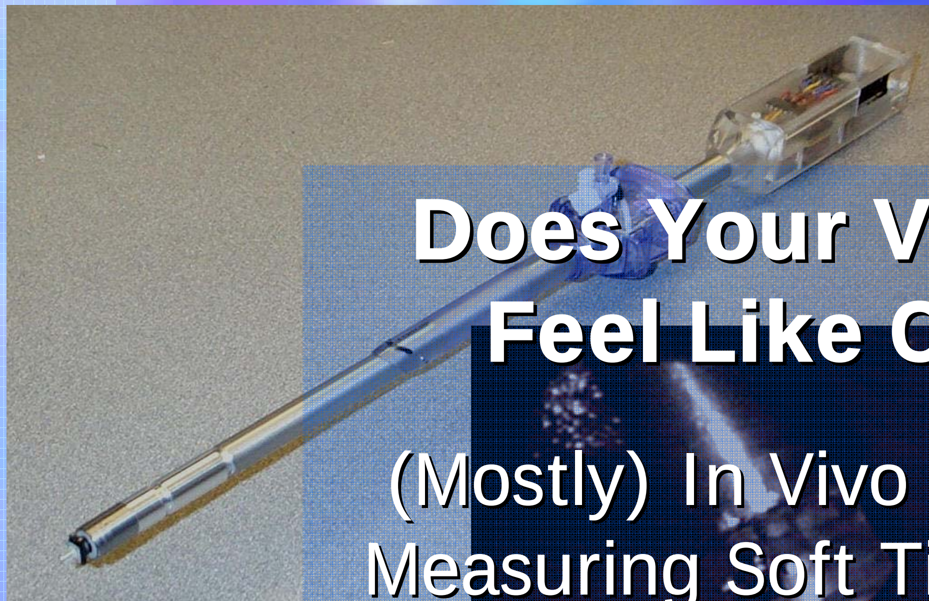
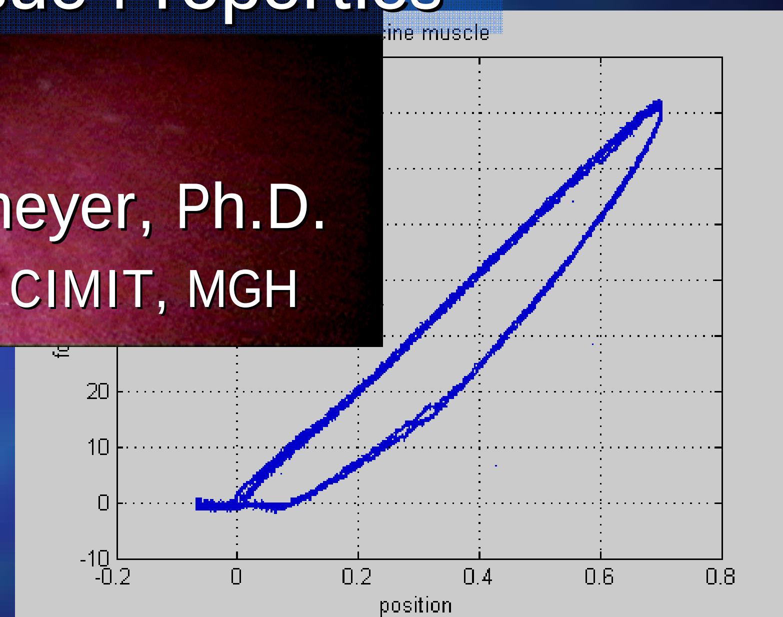


Does Your Virtual Liver Feel Like Concrete?

(Mostly) In Vivo Techniques for Measuring Soft Tissue Properties

Mark P. Ottensmeyer, Ph.D.

Simulation Group, CIMIT, MGH



THE SIM Group

CIMIT
Innovative Technology for Medicine

MGH 1811 MASSACHUSETTS GENERAL HOSPITAL

VE RI TAS

IPAM mini-review

- Satava
  - sims good enough to allow mistakes
  - digital libraries of patient specific cases (from Virtopsy)
- Teran/Oliker/Cutting
  - fast FE, spring-mass models for plastic surgery
  - deformation & cutting
- Terzopoulos
  - facial tissues, neck/body muscles
- Schill
  - ophthalmic surg sim – deformation & tearing
- Meglan
  - generalizability, “provenance”
  - Top-down face validity requires redo for each new sim

- Soft tissue model material parameters – how do you get them?

- Tissue properties - a black hole

  Satava, c. 2001

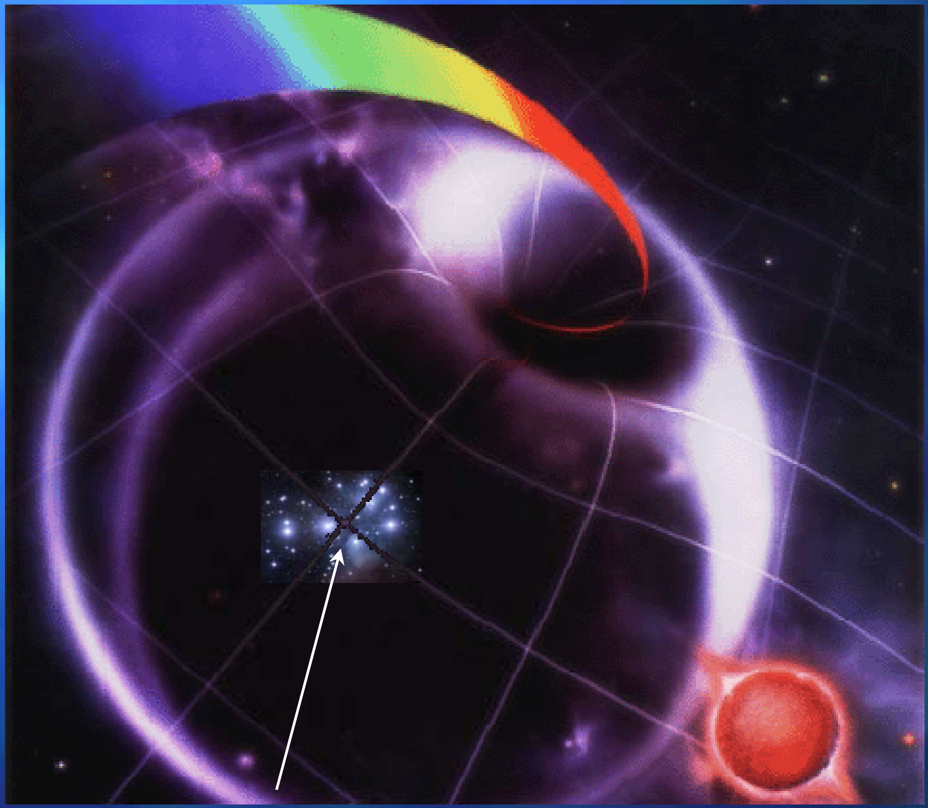
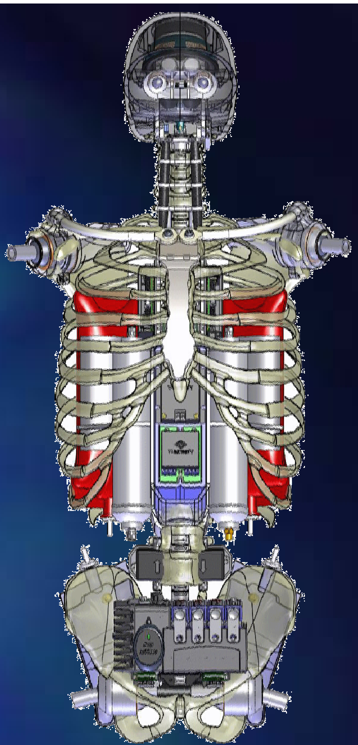
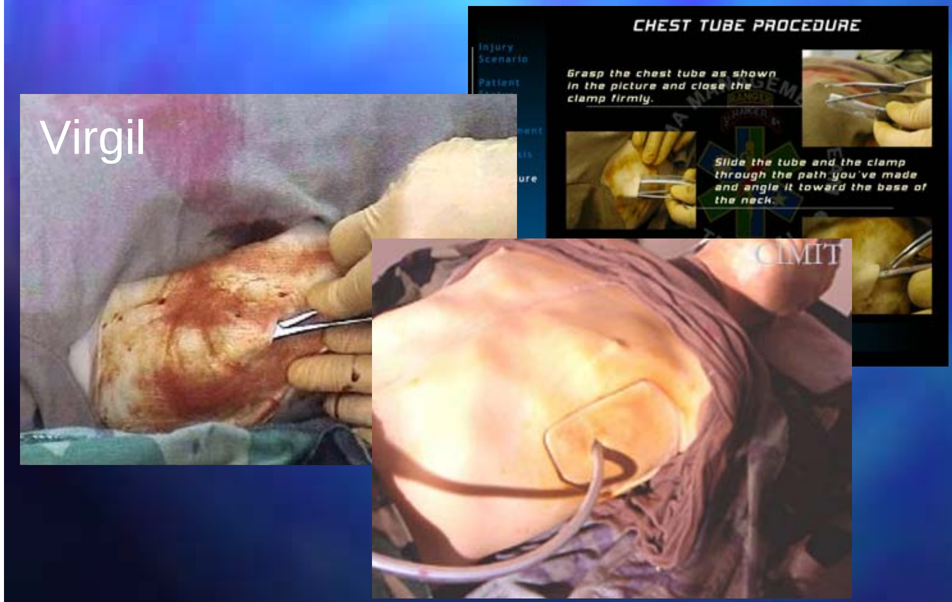


image: National Geographic Picture Atlas of Our Universe, 2nd ed., 1986

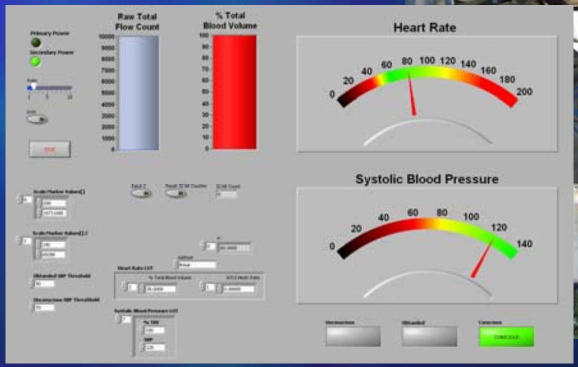
c. 2008: Harders, De, Ottensmeyer & friends!

