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Mechanical characterization of an aligned collagen scaffold by nanoindentation measurement and FE analysis

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Outline

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Numerical simulations

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Introduction

- Most biomaterials are hierarchical and have features at submicron scale or nanoscale.
- To understand the overall mechanical behaviour, it is necessary to understand the properties of these features.
- Collagen is investigated here because it is used as scaffolds for various engineered tissues (e.g. artificial skin, bone, heart valves, skeletal muscle)

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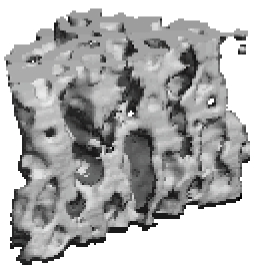
Why nanoindentation

Characterize the materials response at nanoscale

- Elastic modulus, hardness, viscoelasticity
- Fracture toughness of brittle materials



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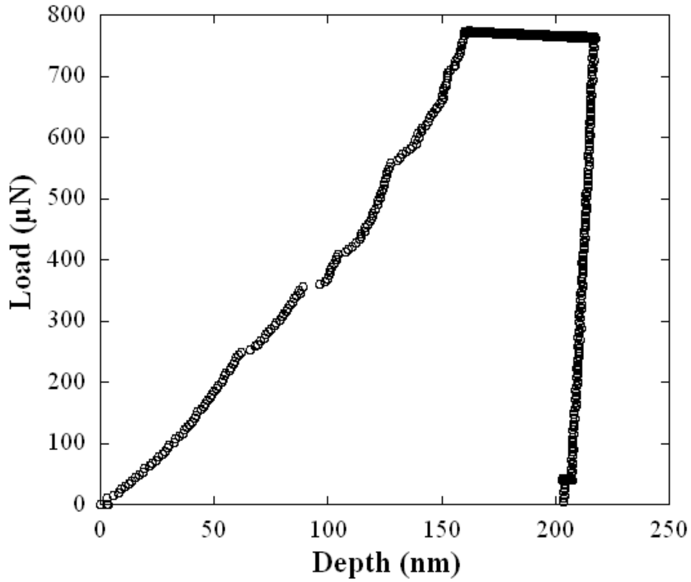
What is nanoindentation?

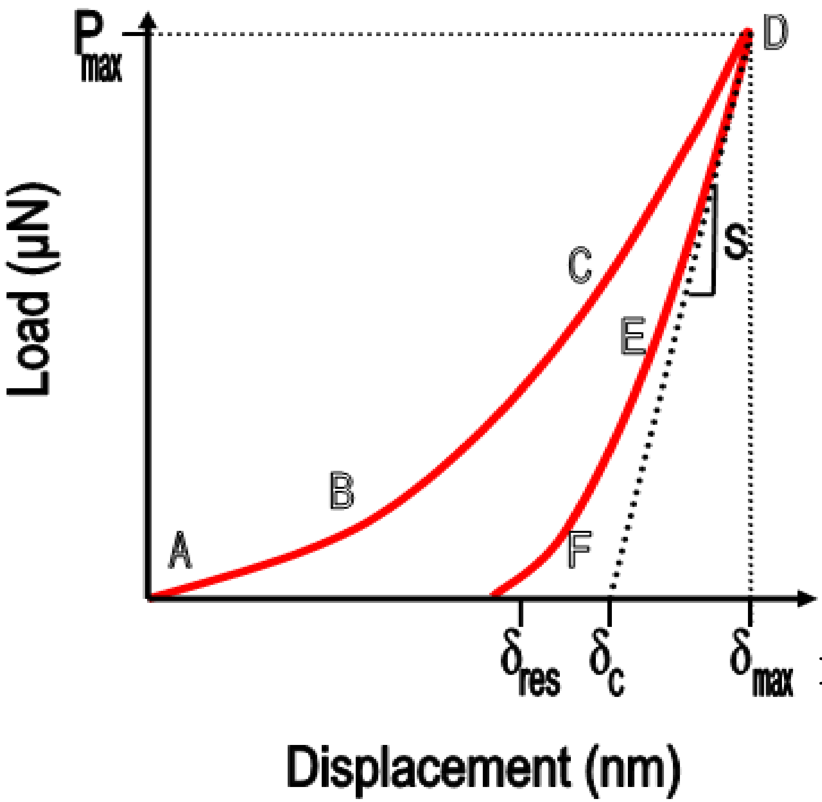
Nanoindentation is a technique in which a continuous record of the applied load and displacement is made during indentation.

