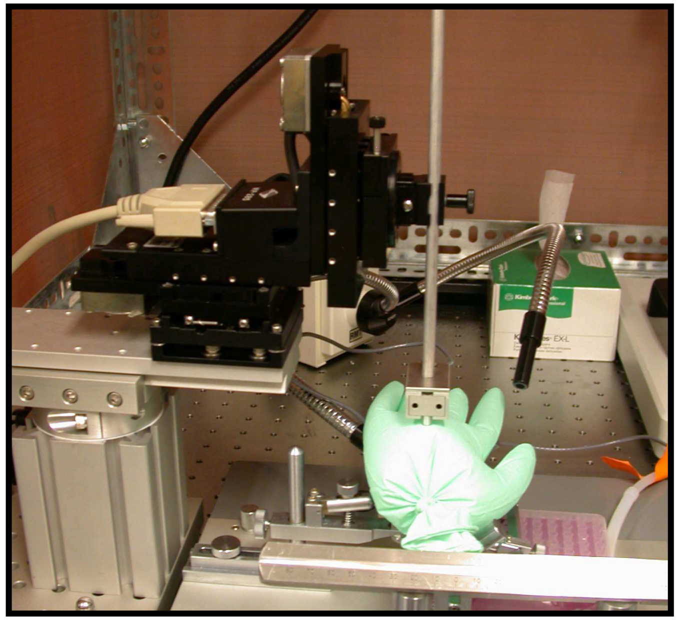
Penetration Mechanics and Mechanical Properties of Mouse Brain Tissue



CMM Brain Neuromechanics Workshop
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SIU

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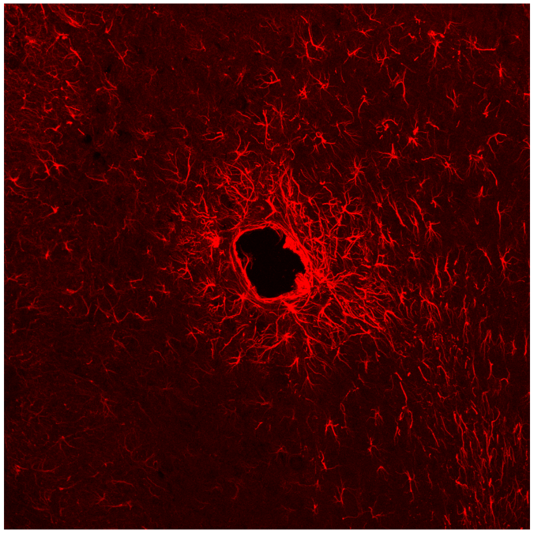
Motivation:

- Insertion of foreign objects into the brain gives rise to neuronal necrosis and apoptosis, inflammatory processes and gliosis

Goal:

- Design more biocompatible implants and implantation processes to minimize deleterious tissue responses

