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A Robotic Indenter for Minimally Invasive Characterization of Soft Tissues

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September, 2005

Outline

- Problem
- Our Approach
- Literature Review
- Design of the Robotic Indenter
- Controller Design & GUI
- Animal Experiments
- Experimental Results

Problem

The lack of data in current literature on *in-vivo* material properties of soft tissues has been a significant impediment in the development of virtual reality based laparoscopic simulators that can provide the user with realistic visual and haptic feedback for training medical personnel.

Goal

In-vivo characterization of soft tissue properties for integration into tissue models to be used in VR based surgical simulators.

Challenge

Soft organ tissues exhibit

- nonlinear
- anisotropic,
- nonhomogeneous,
- time, and rate dependent behavior,

which are extremely challenging to measure, especially in vivo.

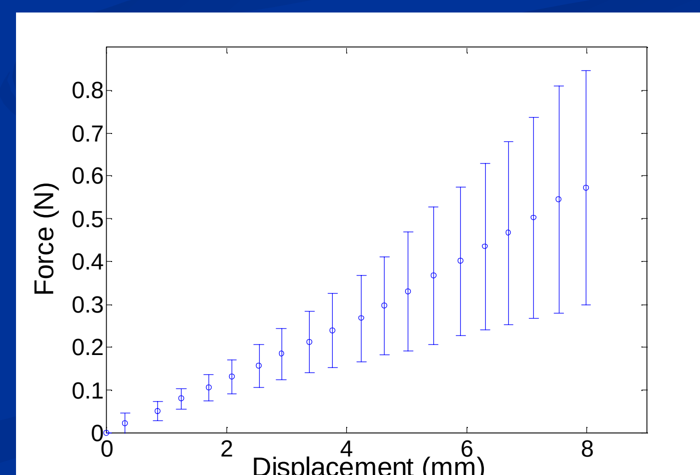
Our Approach

- Development of a robotic indenter
- Design of measurement experiments
- Extraction of tissue properties from measured data

Our Approach

Robotic Indenter

Experiments



Collected Data

Tissue Properties

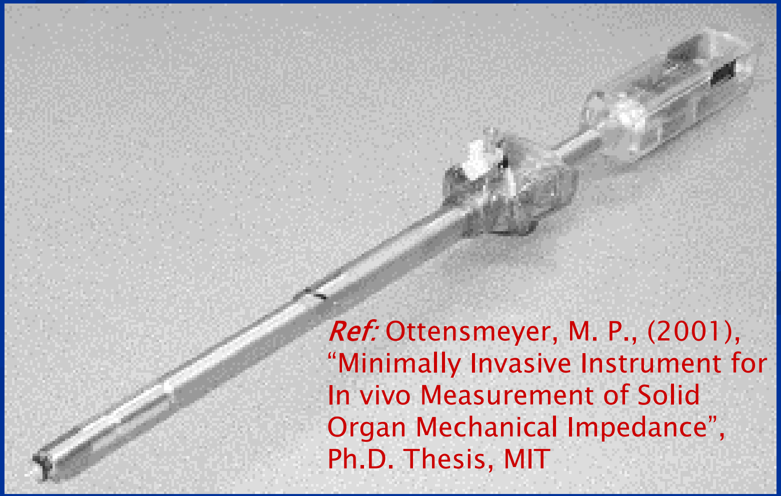
Literature Review

- Measurement site
  - in a living body (*in-vivo*)
  - within a body (*in-situ*)
  - outside the living body (*in-vitro*, *ex-vivo*)
- Measurement methods
  - *invasive*: a part of the body is entered, as by puncture or incision
  - *non-invasive*: the body is not cut open, e.g. ultrasound
  - *minimally invasive*: e.g. laparoscopy

Literature Review

- Hand-held
  - *Invasive*
    - Carter et al.
  - *Minimally Invasive*
    - Kauer et al.
- Robotic
  - *Invasive*
    - Tay et al.
  - *Minimally Invasive*
    - Ottensmeyer
    - Brown et al.