The nanoindentation load-displacement curve provides a "mechanical fingerprint" of a material response.

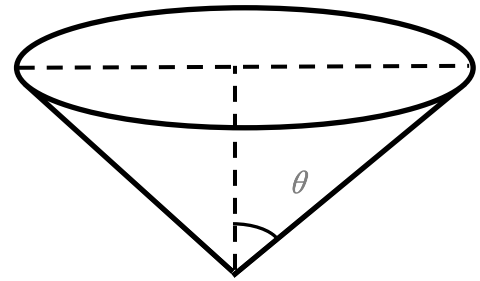


Some basic concepts

Young's modulus, E can be determined by,

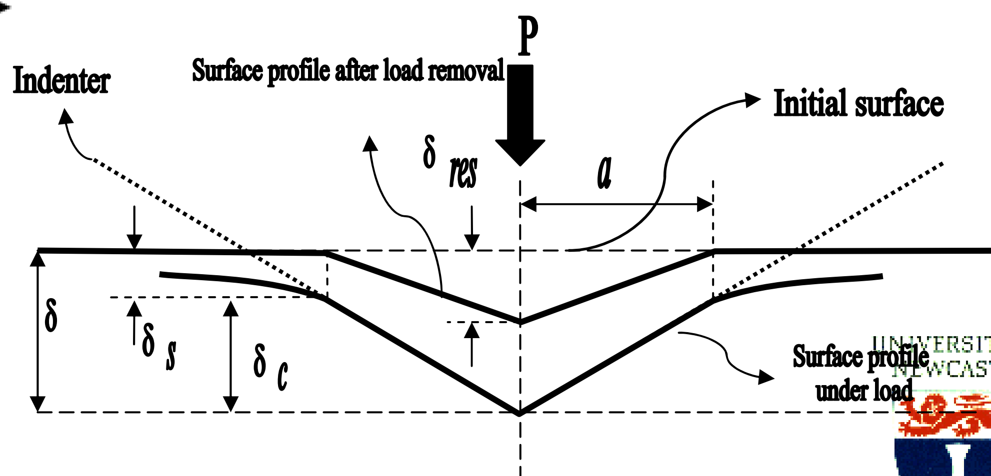


$$S = \frac{dP}{d\delta}$$



$$E_r = \frac{\sqrt{\pi} S}{2\sqrt{A_C}}$$

$$A_c = \pi \delta_c^2 \tan^2 \theta$$



Hardness: $H=P/A_c$

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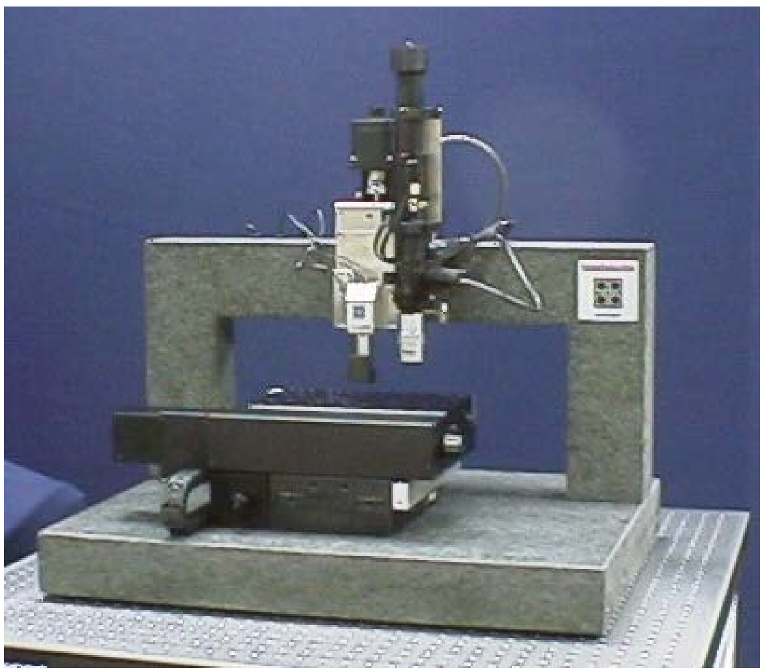
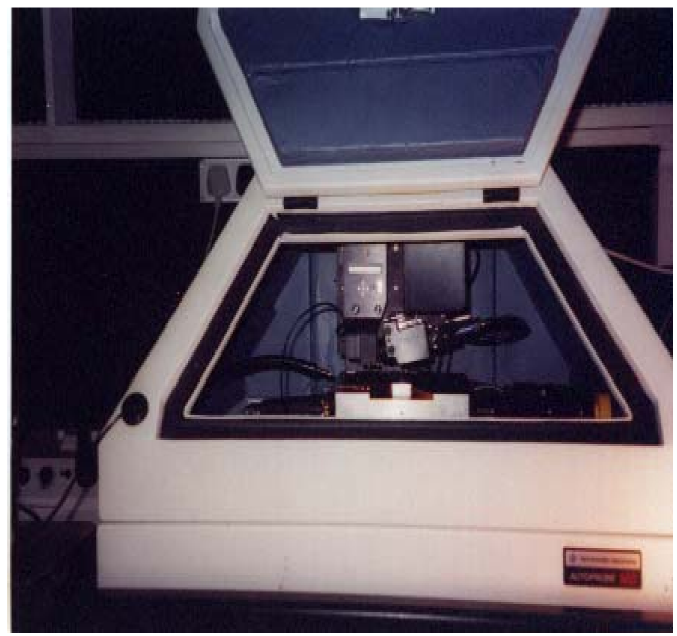
Instruments

