Deconvolution of the Mechanical Effects in Atomic Force Microscopy Material Characterization in Living Cells

Isaac Coello Dantus, Mechanical Engineering
Mentor: Masoud Yekani Fard, Ph.D.
School for Engineering of Matter, Transport & Energy

Abstract and Motivation

Abstract

Atomic Force Microscopy (AFM) has been extensively used to determine the mechanical properties of materials ranging from ceramics to living soft tissue. There is an increasing use of AFM for the characterization of biological structures, which has resulted in new diagnostic techniques. However, the effects of cell size, substrate and inclusion presence on AFM measurements have not been exhaustively investigated. This study aims to understand these effects through Finite Element Analysis (FEA) of a size varying cell resting on a glass substrate.

Motivation

The proper measurement of a biological tissue's mechanical properties will improve modern diagnostic technics and prosthetic devices.

"Changes in mechanical properties are closely connected to disease and physiological processes."

- Efremov et. al. 2020

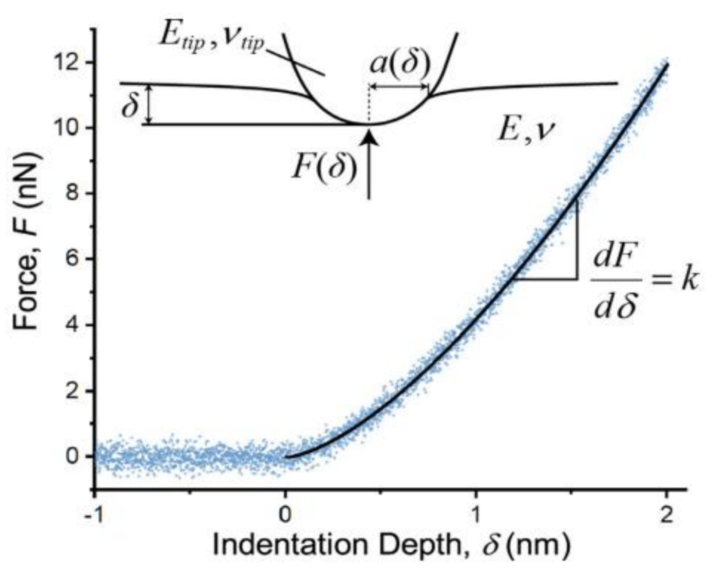

Fig. 1 Force-displacement curve example and geometry of AFM indentation.
- Collinson et. al. 2021

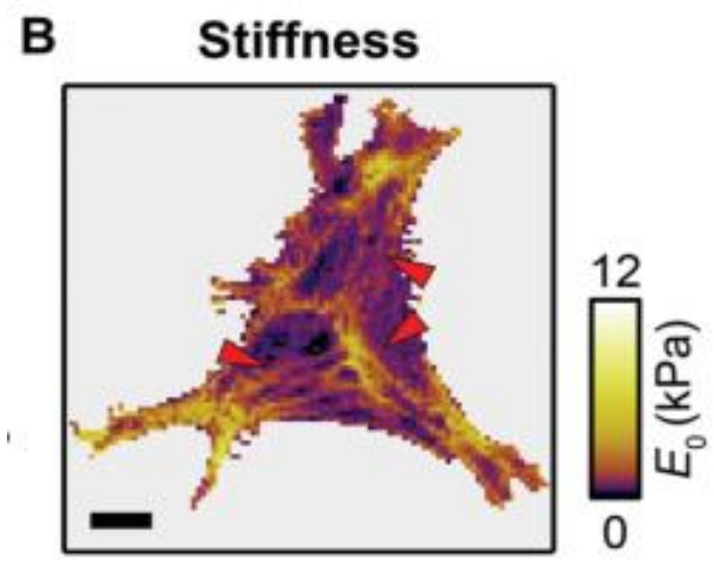

Fig. 2 Stiffness of a cell in different regions. Measured by AFM.
- Schierbaum et. al. 2019

Experimental Setup

A cell has been modeled as a cylinder with elastic modulus $E_{cell} = 4kPa$ and Poisson's ratio $\nu_{cell} = 0.495$. At this stage of research, the material remains linear and isotropic.