- MGH/CIMIT Simulation Group
  - basic science and proof-of-concept systems for medical training through simulation
- Multi-disciplinary research team
  - M.D. (radiology), mech. eng., comp.sci., industrial designer, fine arts





COMETS



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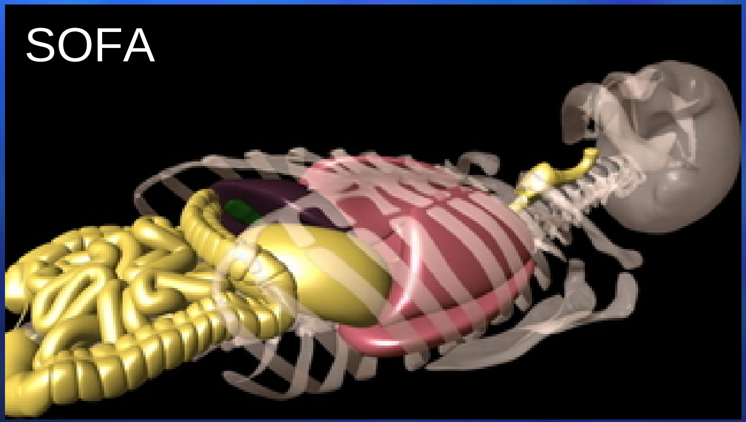

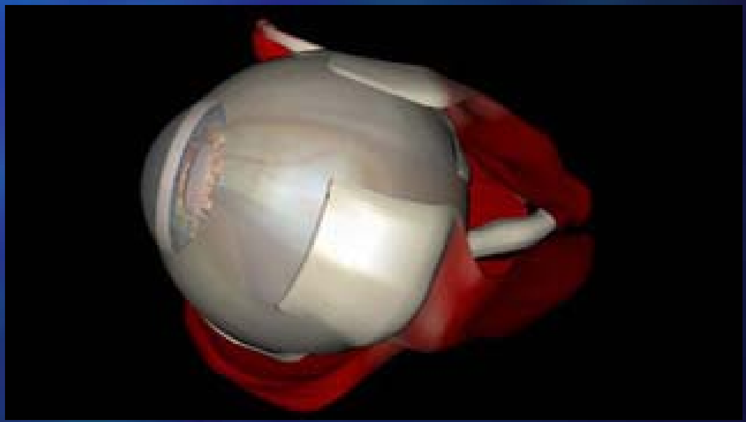

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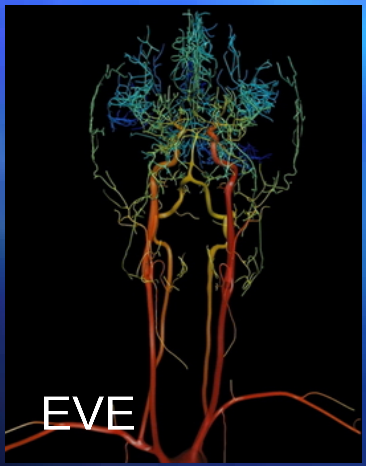

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Student practices smallpox inoculation on SITU

SITU kit components.

Outline

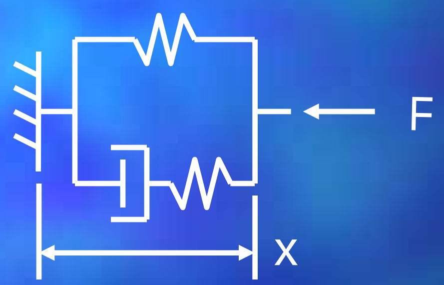
- *in vivo* tissue testing techniques & devices
  - taxonomy axes?
  - compliance testers
  - elastographic techniques
  - briefly cutting/piercing
  - applications sprinkled in
- summary & a few extra slides

Possible tissue testing taxonomies

- Measurement interaction technique
  - Tension, compression, indentation, shear, aspiration
  - Puncture, cutting (single blade/scissors), crushing, fracture
  - Non-contact, non-invasive
- Rate/range of interaction
  - Static/quasi-static (ignoring viscosity)
  - Manual manipulation rates (2Hz or less)
  - Soft impact, moderate frequency (<300Hz)*
  - High speed impact, ultrasound response
  - Strain level: linear to non-linear material and geometric domain
- Tissue type
  - Solid organ (liver, kidney, brain, muscle…)
  - Hollow organ (intestine, stomach, bladder, vessels…)
  - Structural (bone, cartilage, tendon, ligament…)
  - Others?
- Application
  - Surgical simulation (real-time & JND constraints)
  - Tissue engineering, implants, prosthetics (offline models?)
  - Physiology simulation (voice production – here's the *)
  - Body armor development (model impactor + armor + underlying tissue)

Living Tissues

- Material properties/behaviors
  - visco-elasticity—standard linear (Kelvin) model



  - Prefer geom.-indep. properties, *not* spring consts.
  - Non-linear, *poro*-visco-elastic, anisotropic, inhomogeneous, age/temp/pathology-dependent
  - Independent experiments for each parameter!
  - Yamada ('70), Duck ('90), others: *in vitro*

Living Tissues

- Measurement complications
  - Invasiveness of testing—surgical access to organs
  - Motion corrupts data: cardiac, pulmonary action
  - Limited testing periods
  - Non-ideal tissue “samples”: no standard shapes
  - Tensile tests difficult
  - Humidity, temp., body fluids—effects on hardware
  - *Human testing protocol approval!*
  - ...

Measurement Techniques

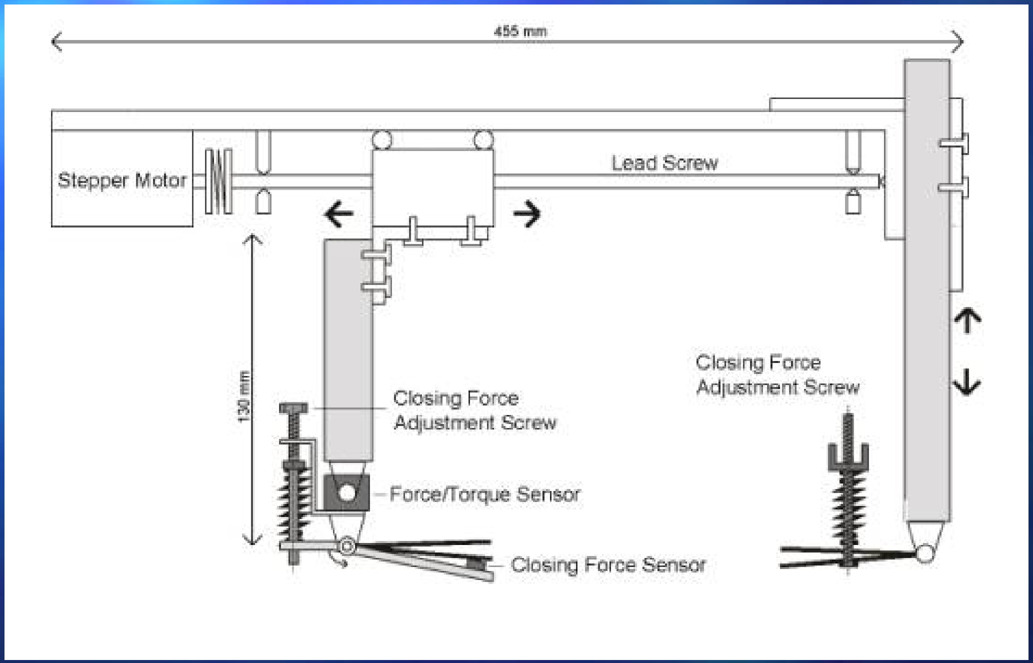
- Compliance testing
  - Deform tissue locally, measure “F(t) vs. X(t)”
  - Use simple approximation or iterative FEA to extract parameters
- Elastographic testing
  - Image strain field (2-D, 3-D), motion amplitude
  - Invert to generate qualitative elastograms
  - Iterate on inverse problem for quantitative
- Cutting & needle insertion
  - Recording F(t) vs. X(t)
  - Separate elastic, fracture, frictional components
  - Currently instrument-specific

Compliance techniques

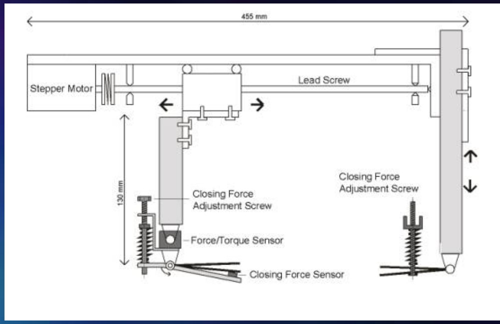
- Deformation modes
  - tension
  - compression
  - indentation
    - side trip into bench top “life support”
  - torsion (shear)
  - aspiration/suction

Compliance: tensile testing

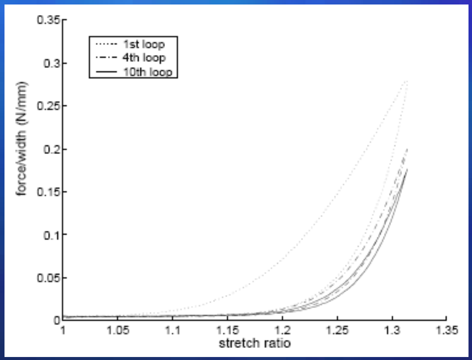
- Tendick, et al.; UCSF/Berkeley
  - GiPSi: open source framework for surgical simulation
  - Enhanced perception for soft tissue manipulation
  - Interactive-rate FEM techniques
  - Creation of tissue property "atlas"

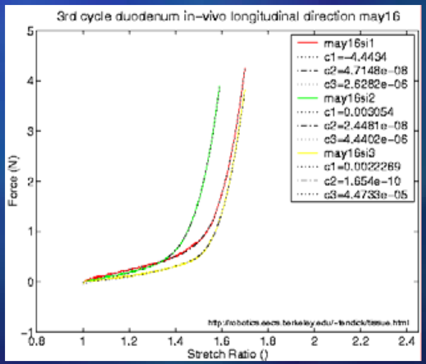


Compliance: tensile testing



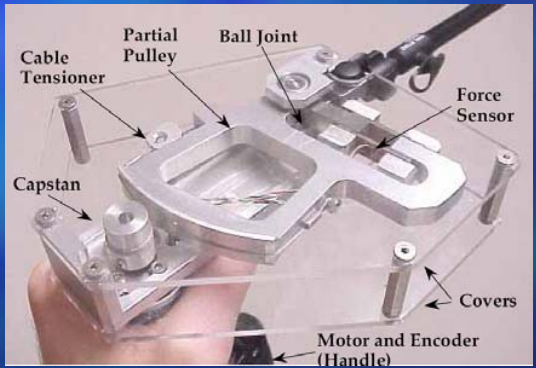
- Uniaxial tensile testing apparatus
  - Babcock graspers; open abdomen
  - in vivo/vitro porcine stomach, sm. bowel, gall bladder (Brower et al., MMVR01)
  - 40Hz control/sampling; >150mm motion; 0-6N applied
- Curve fitting
  - $F(\lambda) = \alpha e^{\beta\lambda}$; $\lambda = l/l_0$
  - Tests include response to pre-conditioning: large for in vitro
  - online resource for force-stretch ratio data