- Hysitron Triboindenter (with in-situ AFM)

  Resolution: penetration: <0.1nm; load: 1nN

Quasi-static , nanoDMA





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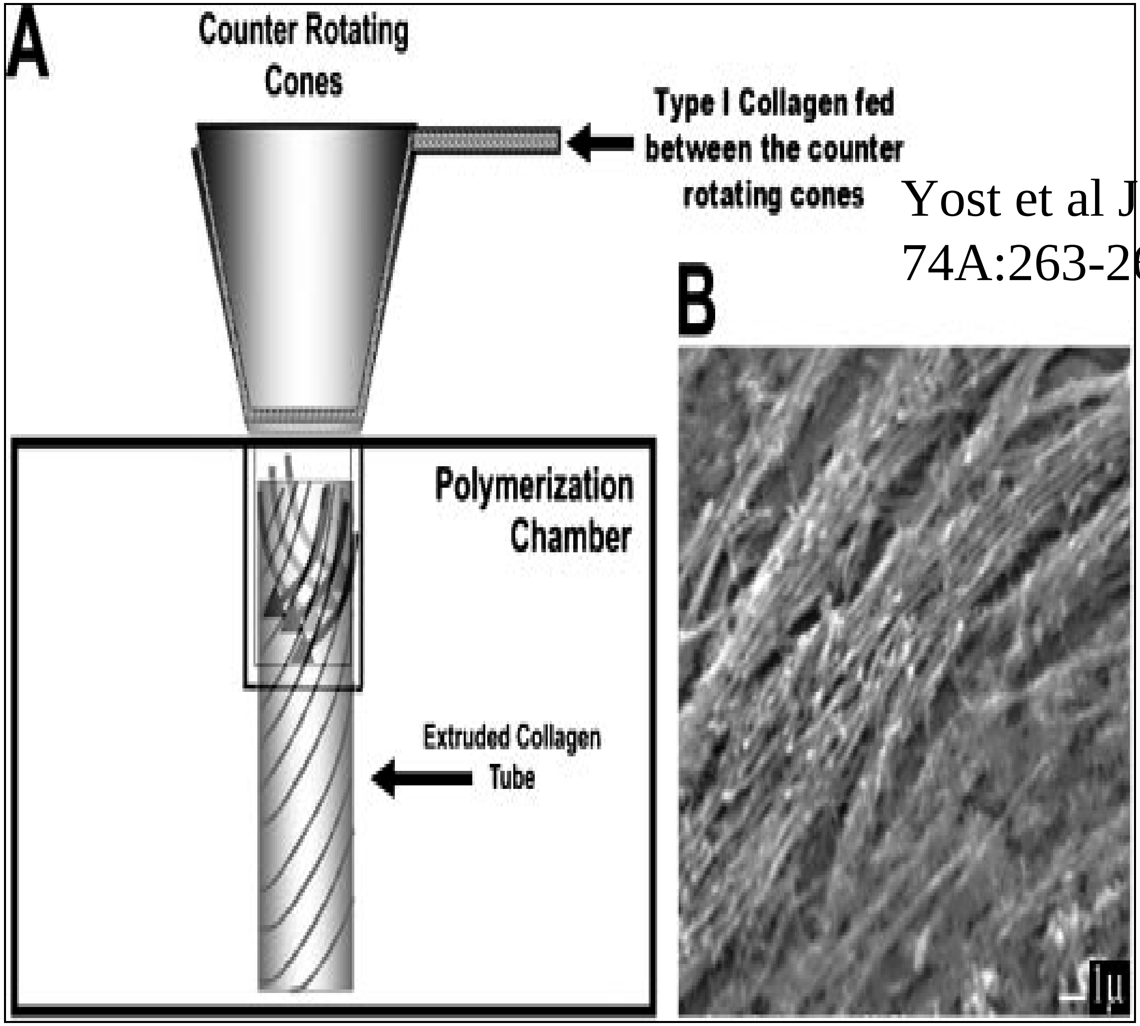
Sample preparation