Ref: Brown, J.D. et al., (2003). “In-vivo and In-Situ Compressive Properties of Porcine Abdominal Soft Tissues”, MMVR, Vol. 94, pp. 26-32, Newport Beach, CA



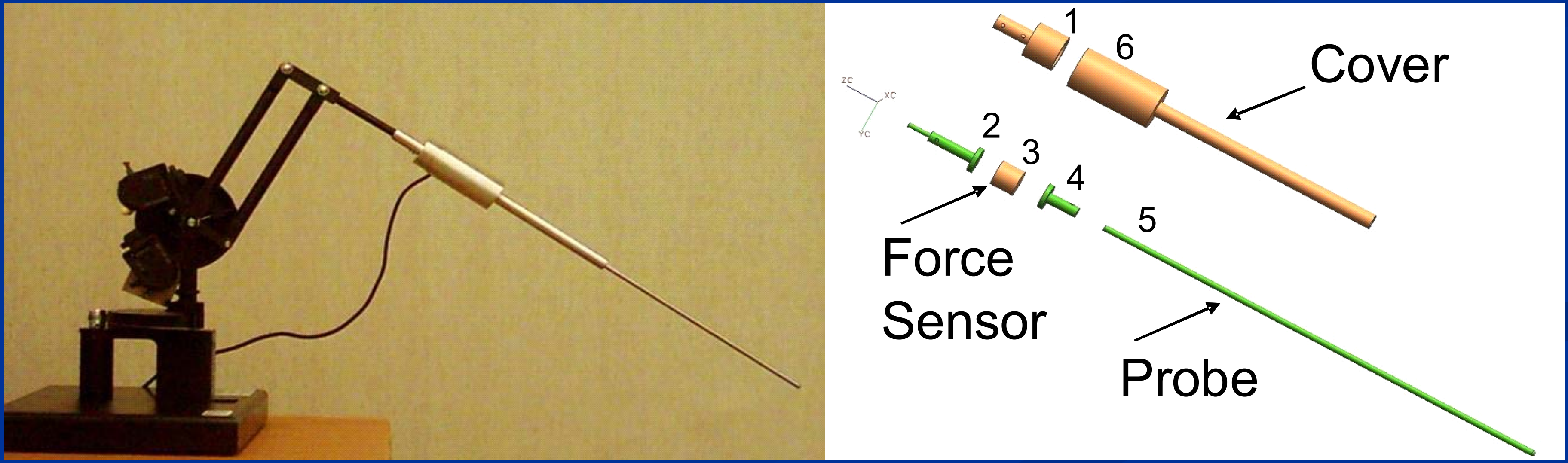
Ref: Ottensmeyer, M. P., (2001), “Minimally Invasive Instrument for In vivo Measurement of Solid Organ Mechanical Impedance”, Ph.D. Thesis, MIT

Our Contribution

- Robotic Probes vs Hand-Held Probes
- Minimally Invasive vs Invasive
- Large indentations vs small indentations
- Static vs Dynamic indentations