Compliance: compression tests

- BioRobotics Lab, U. Washington
  - Hannaford, Rosen, et al.
  - Understanding surgical gestures, force/position range
    - Blue Dragon, Red Dragon, Markov model description
  - Improving tactile feedback for MIS
  - Supporting surgical simulation community

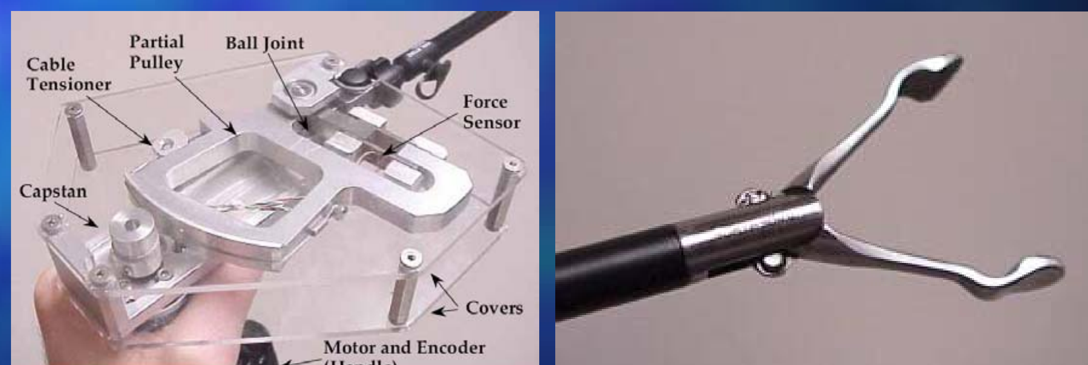


http://brl.ee.washington.edu

Compliance: compression tests

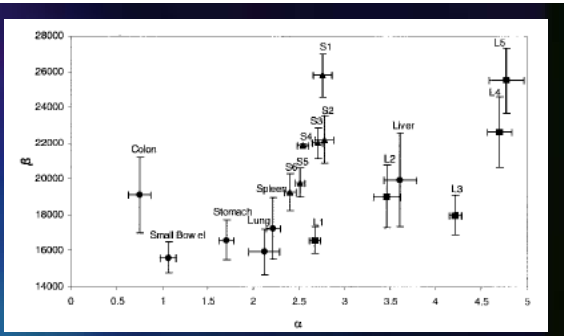
- Motorized Endoscopic Grasper
  - Babcock grasper, MIS (10mm port), usually open laparotomy
  - *in vivo* porcine solid & hollow organs
  - improved haptic tissue discrimination; characterize tissue *in vivo vs. post mortem*
  - testing up to 3Hz; 30mm RoM; 25N (70 max) force (surgical scale)

FREG

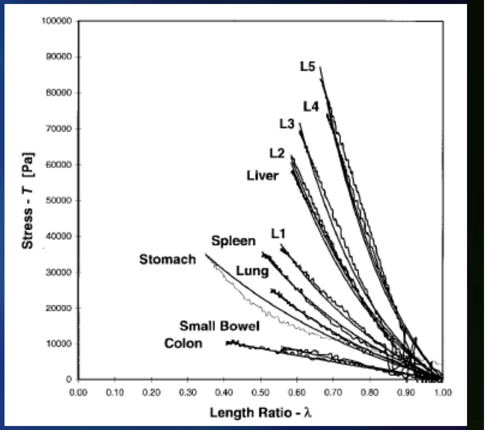


MEG

FREG/MEG: selected results



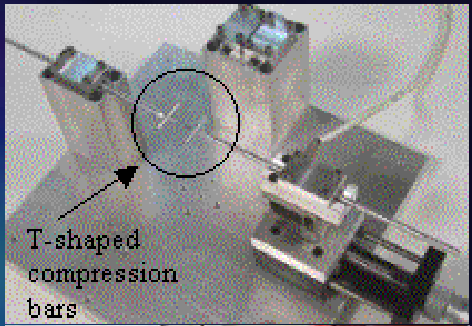
- Tissue stiffness (FREG) (Rosen et al., MMVR98)
  - distinguishable stiffness: *in vivo* porcine liver, spleen, small bowel, colon, stomach, lung
  - Curve fitting: $\sigma(\lambda) = \beta(1\text{-}e^{\alpha(1-\lambda)})$; $\sigma=F/A_0$; $\lambda=l/l_0$

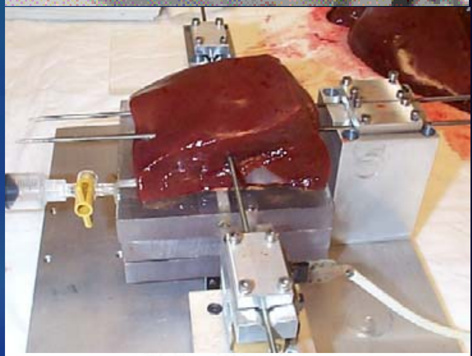


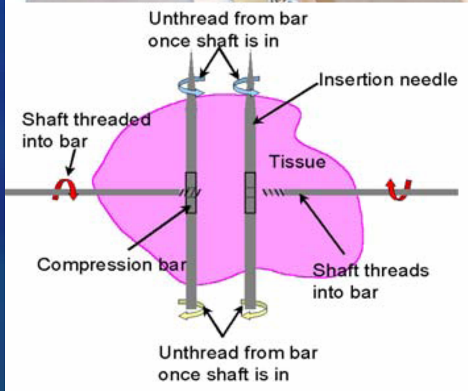
- Tissue stiffness (MEG) (Brown et al., MICCAI03)
  - liver/small bowel *in vivo* ⇒ *in situ* ⇒ *ex corpus* (3x)
  - preconditioning, stress relax'n effects differ *post mortem*, changes between *vivo*, *ex corpus* @ 25hrs
- Color change (De et al. MMVR06)
  - MEG compression, Canon Powershot A80, spectrophotometer, subjective validation
- Damage thresholds (De et al., IJRR07)
  - porcine liver (<80kPa @ 30s), ureter (~100kPa), small bowel (~100kPa)
  - H&E (morphology), MPO IHC (inflammation), caspase-3 IHC (apoptosis) staining

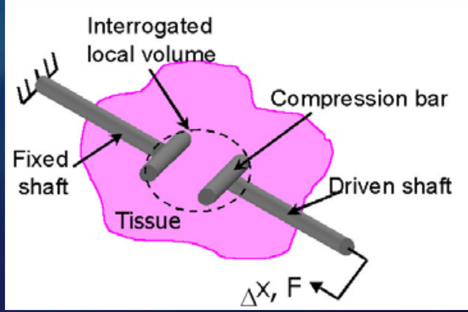
Compliance: compression tests

- BioRobotics Lab, Harvard U.
  - Howe, Kerdok, Maeno, et al.
  - “Enabling Technologies for Advanced Soft Tissue Modeling”
  - Internal parenchymal tester for solid organs
  - Motorized, integrated with NELP system
    - 0-100mm/s, 36% strain (7mm compression)
  - Proof of concept results (Kerdok&Howe’03)
  - QLV model, 3 time constants: 0.102, 1.47, 27.76s



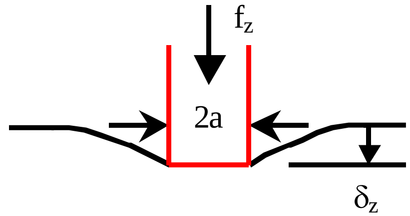






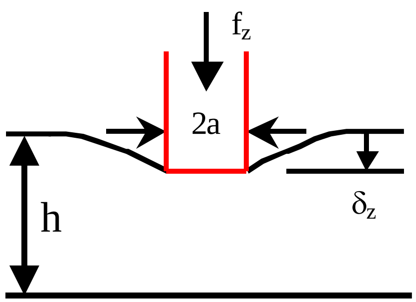
Compliance: indentation

- Closed form solutions
  - linear, isotropic, homogeneous, semi-infinite
  - normal indentation (frictionless)



$$E_{slip} = \frac{(1-\nu^2) f_z}{2a\delta_z}$$

  - Hayes' correction (Hayes et al., J.Biomechs72)
    - correction exists for hemispherical indenter as well



$$E_{slip} = \frac{(1-\nu^2) f_z}{2a\delta_z K\left\{\frac{a}{h}, \frac{x}{h}, \nu\right\}}$$

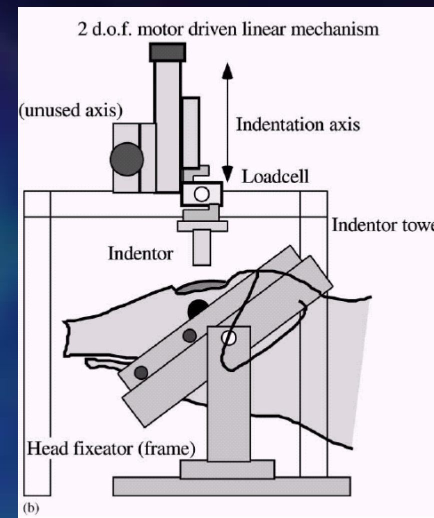
$$K = 1.23 + 1.26\frac{\delta_z}{h}$$

Compliance: indentation

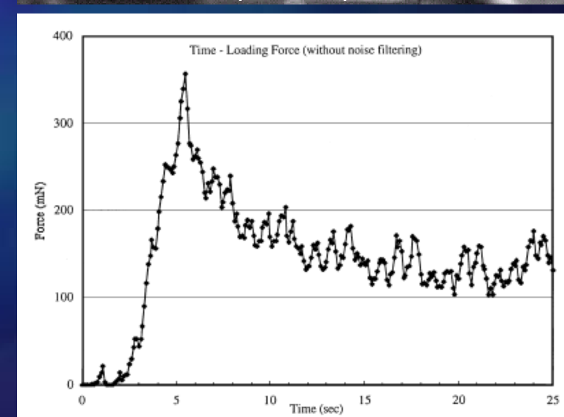
- Common method for tissue testing *in vivo*
  - Miller, U. Western Australia: porcine brain
  - Carter, U. Dundee, UK: human liver
  - Ottensmeyer, MIT: porcine liver
  - Kerdok, Harvard: porcine liver, spleen
  - Tendick, UCSF; Srinivasan, MIT: porcine abdominal tissues
  - De, RPI: porcine tissues, human cadavers