Yost et al J. Biomed Res 74A:263-268, 2005

Φ=200nm

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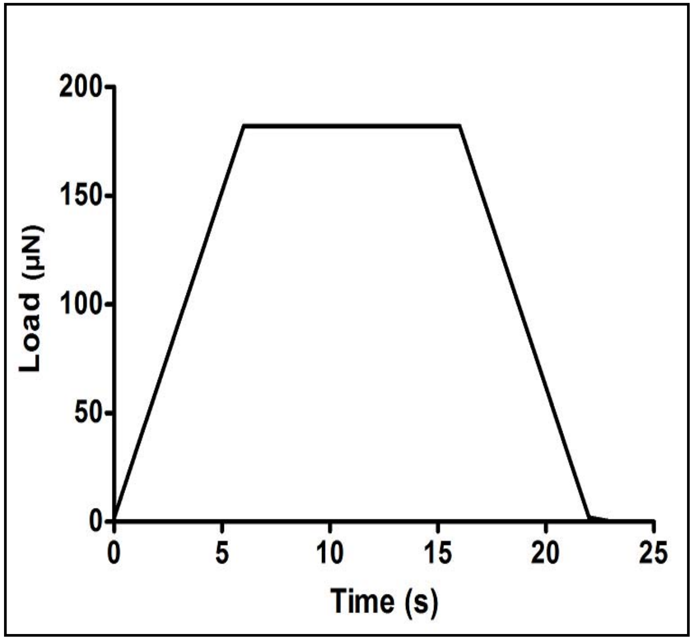
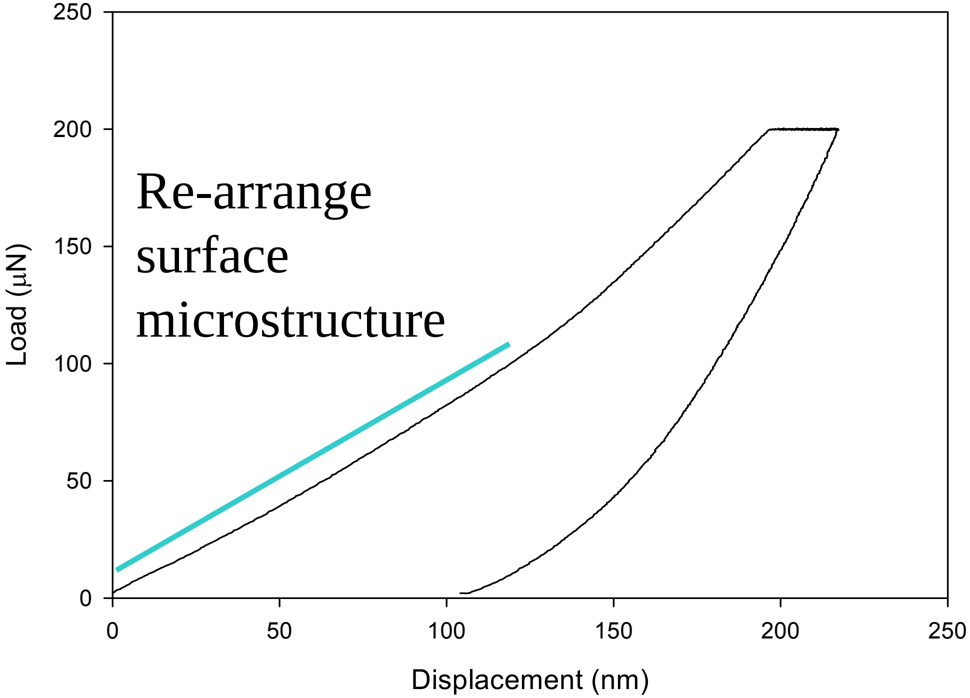
Quasi-static nanoindentation (load-control)