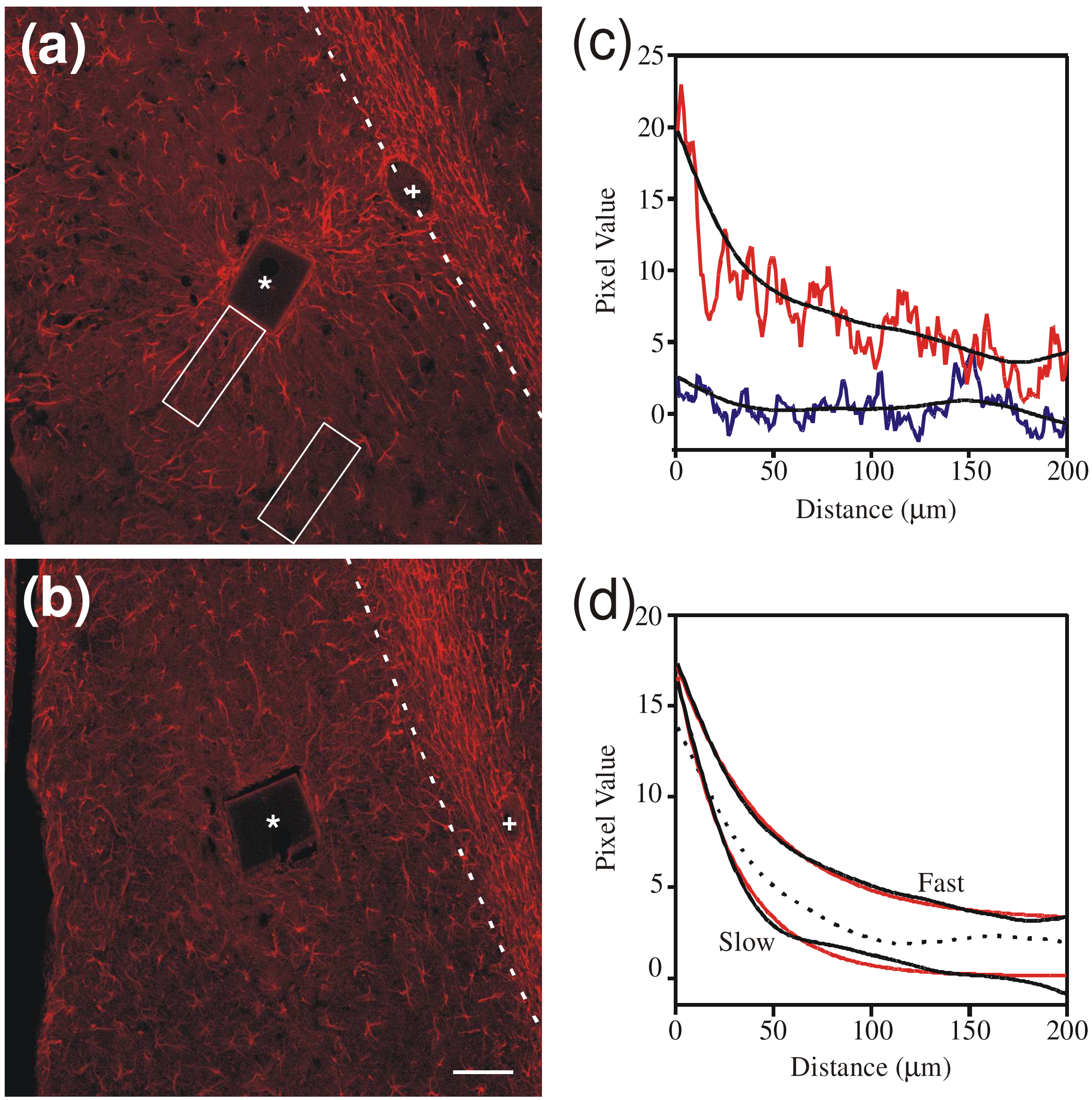


Astrocytosis caused by implantation of silicon in OB after 1 month.
Sharp et al. (2006) J. Neural Eng.

Things known to affect biocompatibility of implant:

-size
-shape
-material
-compliance
-shear from tether
-rate of insertion

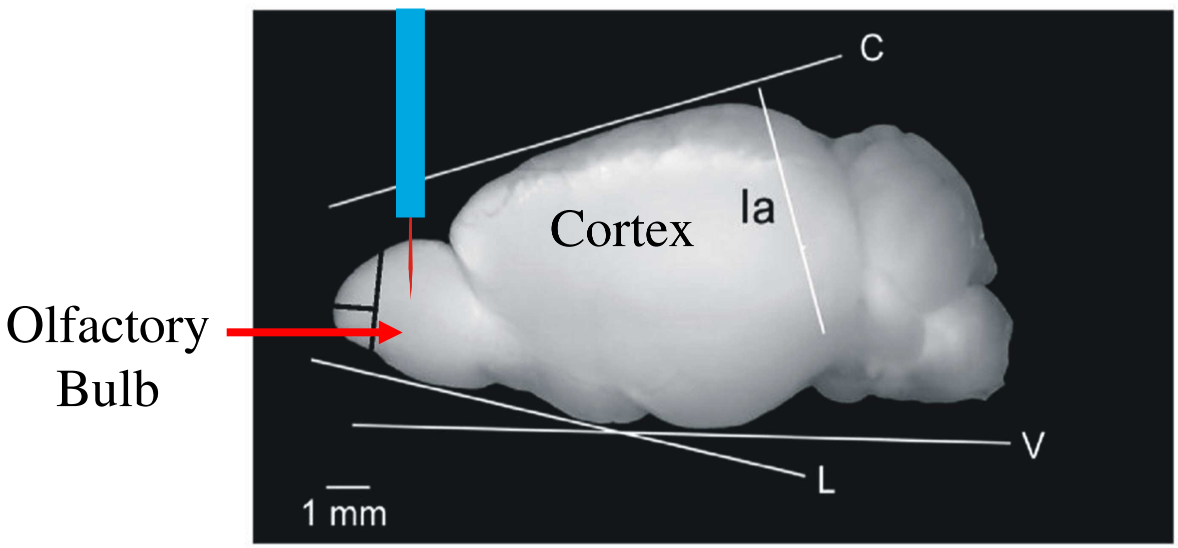
Insertion Rate affects Biocompatability



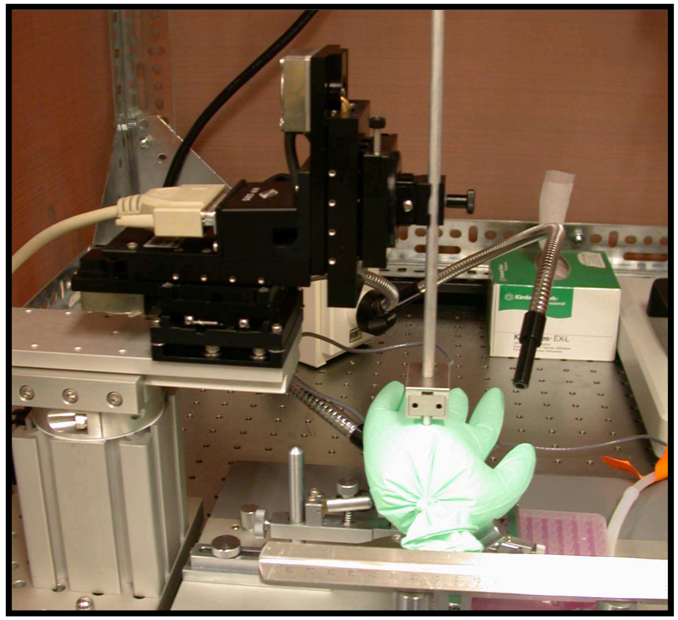
Sharp et al. (2006) J. Neural Eng.