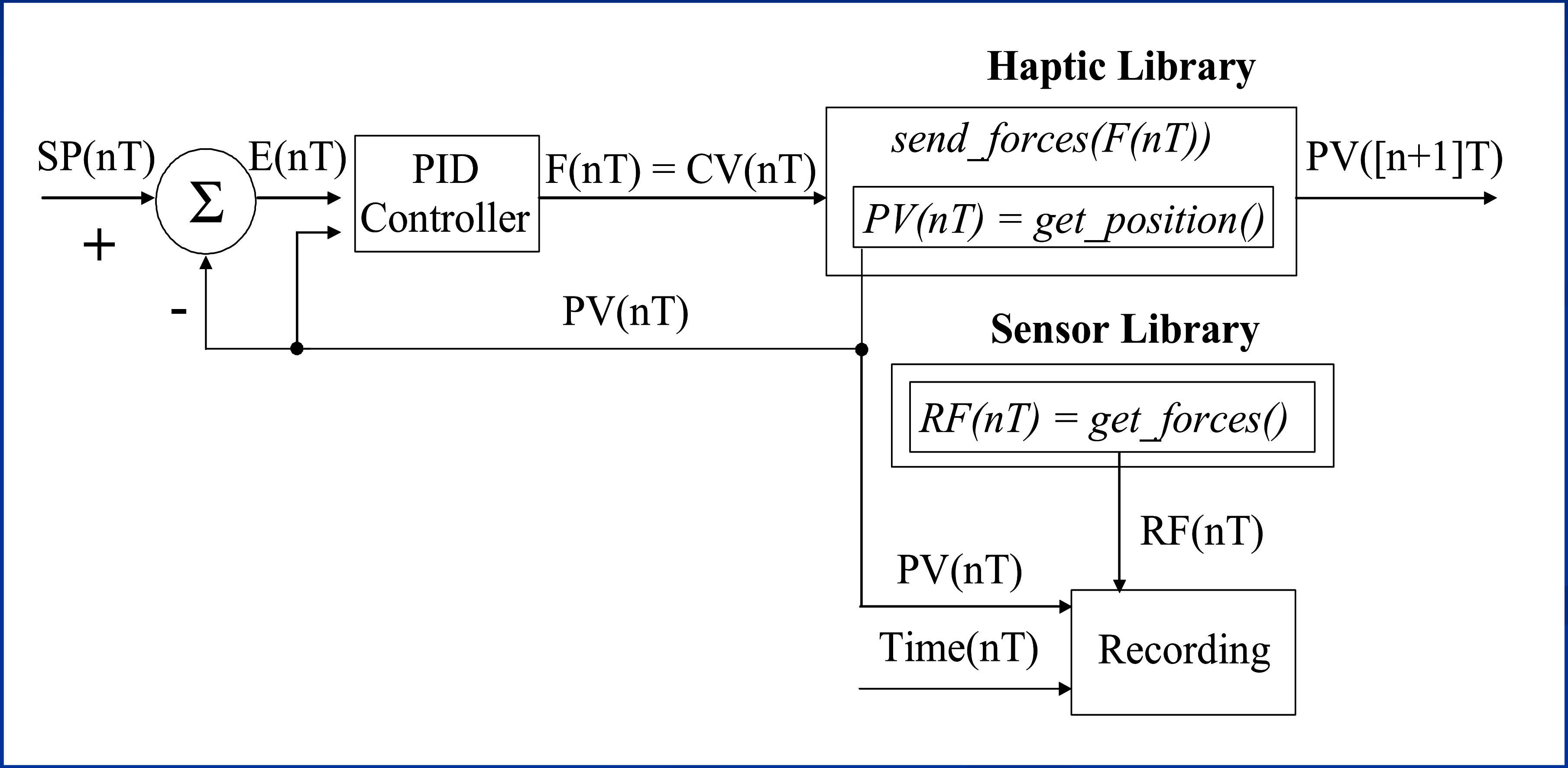
Components of the Robotic Indenter

- Phantom haptic device (encoders for 3D position sensing)
- Laparoscopic Probe
- Nano 17 force sensor (3D force/torque sensing)
- Cover