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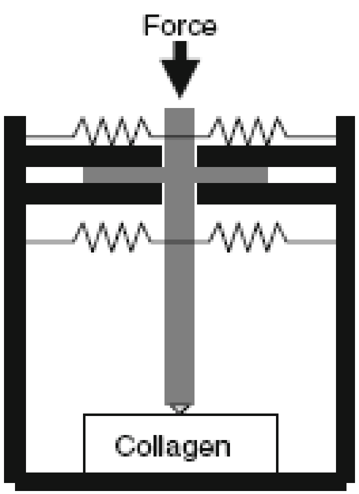
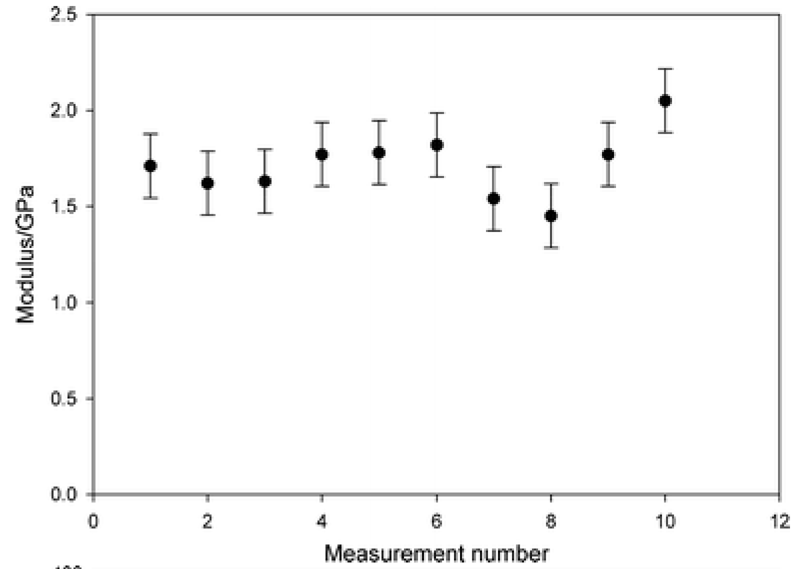
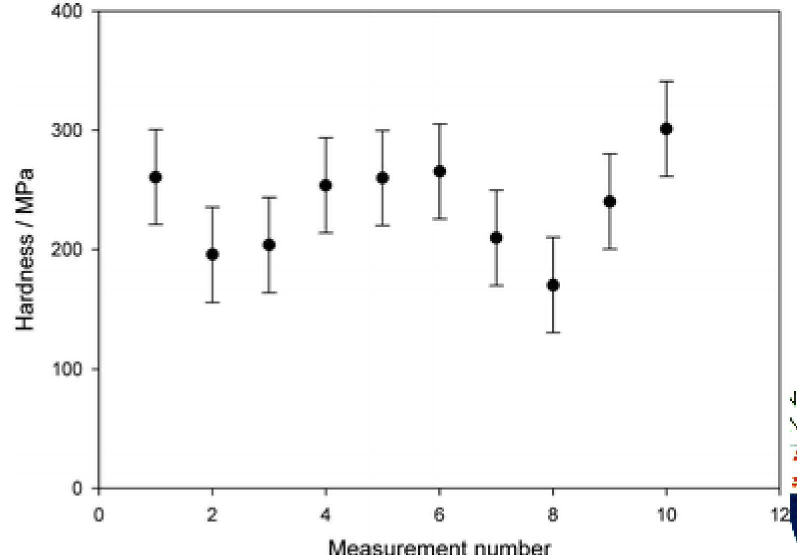
Elastic modulus and hardness

E=5~10GPa by AFM (Wenger et al, 2007)

AFM does not approach the materials surface vertically but engages in an arc . It measures the surface property







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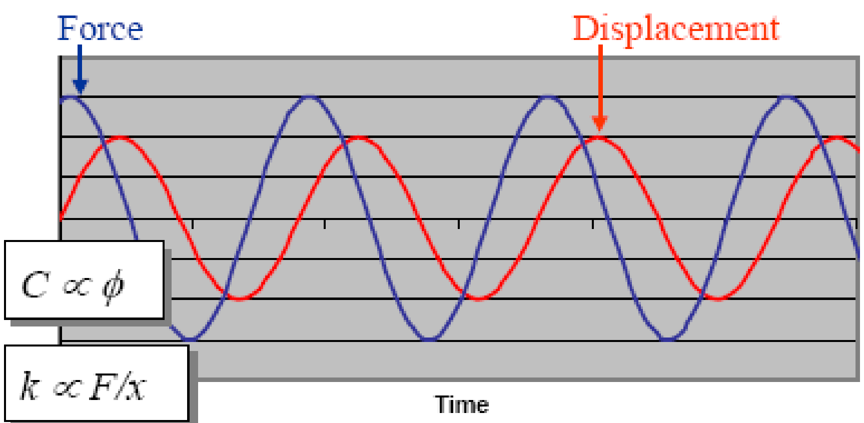
NanoDMA analysis

