during relaxation
- These are real movements of the cells, not random errors
- The fibres slide, making large strains between adjacent cells
- Contraction in x direction due to fluid loss

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Conclusions

- A good way to find strain distribution from random point displacements
- Large strain changes although the overall strain was constant
- The cells "see" very different strains from the overall strain
- The extracellular matrix is important
- Implications for mechanotransduction?

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