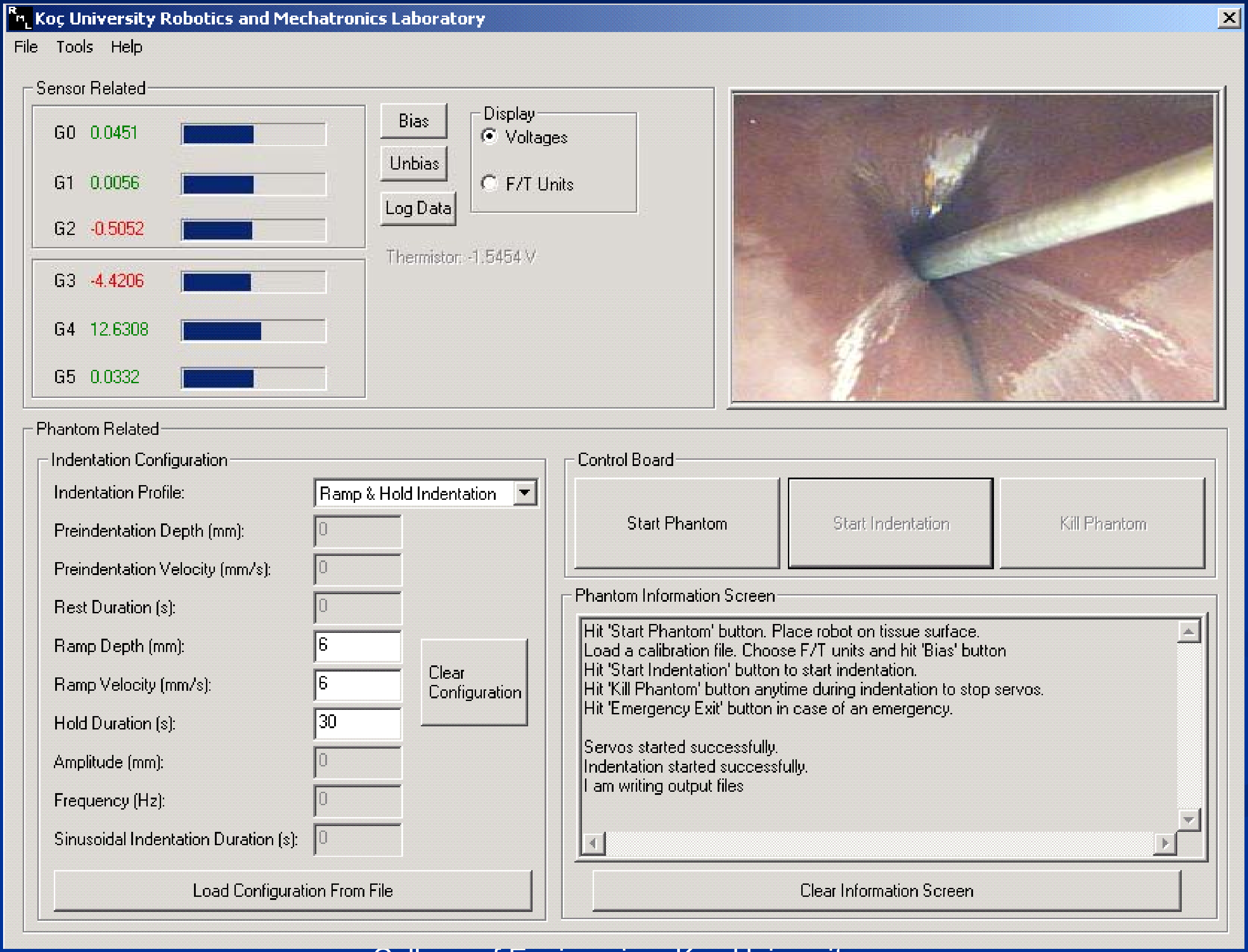
Controller Design

- PID control and tunning

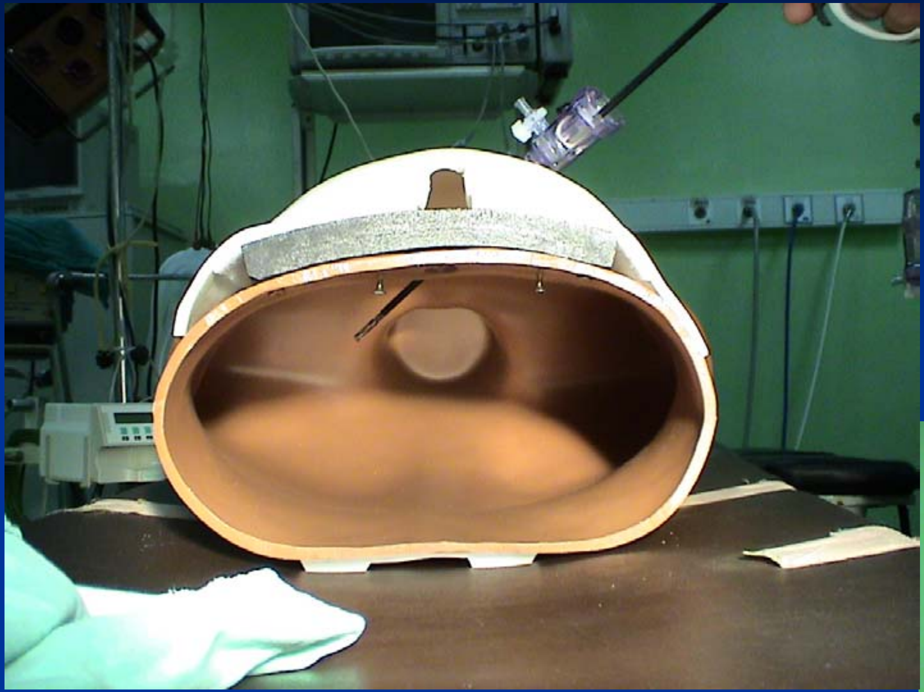


Graphical User Interface

- Automates the generation and execution of indentation profiles and data collection.