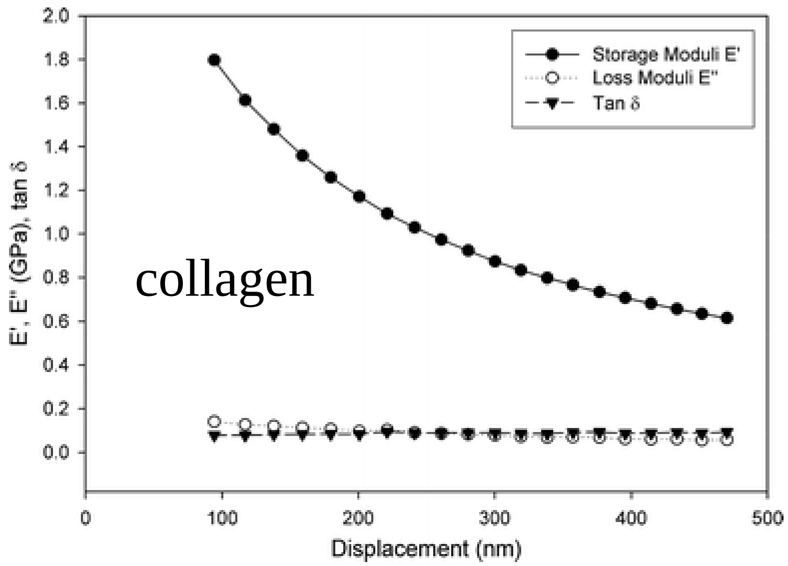
The nanoDMA technique increases the sensitivity of the instrument to provide augmented testing capabilities. The noise floor specifications in dynamic mode are seen below.

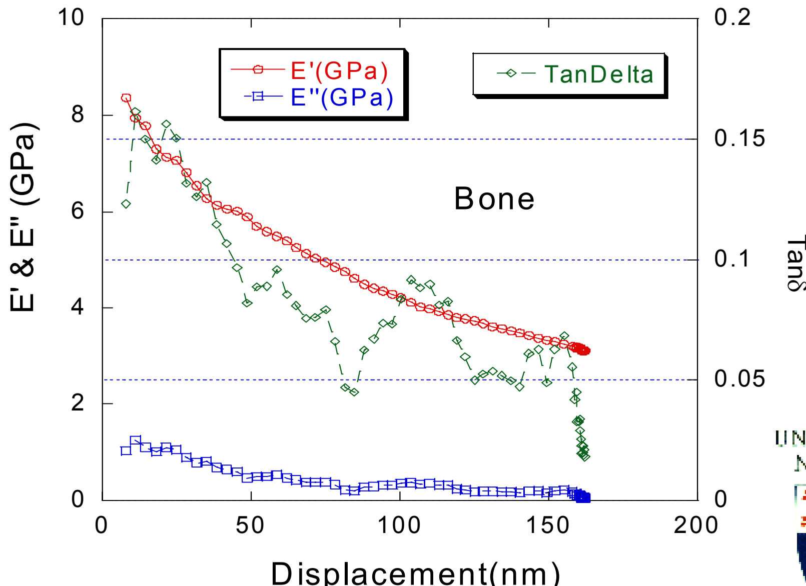
- Frequency range: 1.0-300 Hz
- Load noise floor: <100 nN
- Displacement noise floor: <1 Å