Objective: Use compliant materials (polymers?) to engineer more “compatible/effective” implants.

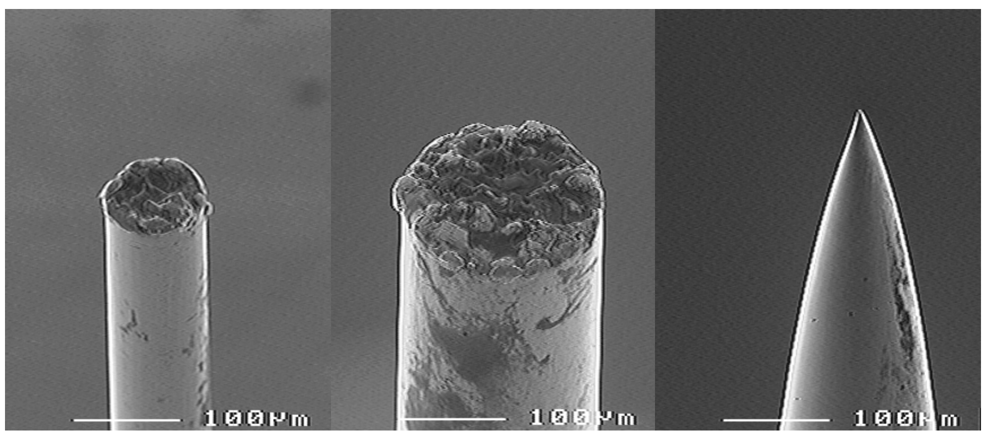
Design Issue: How stiff does the implant need to be or how much force does it need to withstand during insertion?



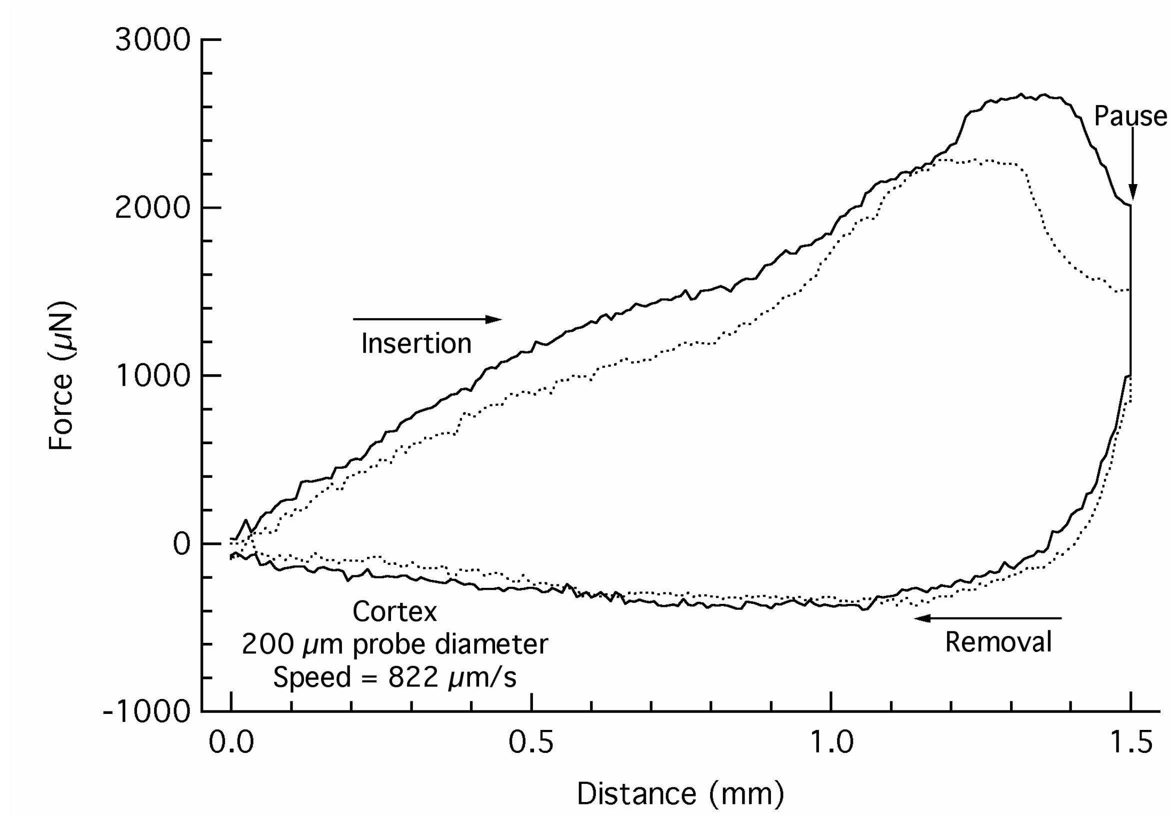
Measure Force during Controlled Insertion



Sharp et al. (2009) IEEE Trans. Biomed. Eng.