FEA was conducted assuming that the contact between the probe and the cell is frictionless. Displacement control was used, and the reaction force on the tip is used for the analysis.

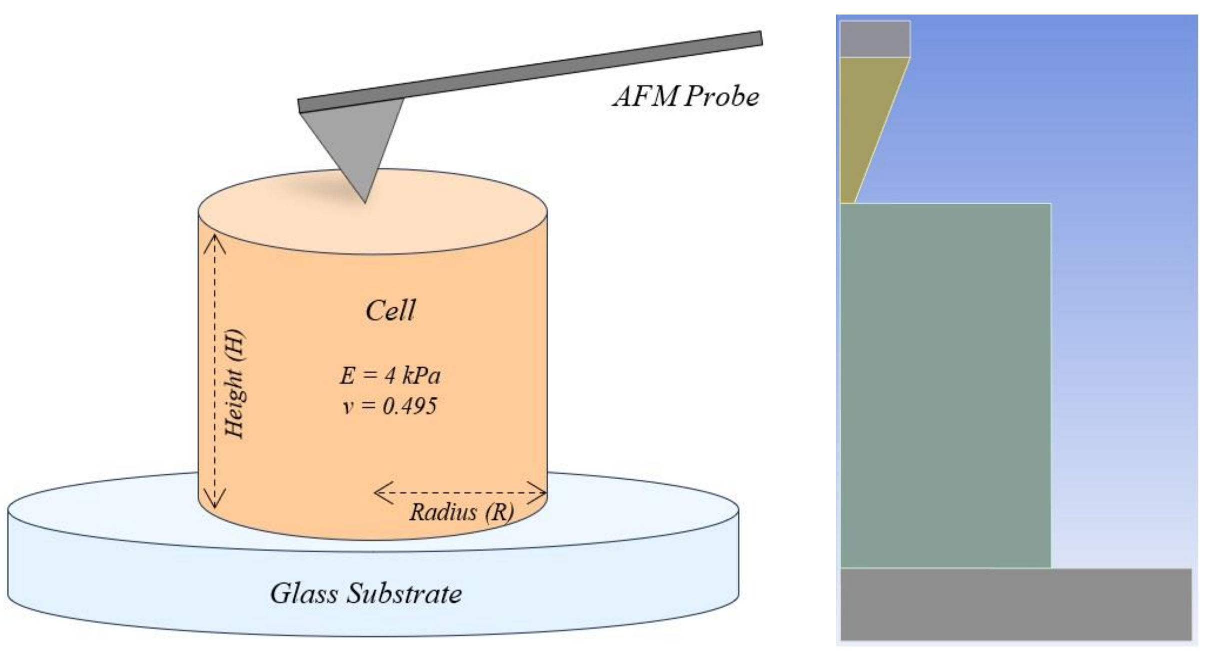

Fig. 3 Experimental setup (right) and FEA setup for cell with height of 500 nm (left).