Compliance: indentation tests

- Intelligent Systems for Medicine Lab; U. Western Australia
  - Miller, et al.
  - non-rigid registration, neurosurgical planning & simulation, predicting injury due to baseball impact
  - porcine brain *in vivo*, 10mm flat cylindrical indenter
  - 1mm/s max V; 3.9mm indentation used; 400mN max (applied *in vivo*)
  - Iterative FEA using hyperviscoelastic constitutive law, MRI for BCs

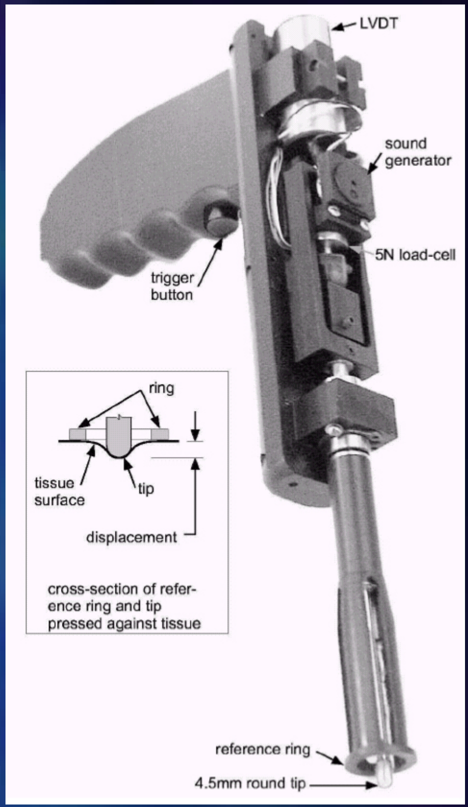



Miller et al., 2000, J. Biomech.

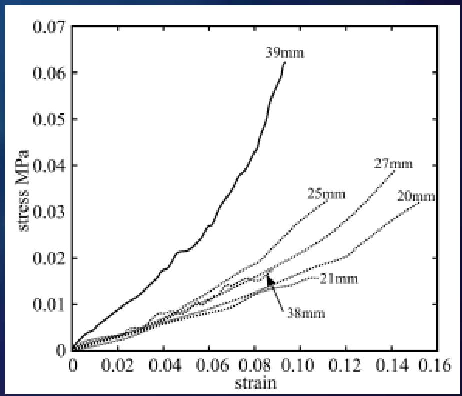


Compliance: indentation tests

- Surgical Skills Unit, Dundee U., UK
  - Carter, Cuschieri, et al.
  - diagnostics, tool design, surgical simulation
  - manual application: 5mm (10 max) *in vivo*; ~1N (5 max) *in vivo*
  - 4.5mm hemispherical indenter, reference ring 12/18mm ID/OD
  - ***first human liver* in vivo!**
  - healthy vs. diseased (cholestatic liver w/bile obstruction: 2x stiffness)
  - porcine liver & spleen *in vitro*

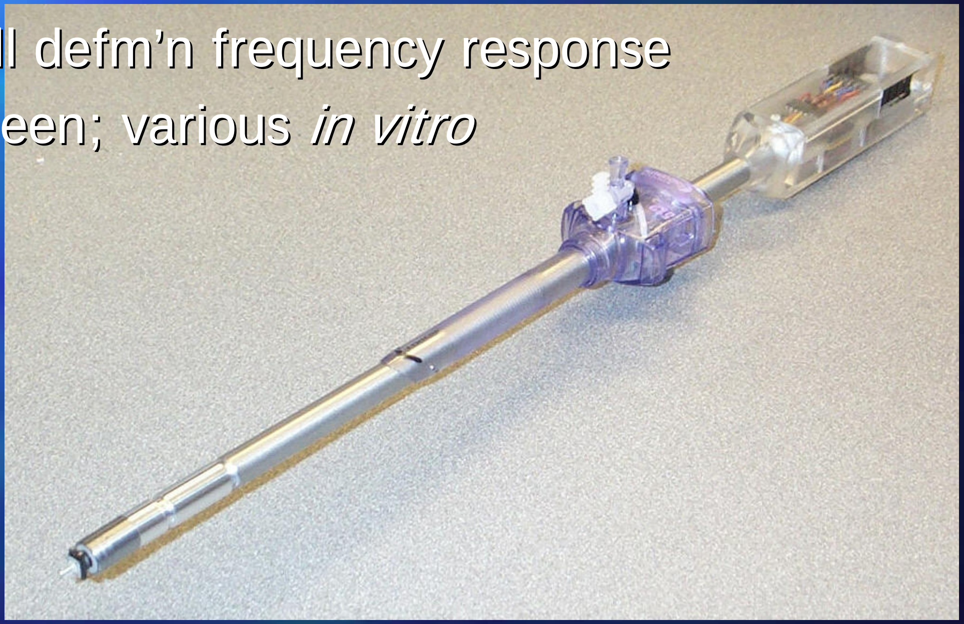


Carter et al., 2001, Med. Imag. Anal.

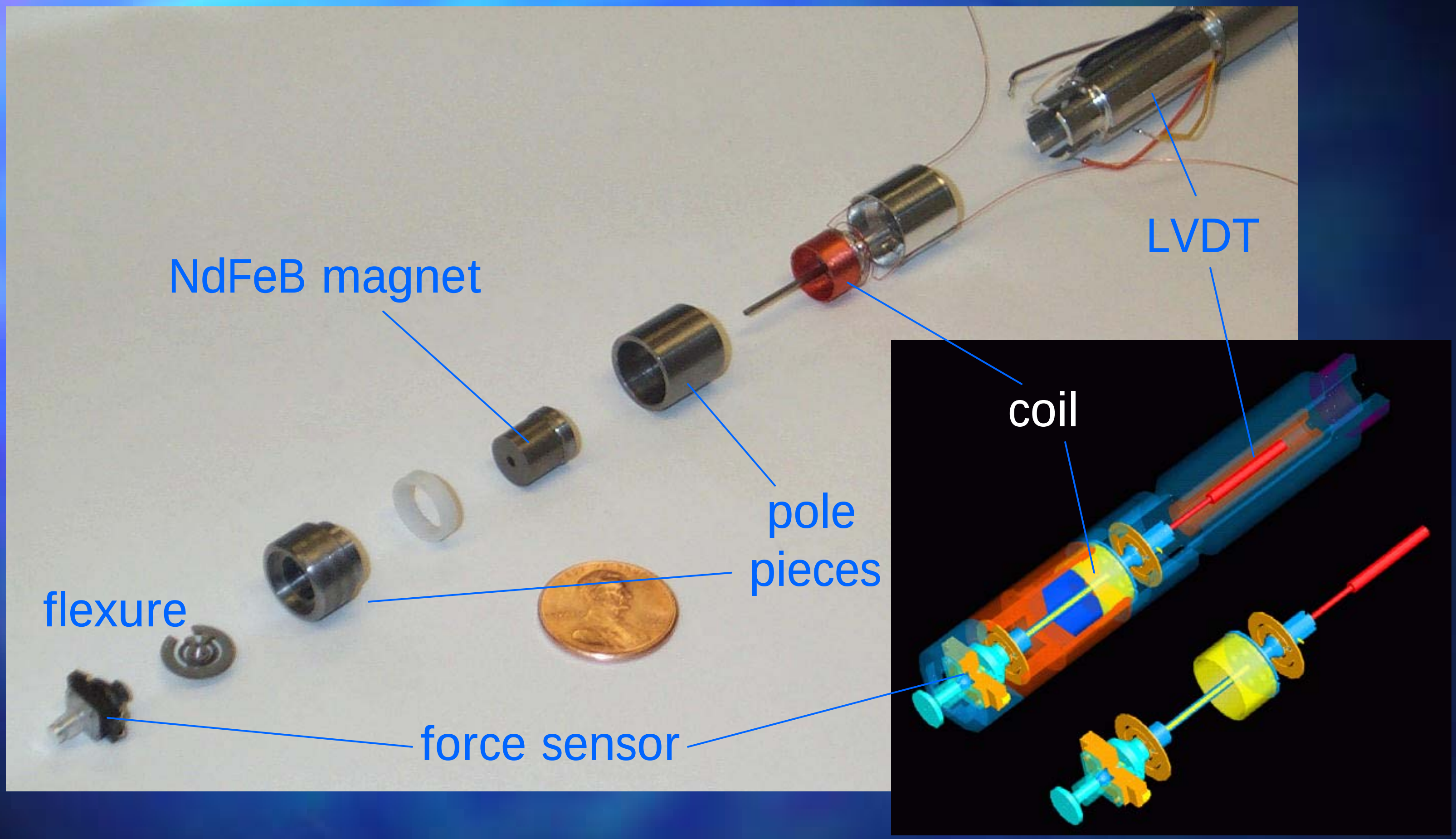


Compliance: indentation tests

- Haptics Laboratory, MIT
  - Ottensmeyer, Salisbury
  - support for planned laparoscopy simulator
  - minimally invasive; 2kHz sampling; 80Hz resonance; 1mm RoM; 300mN max force; 5mm flat cylindrical indenter, 12mm OD
  - characterization of small defm'n frequency response
  - *in vivo* porcine liver, spleen; various *in vitro*