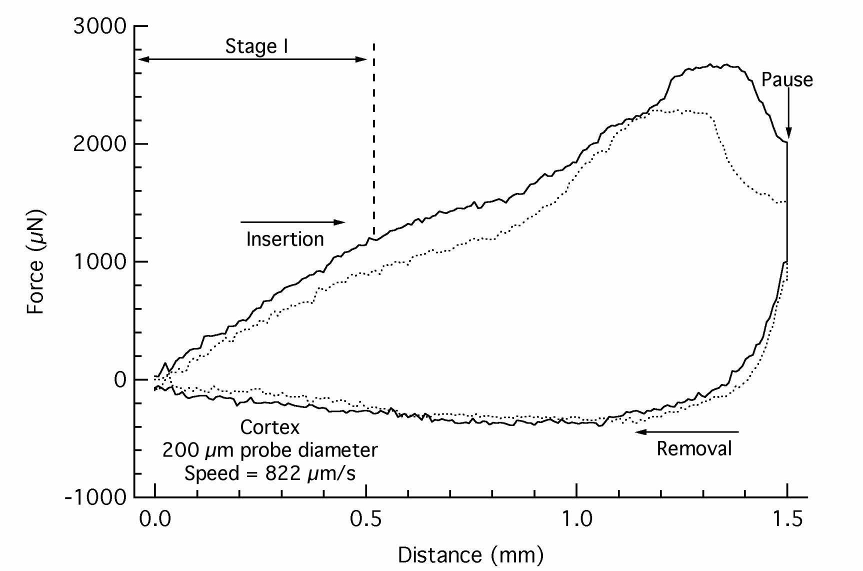
Forces during Probe Insertion and Removal



Young's Modulus of Tissue

$$E = \frac{\Delta F\left(1-\upsilon^2\right)}{\Delta u 2a} = \frac{K_1(1-\upsilon^2)}{d}$$

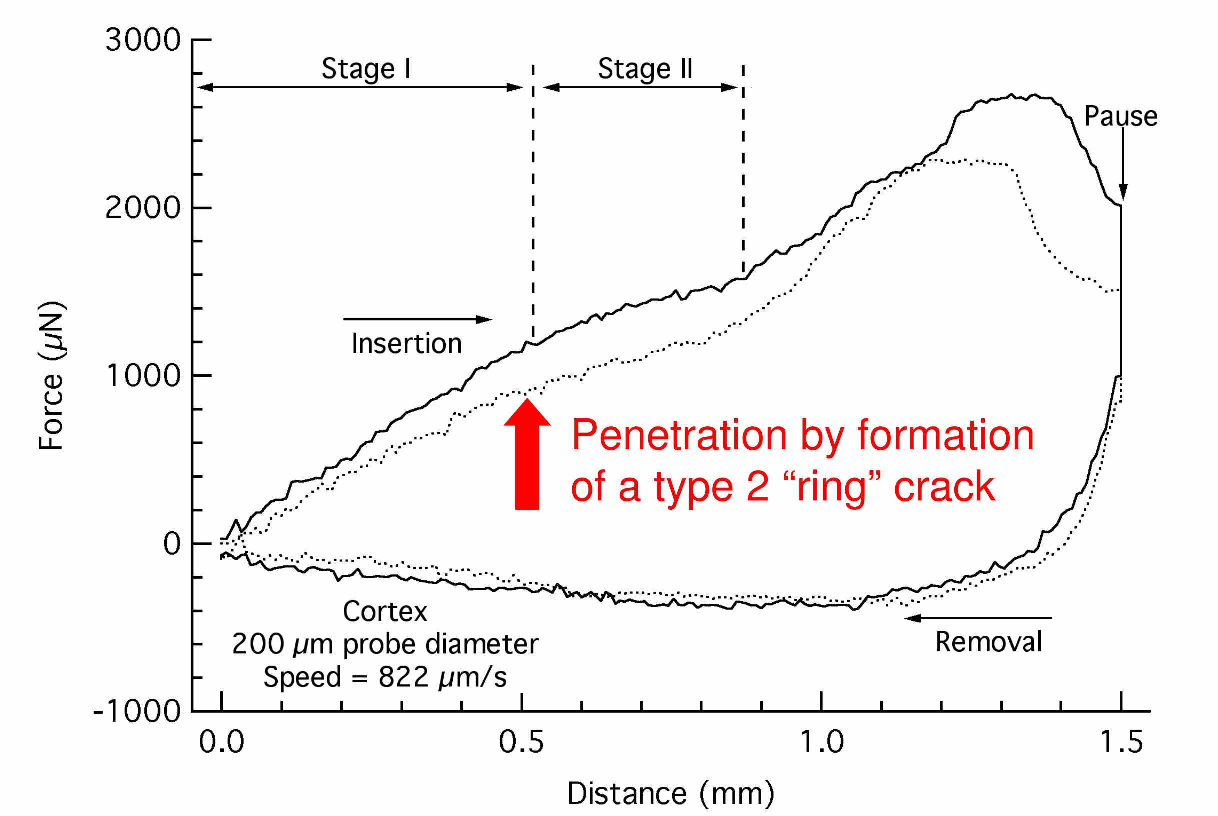
where E = Young's Modulus
K_1 = slope
F = applied force
υ = Poisson's ratio = 0.5
a = radius of punch
d = diameter of punch
u = indentation depth