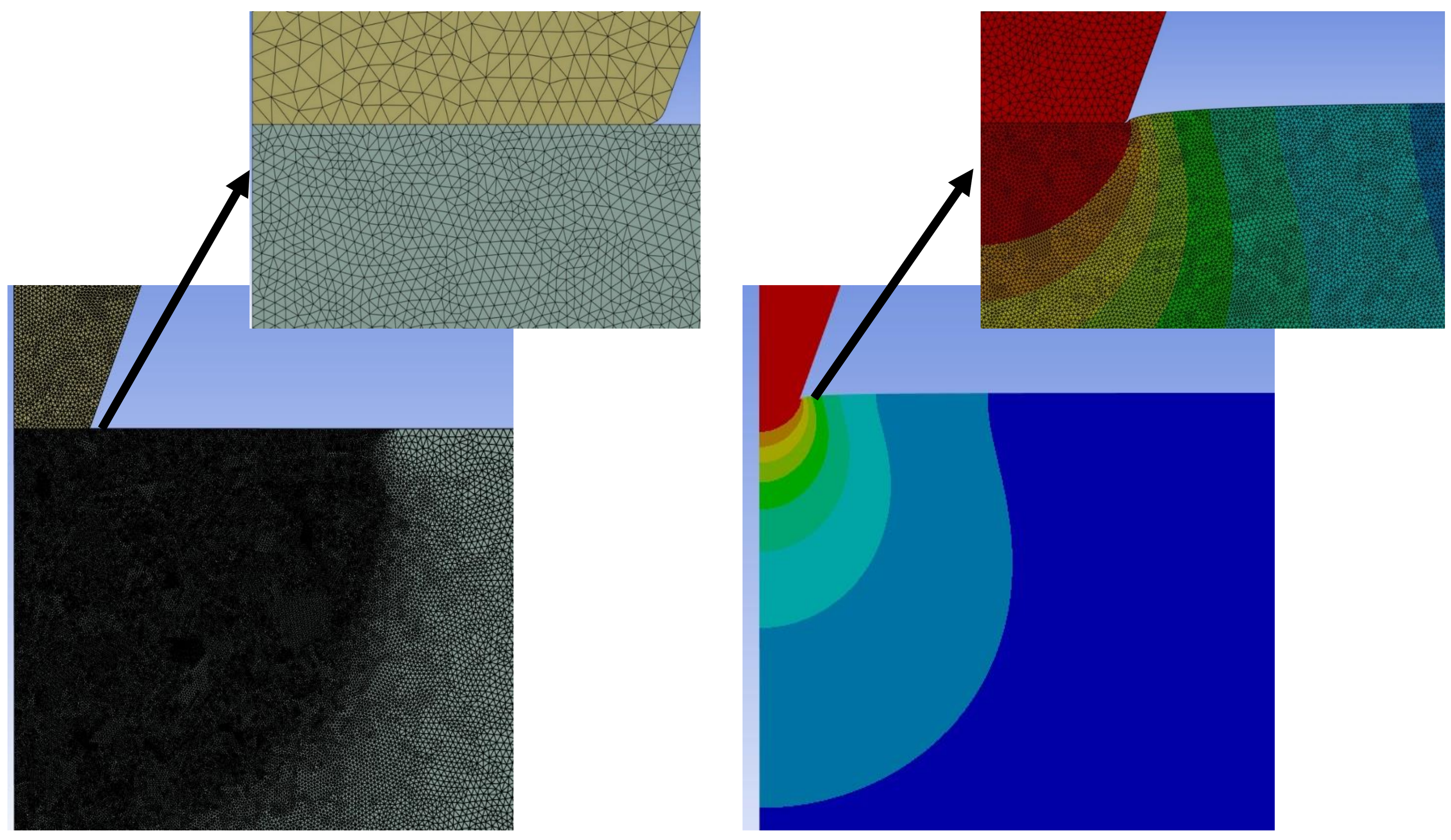

Fig. 4 FEA setup and mesh (left). Deformation contours in force control test (right).

Results and Future Work

Contact mechanics relationships used for these analysis:

$$\frac{1}{E^*} = \frac{1-\nu_{cell}^2}{E_{cell}} + \frac{1-\nu_{tip}^2}{E_{tip}}$$

$$d = a \tan\theta \arccos\left(\frac{b}{a}\right)$$

$$F = E^* \tan\theta\, a^2 [\arccos\left(\frac{b}{a}\right) + \frac{b}{a}\sqrt{1-\frac{b^2}{a^2}}$$

Where 'E*' is the effective modulus of the contact, 'b' the tip radius, 'Θ' the angle between the tip and horizontal and 'a' the contact radius.

Here only the results for a cell with height of 500nm are presented. As expected, the measured elastic modulus is close to 4kPa. Future work involves the collection of data for cells of varying height, then varying width. In this way, the effect of the substrate and size of the cell can be characterized.