Preliminary Experiments

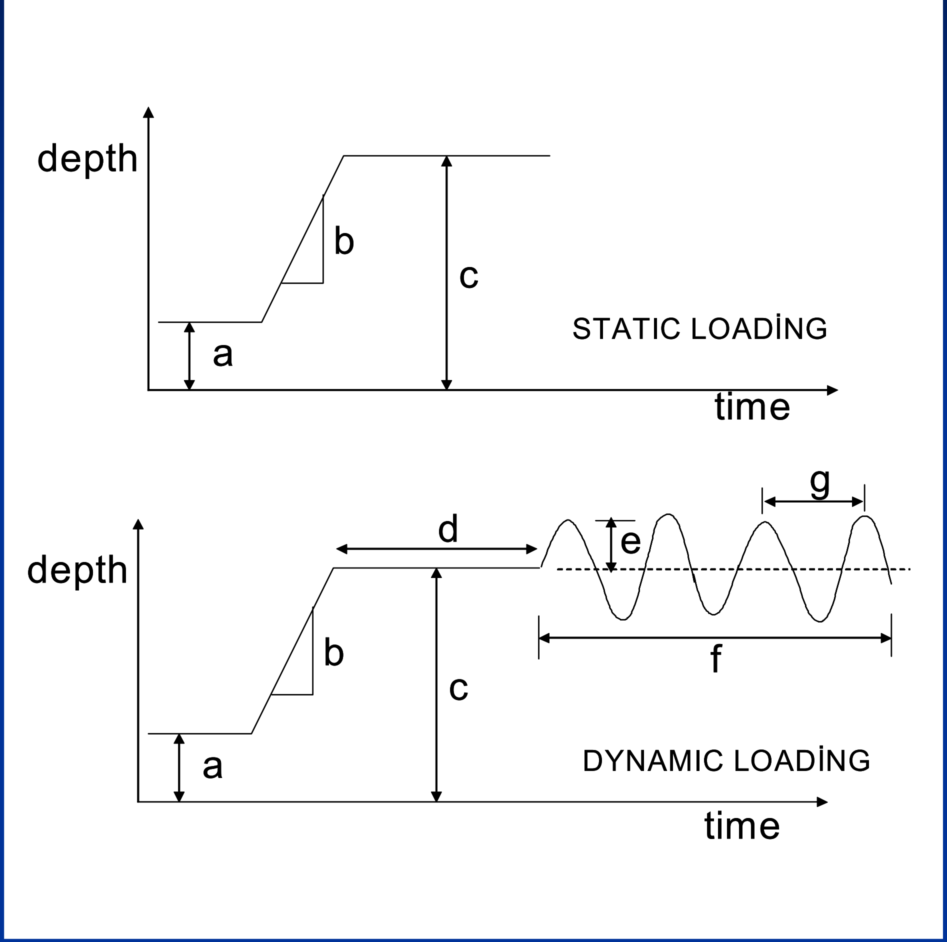


Observation in Operating Room

Animal Experiments

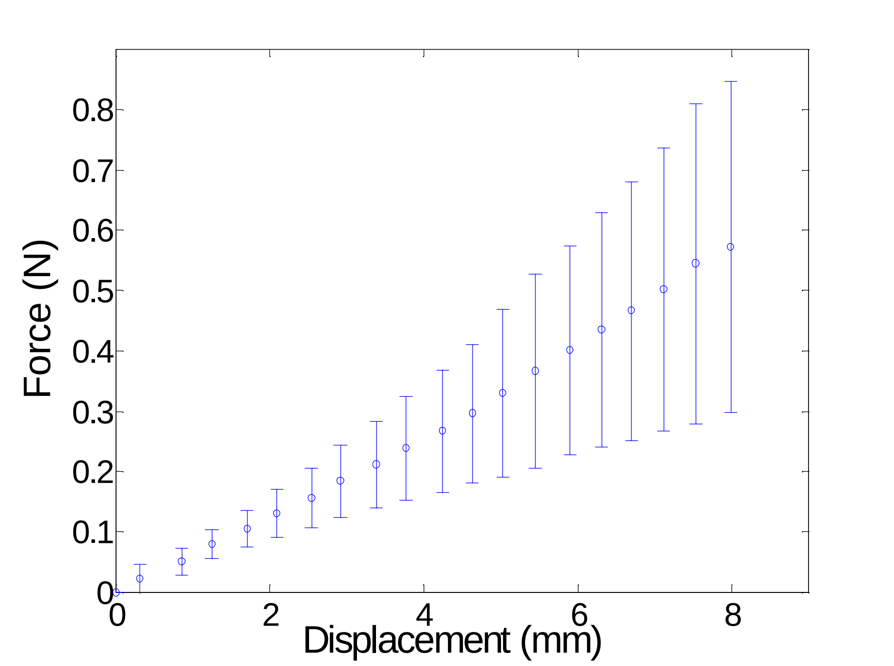
In collaboration with Department of Surgery and Faculty of Veterinary Medicine of Istanbul University.