E = 7.4±0.7 kPa

Assumptions:
1) the brain is a linear, elastic and incompressible material
(really non-linear and viscoelastic)
2) K1 is linear with indentation depth

Penetration Force



F_{crit} = 1092.6±166.2 μN

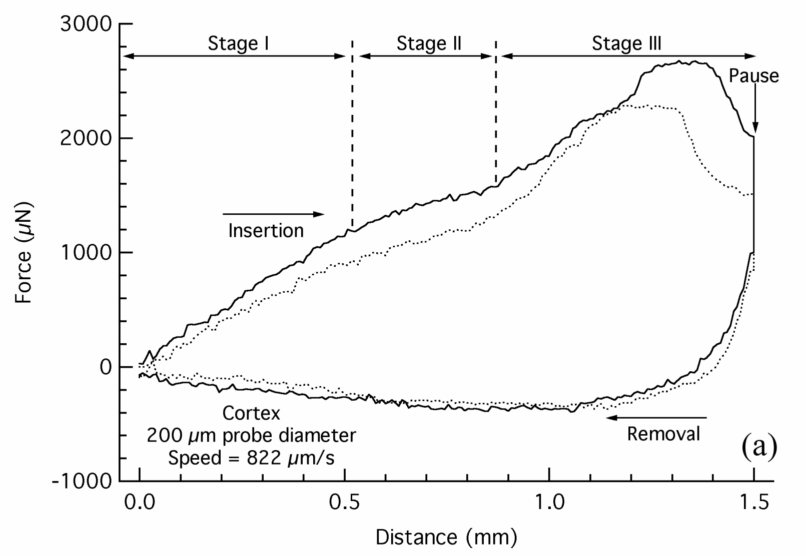
Frictional Forces

-ideally, the linear unloading path is a function of tissue modulus, probe diameter, and the coefficient of friction

-unfortunately, there are various confounds than led us to consider the rate of change in frictional forces as a whole

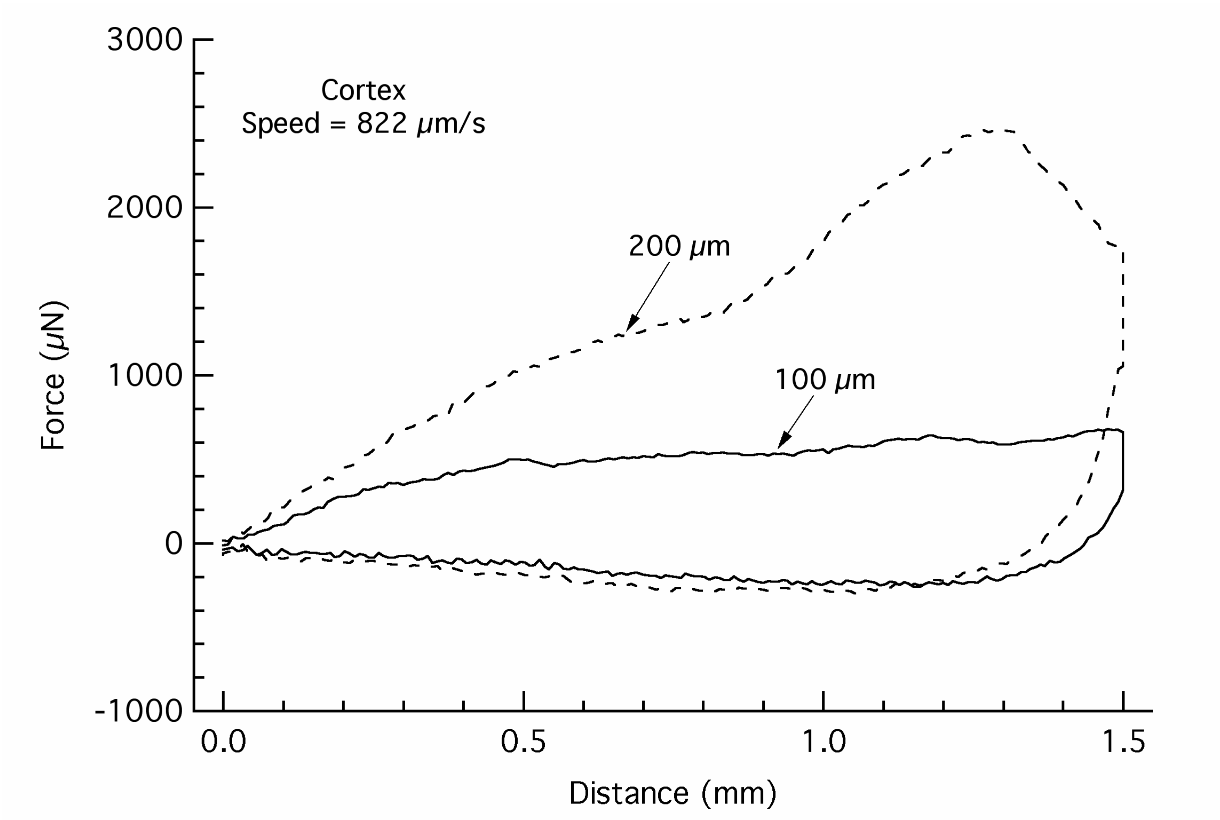
$$\frac{\Delta F_f}{\Delta \delta} = |K_2|$$