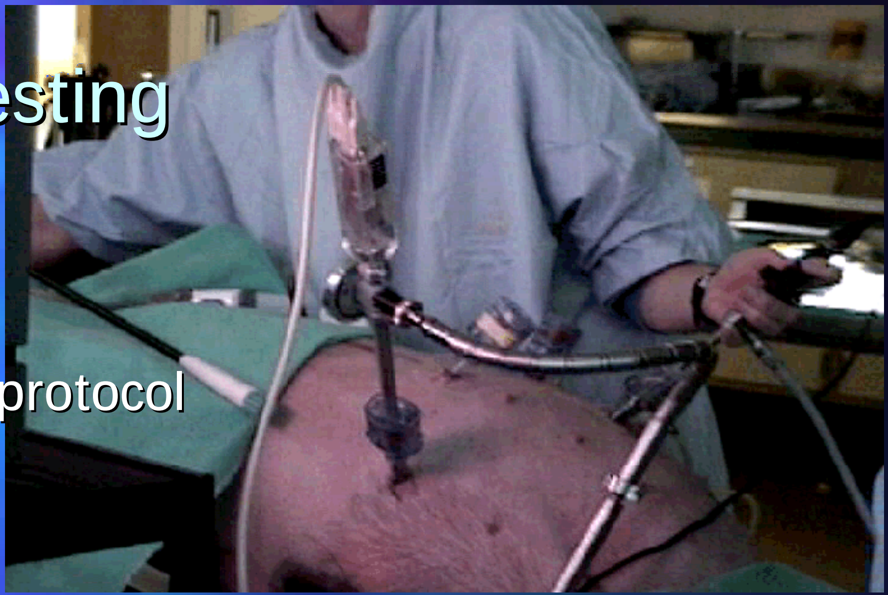


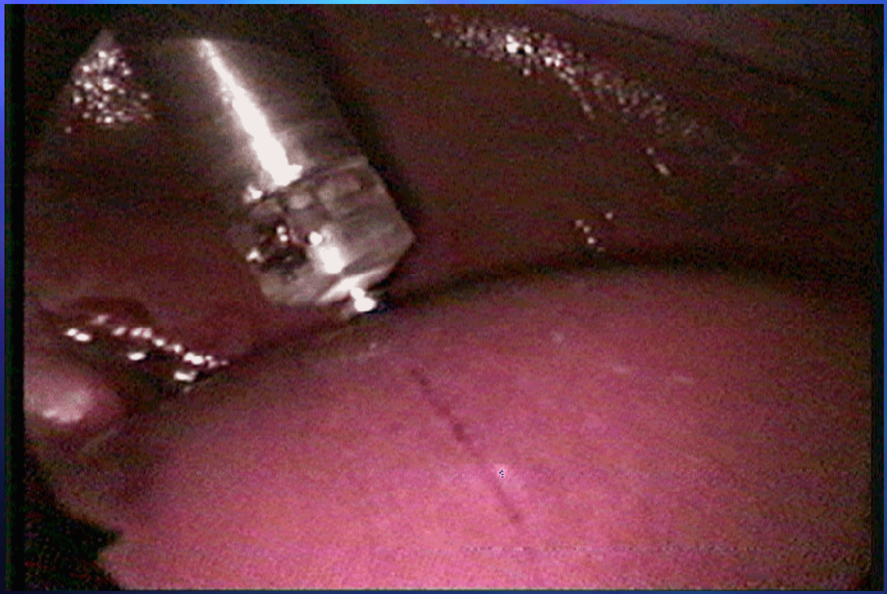
TeMPeST detail

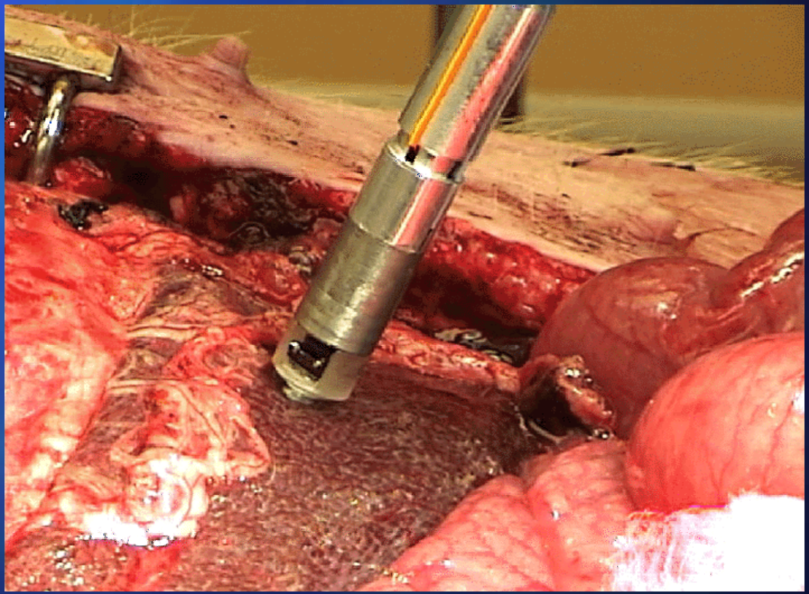


TeMPeST *in vivo* animal testing

- Details
  - ARC (Dartmouth), HCMIS
  - pigs in surgical tool testing protocol
  - laparoscopic & open
  - video clip

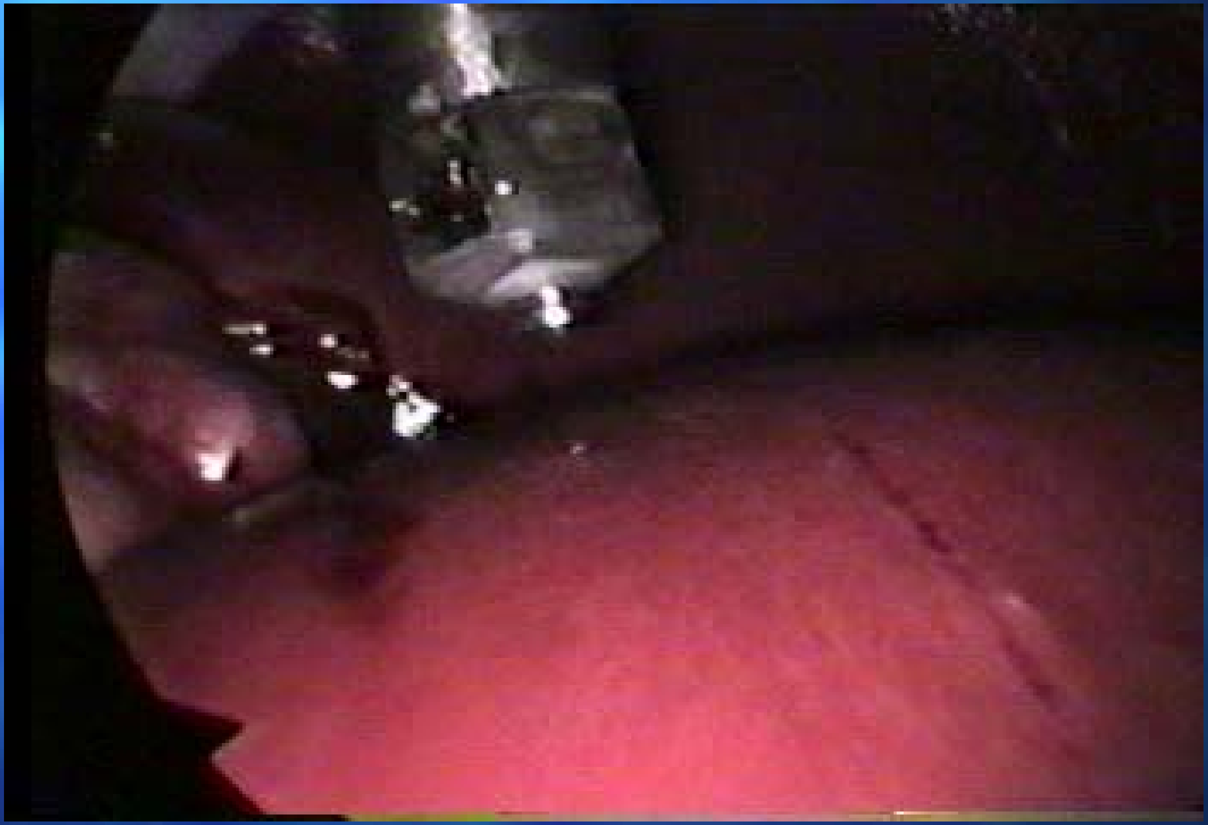






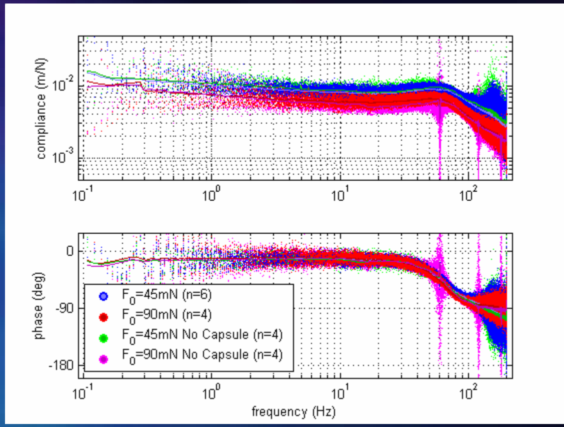
TeMPeST *in vivo* animal testing

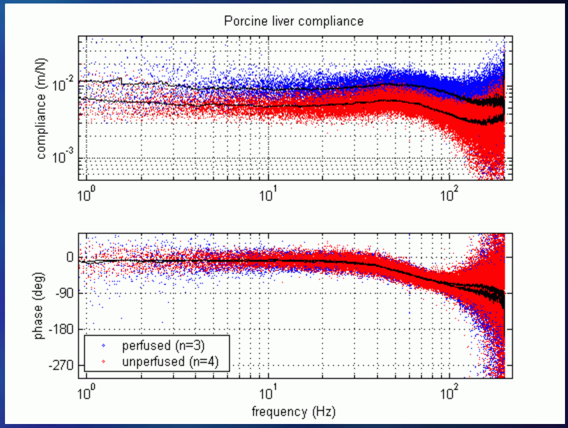
- Typical test sequence

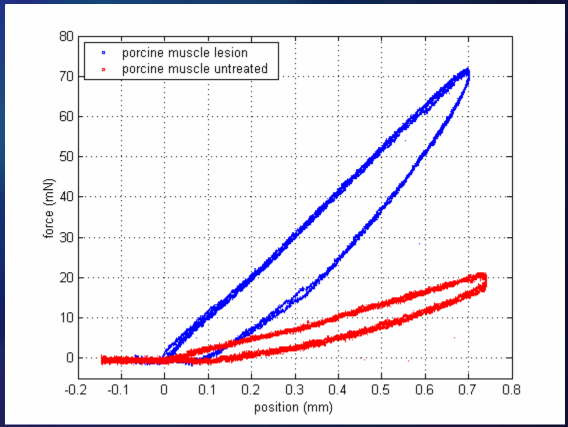


TeMPeST results

- A few examples...
  - examination of effect of capsule
    - stiffer than underlying parenchyma
  - effect of organ perfusion
    - blood pressure pre-stresses capsule
  - porcine muscle
    - quasi-static comparison of normal tissue with HIFU lesion







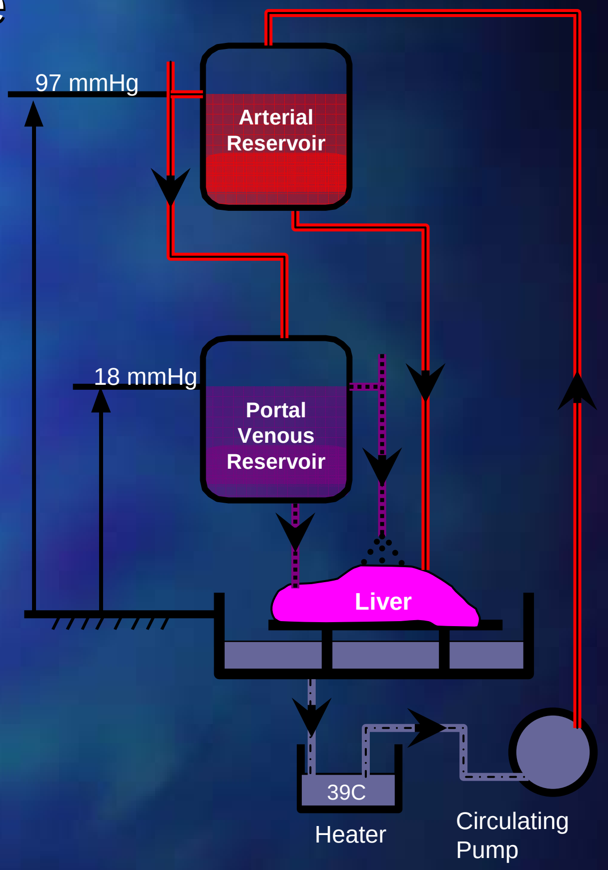
A short detour...