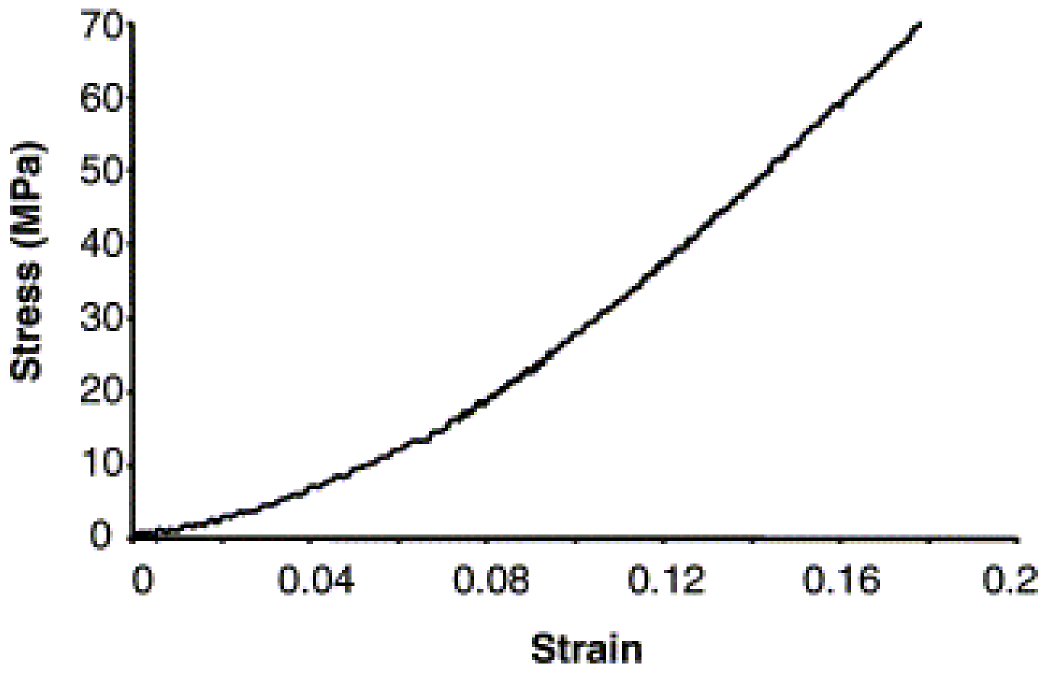
Sinusoidal loading of a viscoelastic material with the strain response lagging behind the stress

$$E' = \frac{k_s\sqrt{\pi}}{2\sqrt{A_c}} \qquad E'' = \frac{\omega C_s\sqrt{\pi}}{2\sqrt{A_c}} \qquad \tan\delta = \frac{E''}{E'}$$