where F_f = frictional force
δ = penetration depth
K_2 = slope



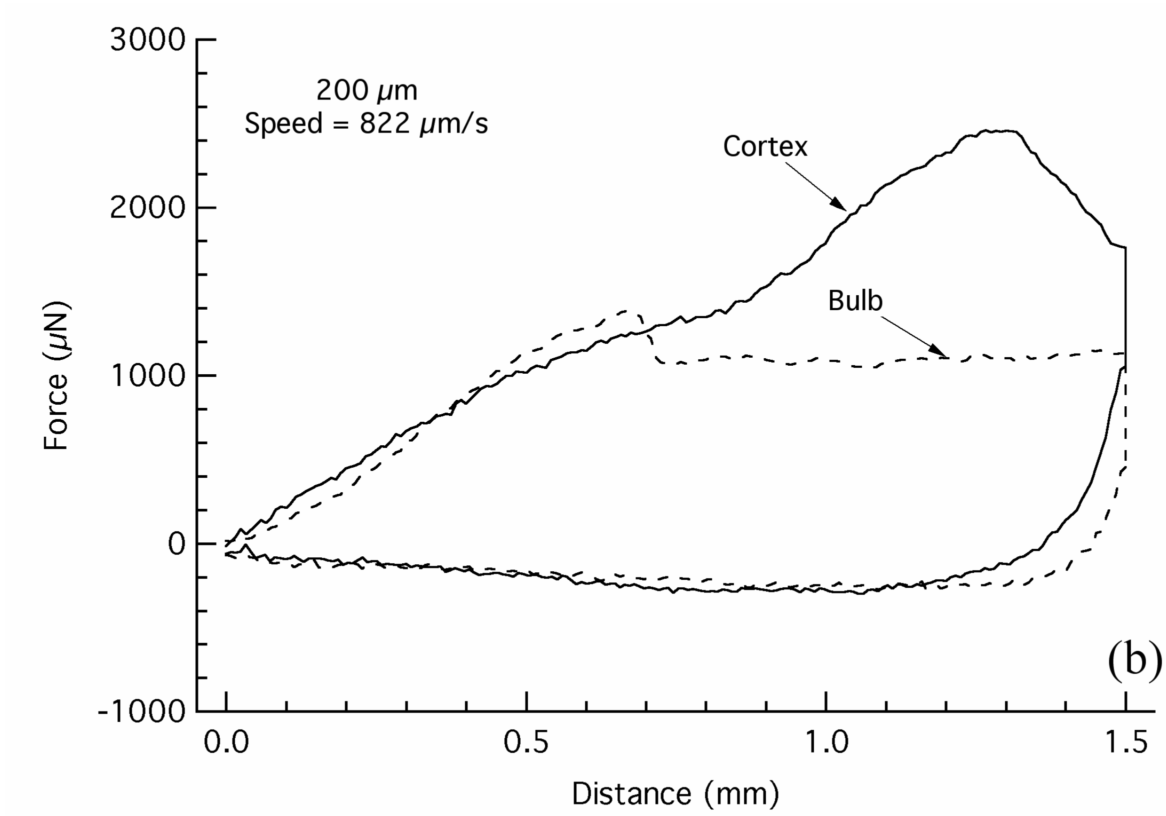
$\Delta Ff / \Delta \delta$ = 269.7±65.4 μN/mm