- *in vivo* "gold standard" subject to limitations
  - time, cardiac/pulmonary action, etc.
- *in vitro* problems
  - coagulation, loss of fluids, change in boundary conditions

- Perfusion
  - inspired by transplant literature, without chilling
- *in vitro* "silver standard"
  - maintain blood pressure (venous, arterial)
  - maintain temperature
  - maintain osmotic, oncotic balance

Normo-thermic Liver Perfusion System

- Perfusion system
  - provides physiological solution to whole organ
  - for liver: hepatic arterial and venous pressures, drains through portal vein
  - physiologic temperature control
  - hydration maintained
  - Lactated Ringer's w/dextrose, Hetastarch (osmotic & oncotic balance)

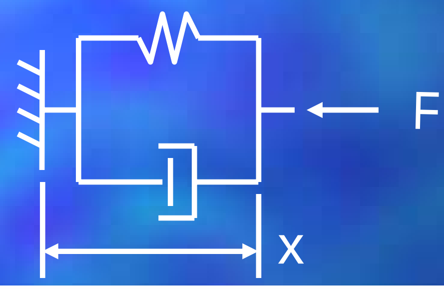


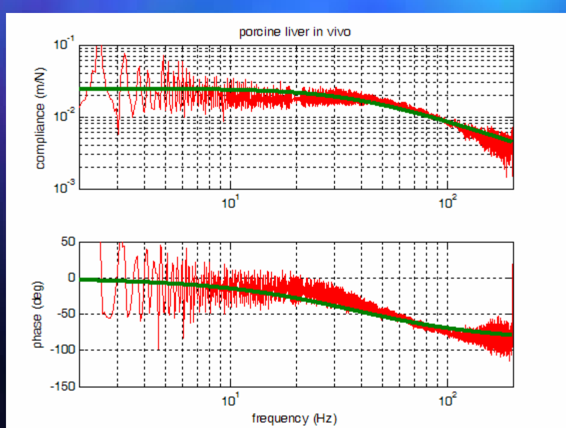
Perfusion Rig

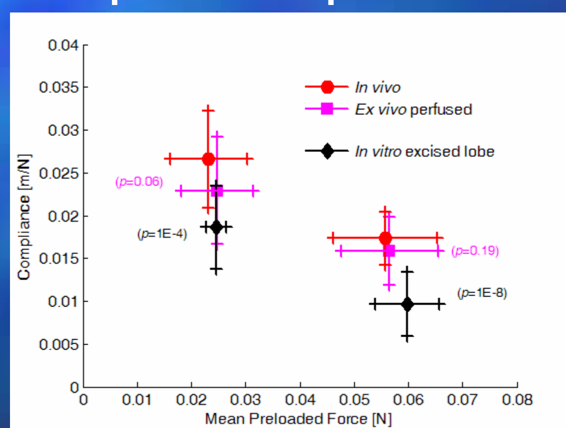
- Initial version
  - hydrostatic supplies of perfusate: high elevation for arterial supply, lower elevation for venous
  - pump, heater below bench

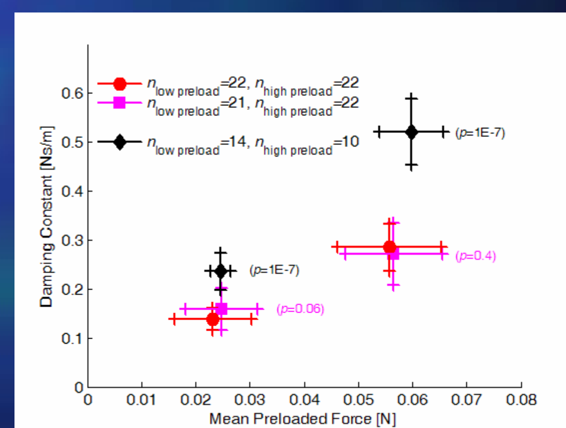
Perfusion validation

- TeMPeST tests
  - compared *in vivo*, perfused, unsupported conditions
  - response similar to linear spring-damper
  - statistical comparison of stiffness, damping coefficient



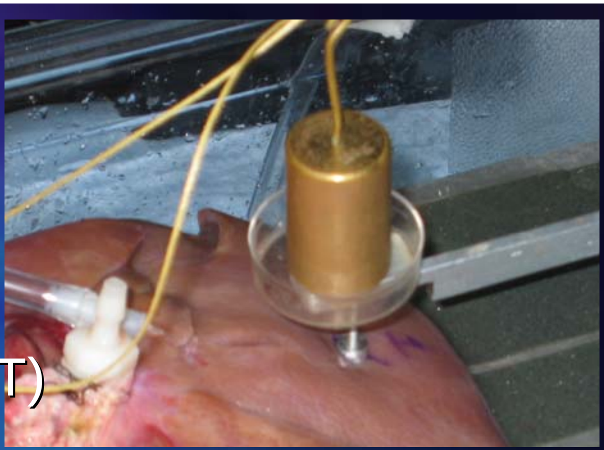


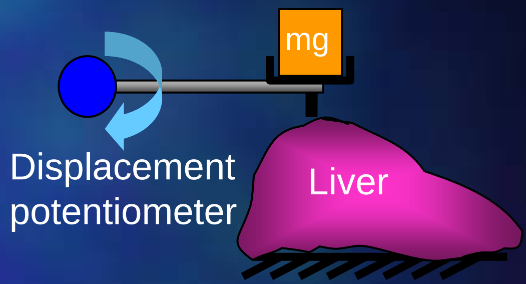


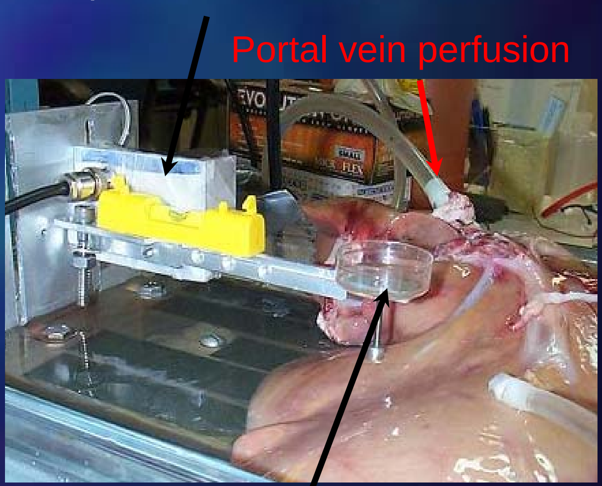


Compliance: indentation

- BioRobotics Lab, Harvard
  - Kerdok, Howe (BRL); Ottensmeyer (CIMIT)
  - large deformation tissue characterization
  - creep characterization, testing *in vivo vs.* perfused *in vitro vs.* unperfused *in vitro*
  - 0.25" flat cylindrical indenter; 1kHz sampling; 10mm RoM; 20/100/200g step load (manually placed); open abdomen
  - porcine liver *in vivo vs. in vitro*
  - validated perfusion system for large deformation



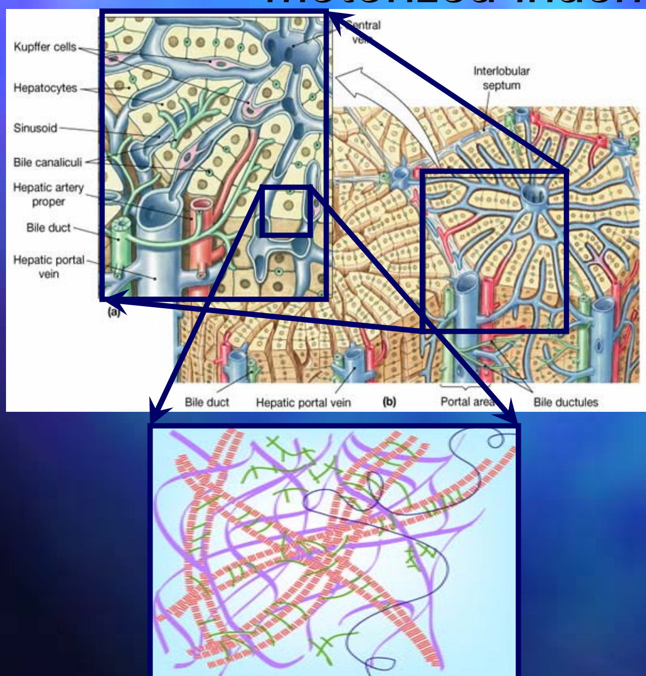


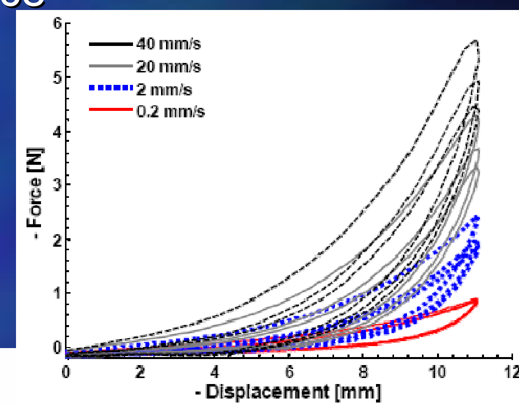


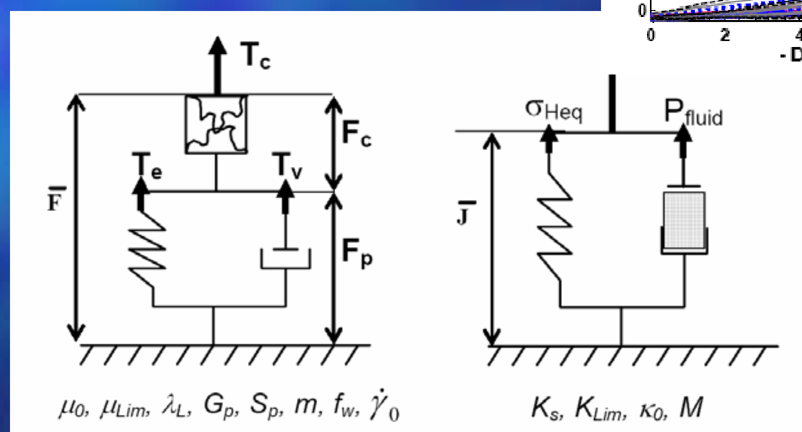
Indentor and weight cup

Compliance: modeling

- Improved model
  - liver anatomy suggests more complex model
  - hyperelastic, poro-viscous elements
    - Socrate/Kerdok modification of Arruda-Boyce
  - motorized indenter experiments