Animal Experiments



- Indentation types
  - Static indentation
  - Stress relaxation
  - Dynamic indentation

Experimental Results

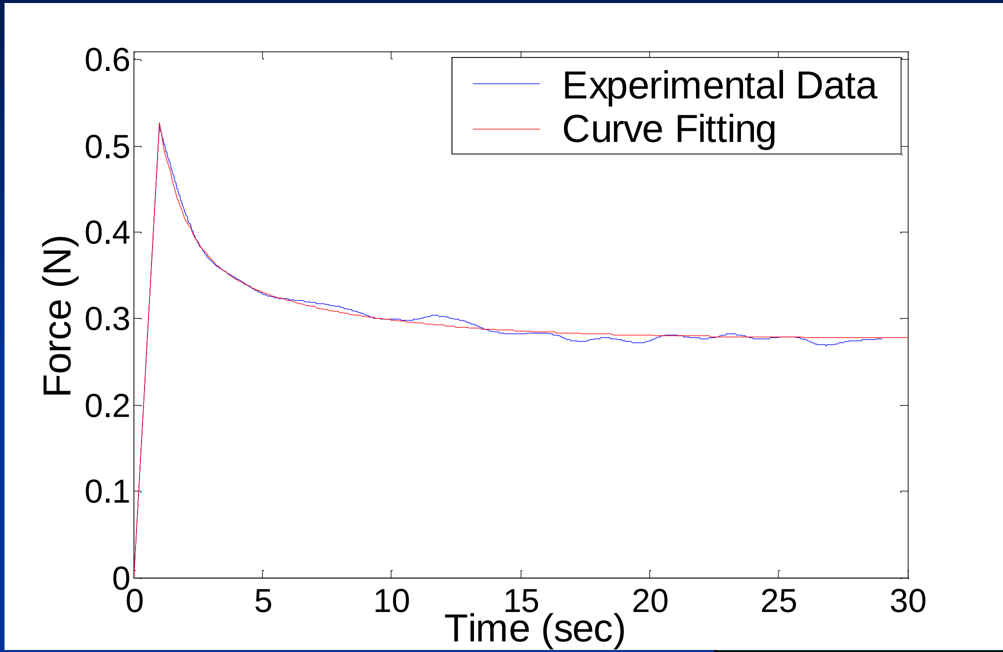


$$G = \frac{3P}{16\delta\sqrt{R\delta}} \qquad E = 2G(1+\nu)$$

- Effective elastic modulus for small indentation of an elastic half-space by a rigid hemispherical indenter

Indentation Depth δ (mm)	Effective Young's Modulus E (kPa)
2	16.9 ± 4.9
4	12.4 ± 4.1
6	10.8 ± 4.7
8	10.0 ± 4.7

Experimental Results



- Prony Series expression

$$G(t) = G_\infty + \sum_{k=1}^{N} G_k e^{-t/\tau_k}$$

	Pig #1	Pig #2	Pig #3
G_1 (kPa)	2.402	3.688	0.827
G_2 (kPa)	1.733	2.495	3.333
τ_1 (s)	0.979	1.000	1.202
τ_2 (s)	5.650	9.000	10.641
G_∞ (kPa)	4.593	3.193	5.093

Acknowledgement

Special thanks to

Prof. Dr. Cagatay Basdogan
(Koc University),
Mert Sedef

(Koc University),
Prof. Dr. Levent Avtan

(Istanbul Faculty of Medicine, Department of Surgery),
Prof. Dr. Oktay Duzgun
(Istanbul Faculty of Veterinary Medicine)

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Proceedings of Computer Assisted Radiology and Surgery (CARS 2005) Conference,
June 22-25, 2005, Vol 1281C pp. 713-718.