Decrease in Probe Diameter



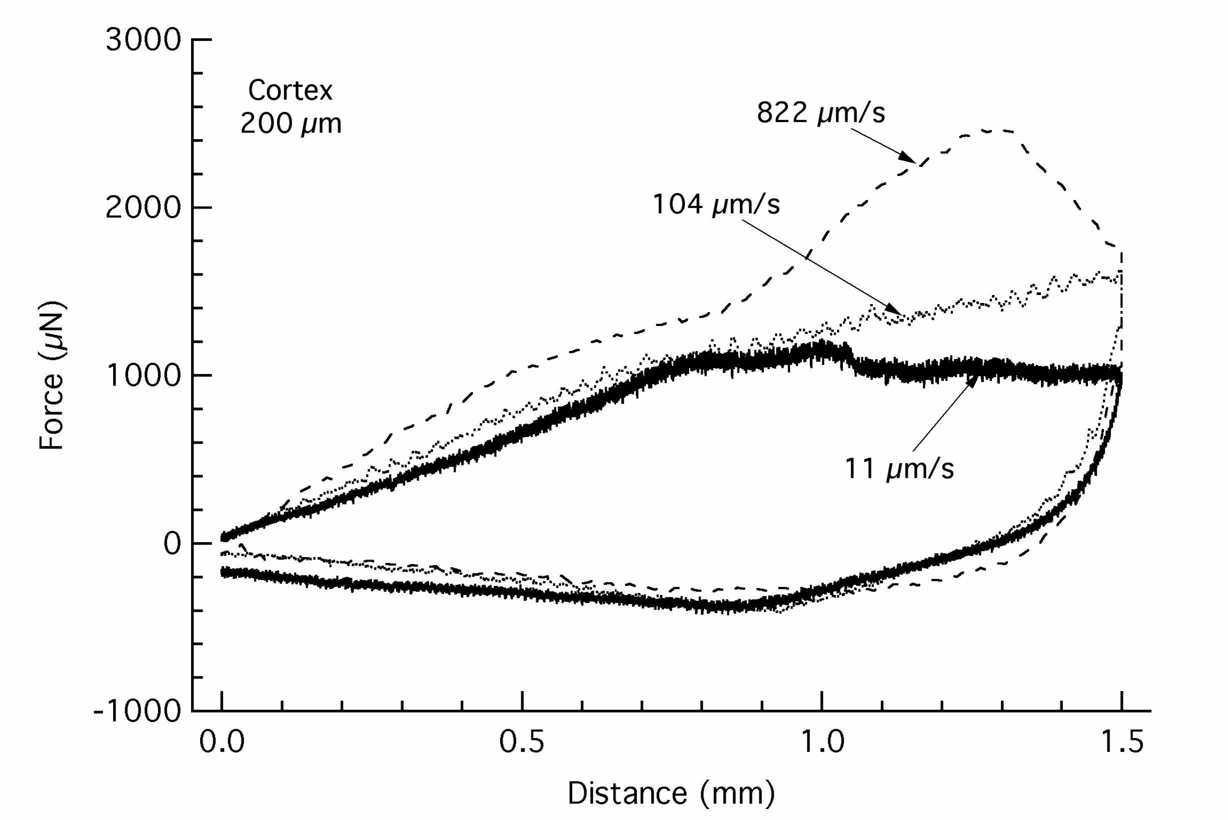
Decrease in maximum force, load/displacement hysteresis, penetration force and frictional force.

Tissue Specific Effects



Modulus was not significantly different between tissues, but frictional forces were lower in the OB.