Compliance: indentation

- BioRobotics Lab, Harvard
  - Howe, Kerdok, Jordan
  - ElectroForce TestBench, *in vitro* w/perfusion system; 12mm motion
  - stress relaxation, arbitrary inputs
  - Non-slip suction contact
  - 3-D ultrasound

indenter tip

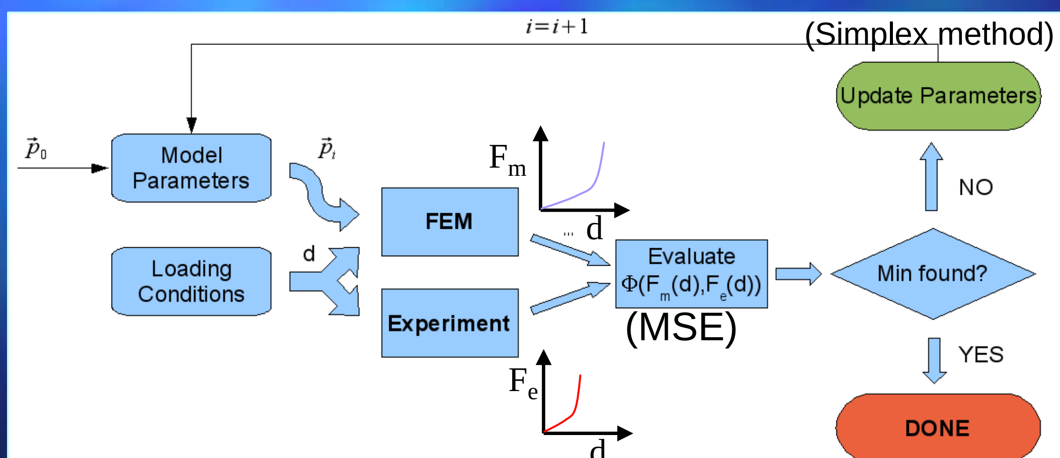
ultrasound probe

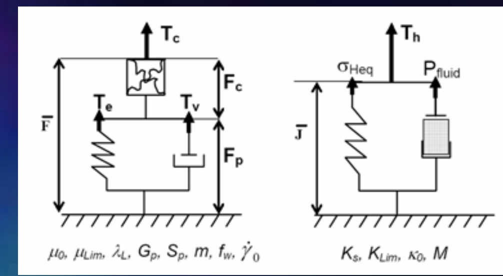
arterial reservoir

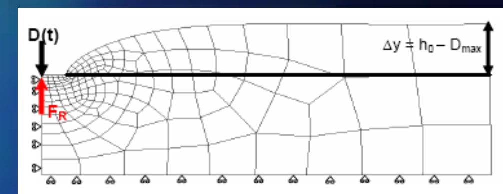
venous reservoir

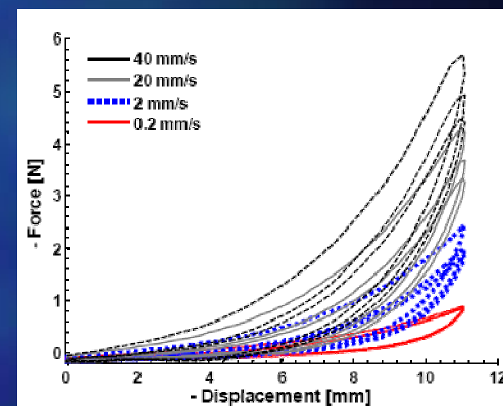
Compliance: parameter extraction

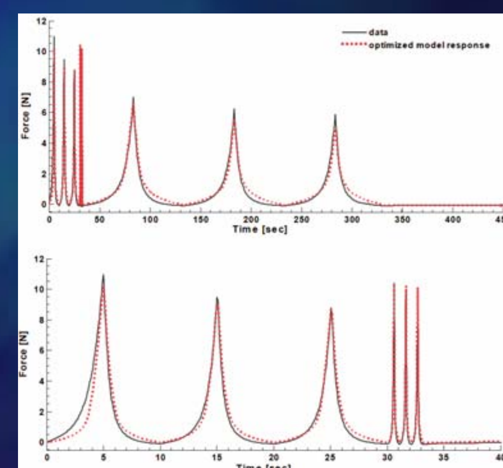
- Parameter identification algorithm
  - iterative FE approach
  - simulate with trial parameters
  - compare with experiment
  - update parameters
  - repeat until convergence



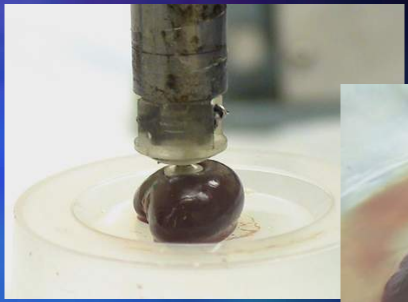




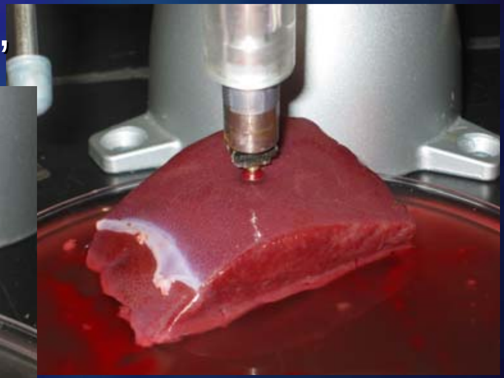


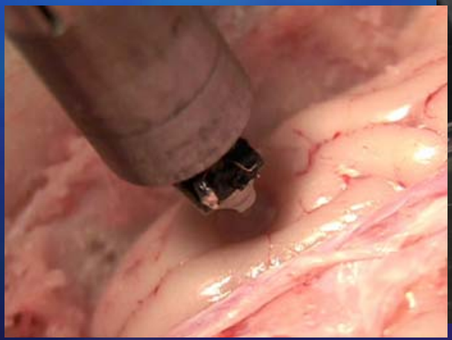


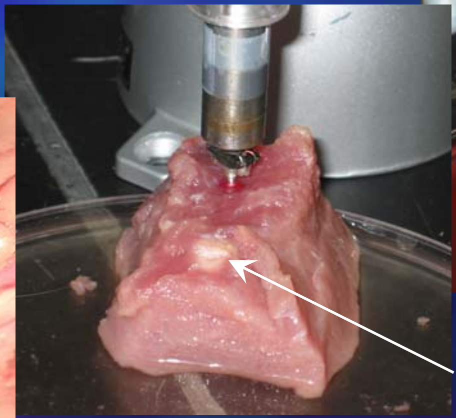
Compliance: more tissues



- *In vitro* tests
  - Rodent (rat) liver, kidney
    - NASA Ames/Stanford Virtual Rat Project
    - (Bruyns & Ottensmeyer, MICCAI'02)
  - Ovine, bovine, human vocal tissues
    - MGH Ctr. for Laryngeal Surgery & Voice Rehabilitation
    - Testing real tissues to quantify properties to develop compatible biopolymers
  - Porcine brain, muscle/liver
    - In situ cerebral cortex testing
    - Harmonic Motion Imaging (Konofagou et al., Ultrasonics'04)



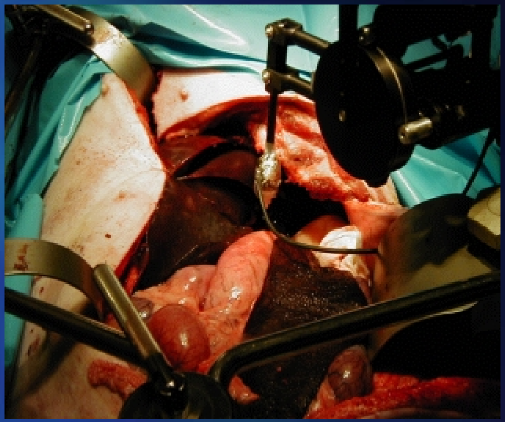


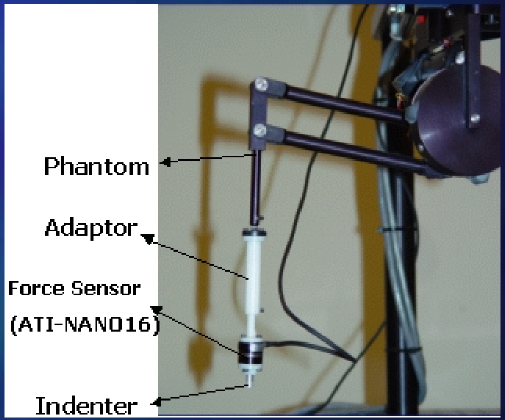


HIFU lesion

Compliance: indentation tests

- Phantom 1.5 (SensAble) – a neat little robot!
  - 125Hz mechanical resonance
  - 190x270x380mm workspace
  - 1.4N continuous force (8.5N max)
- Tendick (UCSF/Berkeley)
  - 20mm hemispherical indenter
  - *in vivo* porcine stomach/liver/spleen/skin
  - Brower et al., MMVR'01
- Srinivasan (MIT TouchLab)
  - ramp-hold, sinusoidal (0-3Hz) motion
  - 2mm flat cylindrical indenter
  - *in vivo* porcine liver/spleen/kidney/esophagus
  - Kim et al., MICCAI'03, Tay et al., MMVR'02
- De, et al. (RPI)
  - human cadaver measurements, in press