Typical stress strain curve (uniaxial test) for collagen

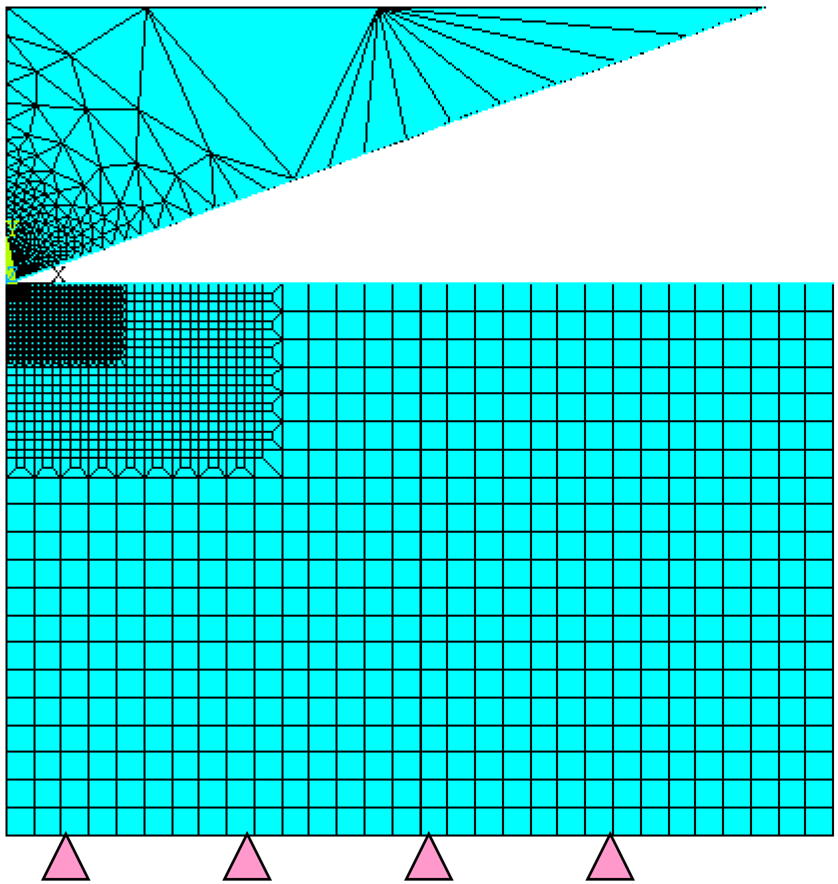


Single crosslinked extruded fibre

Gentleman et al Biomaterials 24 (2003) 3805-3813

Finite element analysis

- Model for nanoindentation



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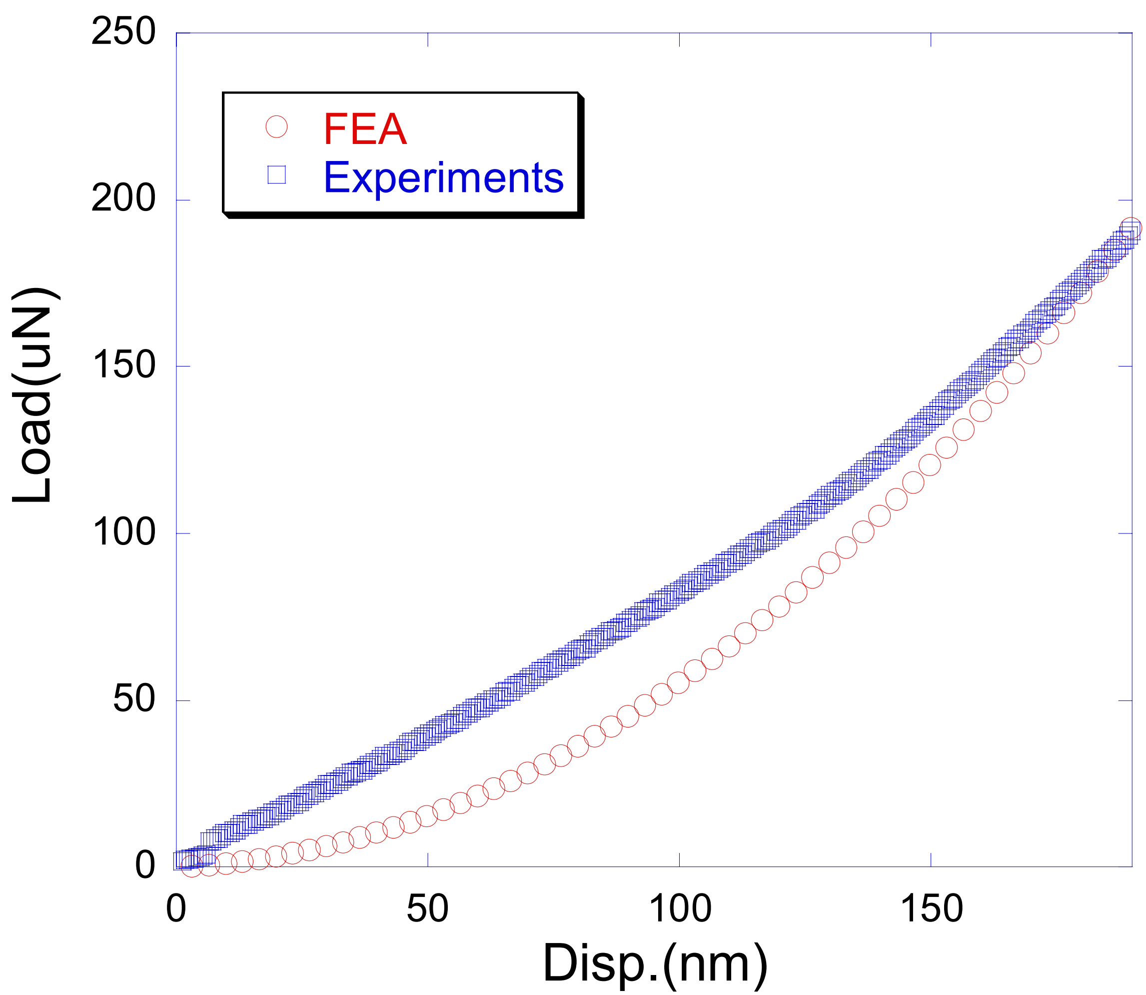
Hyperelasticity of collagen



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Conclusions

➢Nanoindentation techniques are very useful for mechanical characterization of collagen fibres.

➢Finite element analysis shows the effect of changes in surface microstructure on the meaured load-dispalcement curve

---densification of porous surface

---collagen fibre bundles acting like supported springs

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Acknowledgements

H. Ashton, A. Muhamed performed most of the experimental measurements; M. Yost, B. Chaudhry, D. Frankel, M. Birch for providing samples; S.J. Bull for useful discussions.

Thanks for attention!

Any questions?

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