Rate of Probe Insertion



Significant Effects of decreasing the Insertion Rate

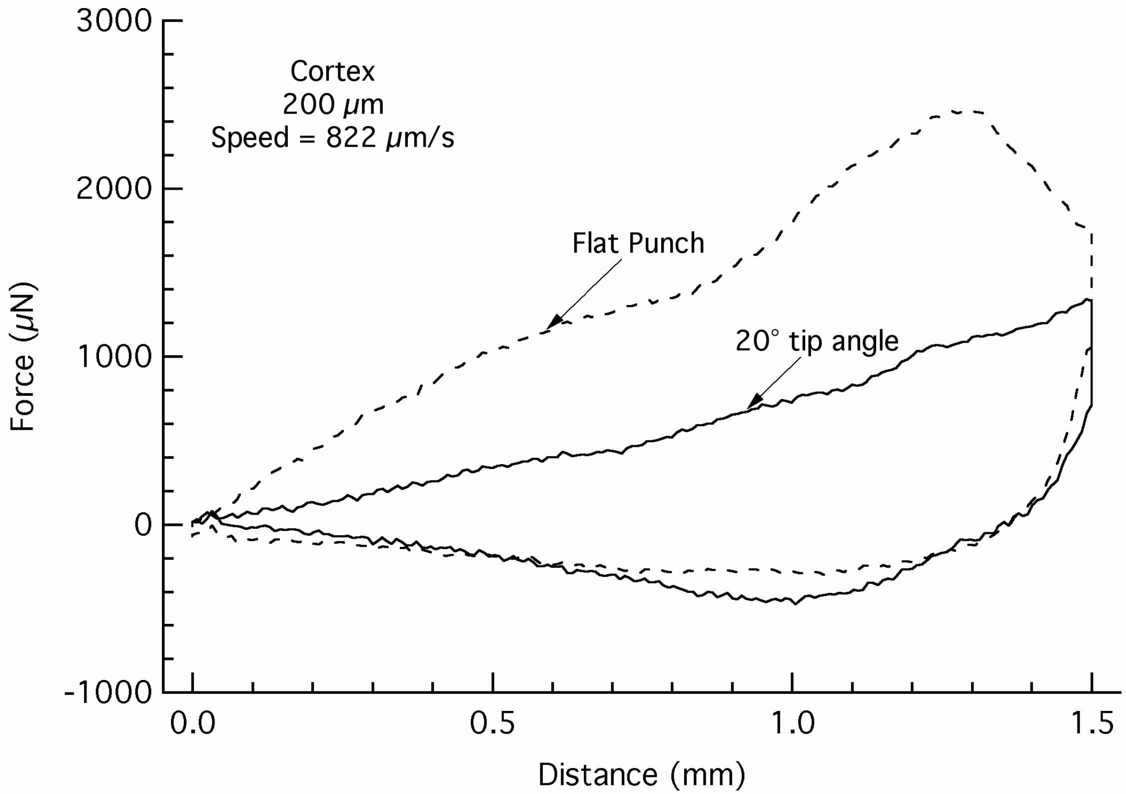
1) Modulus: decreased

2) Maximum Force: decreased

3) Load Displacement Hysteresis: decreased

4) Frictional Force: increase for slowest rate - adhesions

Sharpened (200 μm) Probe



Formation and opening of mode I crack.

Sharpened Probe:

- Decrease in maximum force
- No change in frictional forces during retraction given the same base diameter

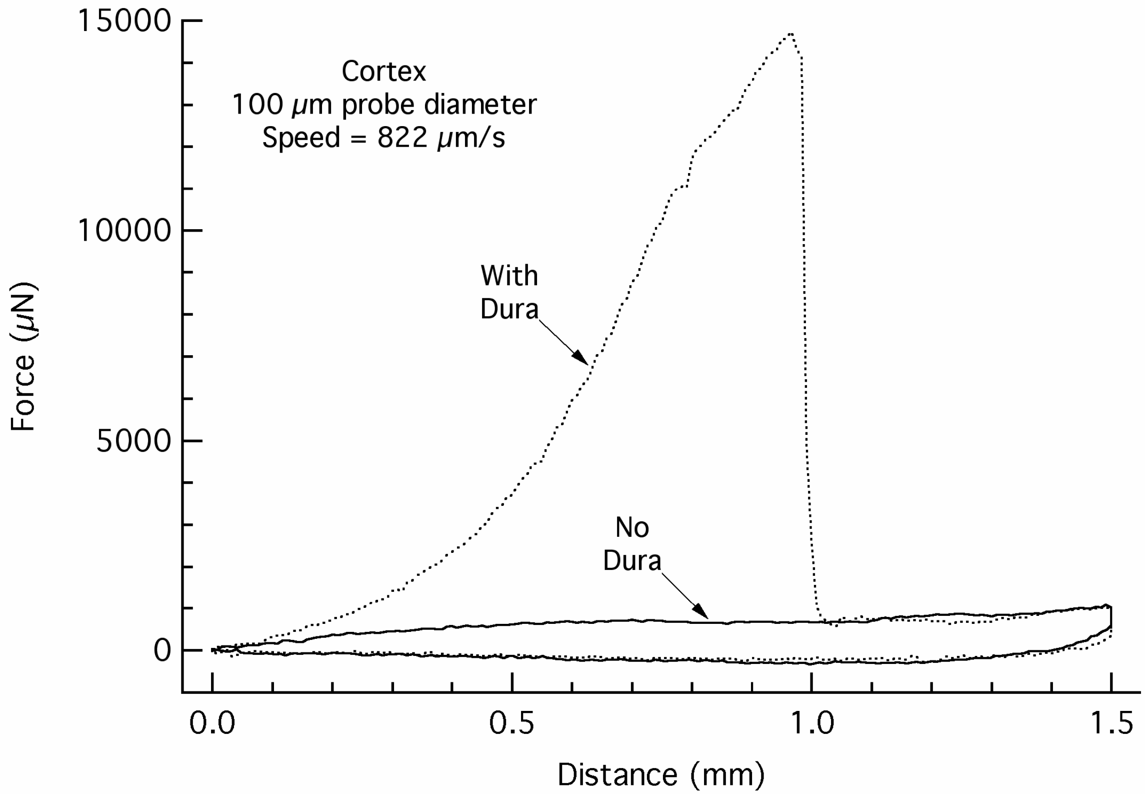
Cutting Force:

$$\frac{\Delta F_{cut}}{\Delta \delta} = \frac{\Delta F_{total}}{\Delta \delta} - \frac{\Delta F_f}{\Delta \delta} = K_3 - |K_2|$$

where F_{cut} = cutting force
K_3 = loading slope
$\Delta F_{total}/\Delta\delta$ = the rate of change of the force read from the load cell
$\Delta F_f/\Delta\delta$ = the rate of change of frictional force

No significant change with rate, but interesting...

Dura and Pia Intact



Massive increase in insertion/maximum force!

Considerations for Future Implant Designs:

1) Points are useful – reduced forces, gradual build-up (shape)
2) Reduce insertion forces (force = energy = tissue damage?
3) Balance implant diameter (shape) against implant stability
4) Relationship between insertion rate and adhesion – low frictional coefficient for insertion then modify to sticky?
5) What happens at fast insertion rates (pneumatic)?
6) Post-implantation modification?

The Team:

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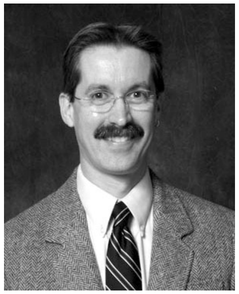

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