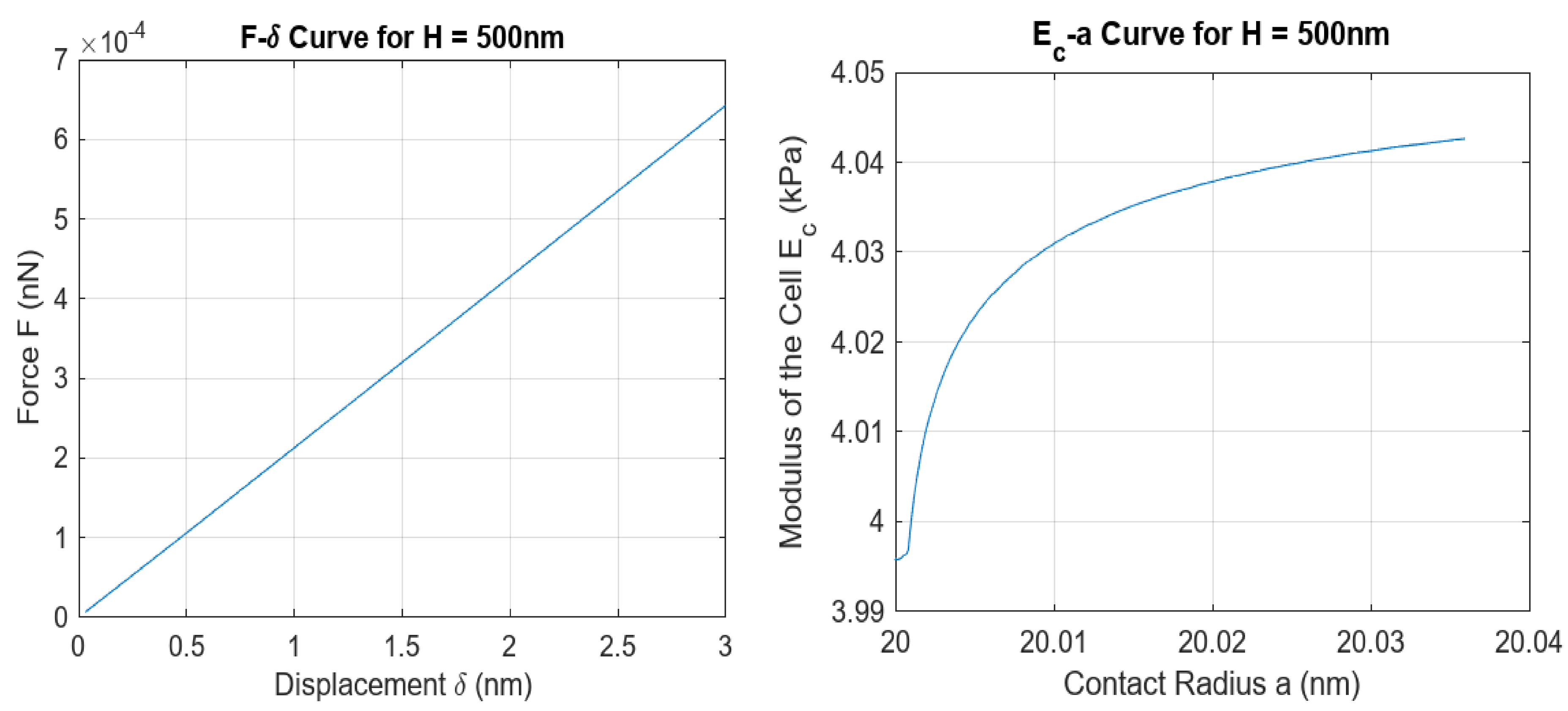

Fig. 5 Force-displacement curve for cell with height of 500 nm (left), load and unloading curves together. Measured elastic modulus vs. contact radius (right) of same indentation test.

Acknowledgements
Special thanks to my mentor, Dr. Yekani Fard, for his great and continuous support and guidance

FURI

Ira A. Fulton Schools of Engineering
Arizona State University