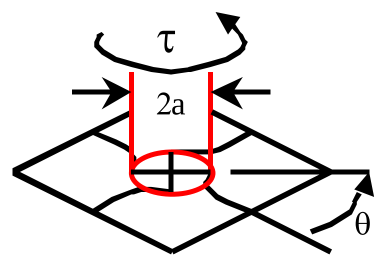




http://touchlab.mit.edu

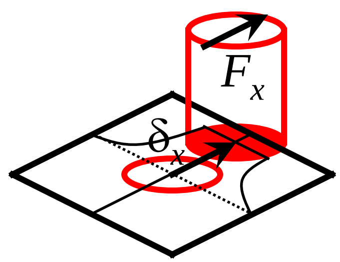
Compliance: shear tests

- Closed form solutions
  - semi-infinite, non-slip, isotropic, homogeneous, linear
- Torsional shear



$$E = \frac{3(1+\nu)\tau}{8a^3\theta}$$

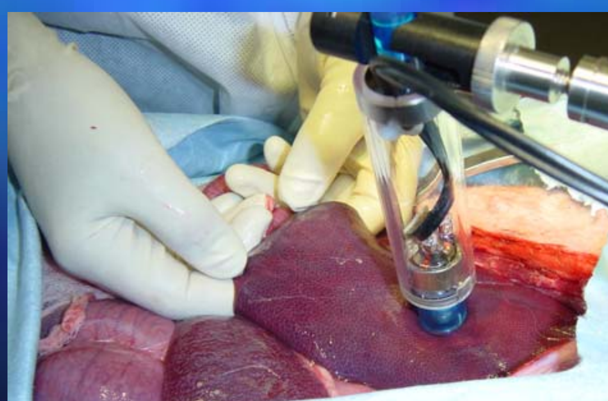
- Tangential shear



$$E = \frac{(2+\nu+\nu^2)\,f_x}{2\pi a\delta_x}$$

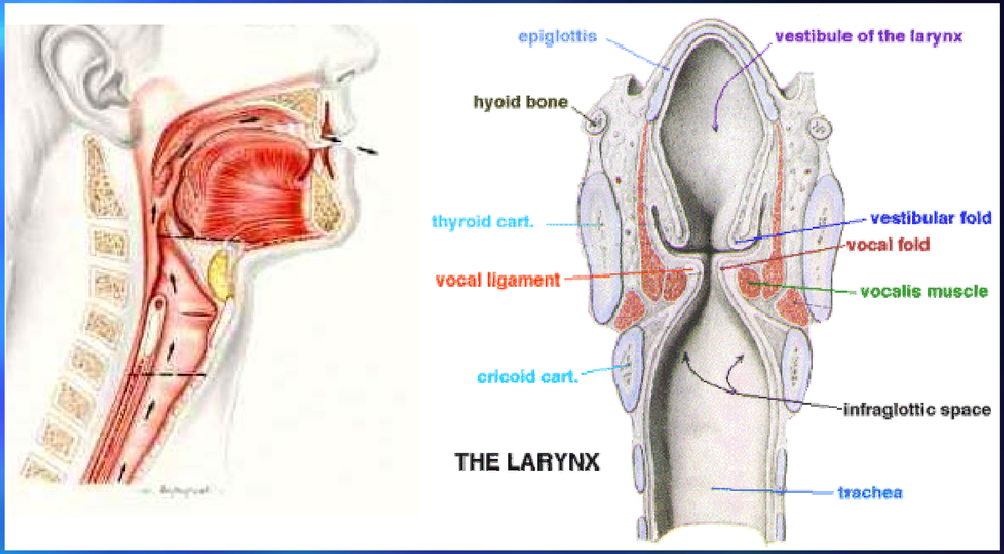
Compliance: torsional shear

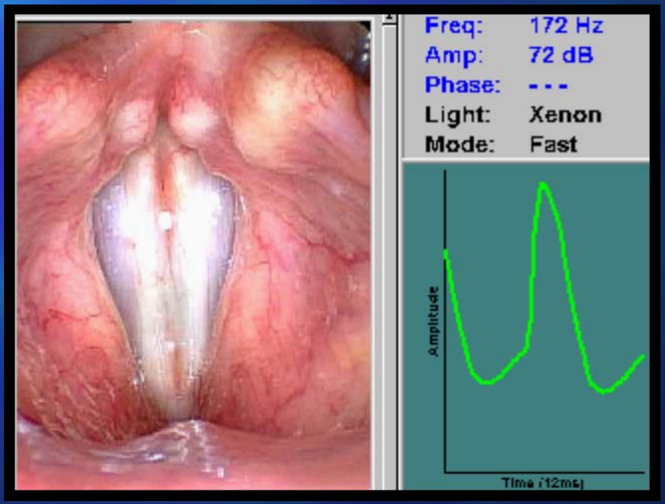
- ROSA2: Kalanovic/Gross (Tuebingen), Ottensmeyer
  - open surgery
  - appl'ns: tissue characterization, surg. sim.
  - 20Hz bandwidth; 30° RoM; 0.45mNm torque
  - 6mm needle/adhesive tip; reference ring 16/20mm ID/OD
  - *in vivo* porcine liver, *in vitro* bovine liver



Compliance: tangential shear

- The Larynx
  - airflow excites oscillation in vocal folds
  - stable, efficient sound production depends on geometry, visco-elasticity





Compliance: tangential shear

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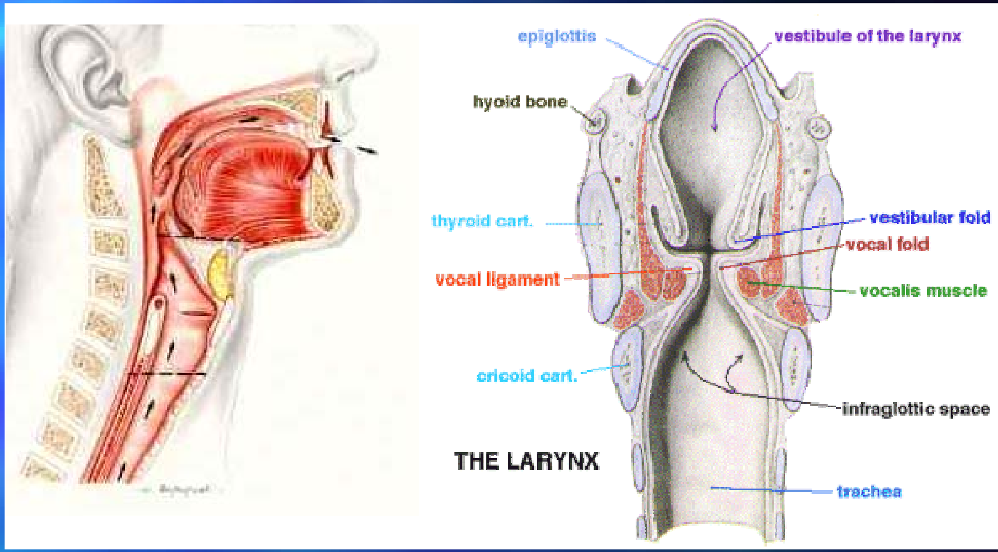


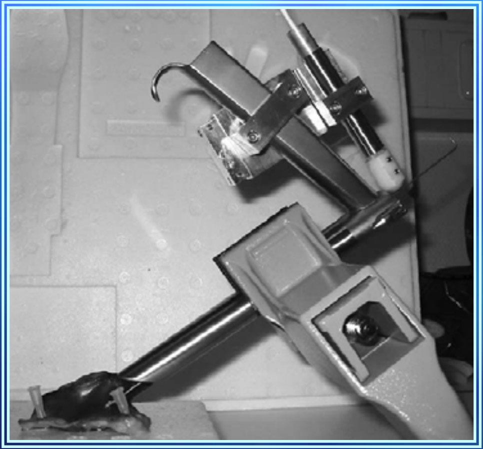
- Vocal fold damage
  - overuse
  - cancer
  - infectious disease

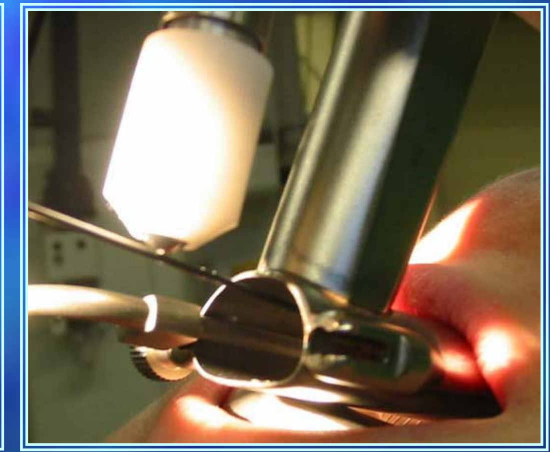
Compliance: tangential shear

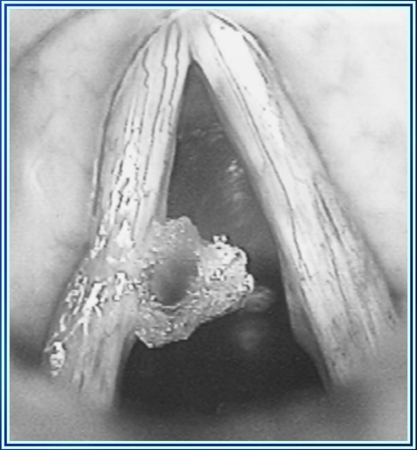
- Therapeutic concept:
  - Inject/implant biomaterial
    - synthetic gels
    - processed autologous fat
  - Necessary properties
    - long residence time; minimal inflammation, no rejection
    - *appropriate mechanical behavior!*
  - Two-part challenge
    - measure normal, healthy tissue response
    - measure implant behavior to confirm success

Compliance: tangential shear

- DeMontfort U., Leicester, UK
  - Goodyer et al. 2006a,b:
    - human in vivo, quasi-static
    - fixed displacement step shear
    - pharmaceutical adhesive bonding
    - G = 0.7-2.2 kPa (possible over-estimate?)

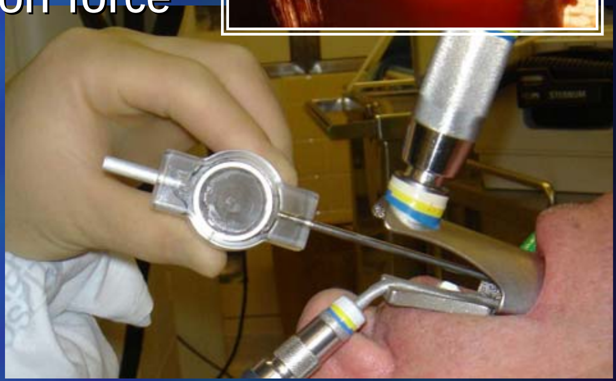


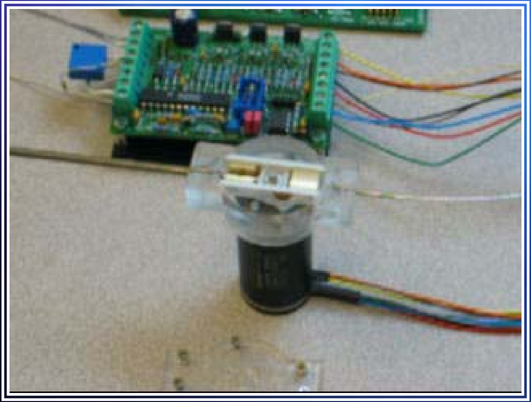


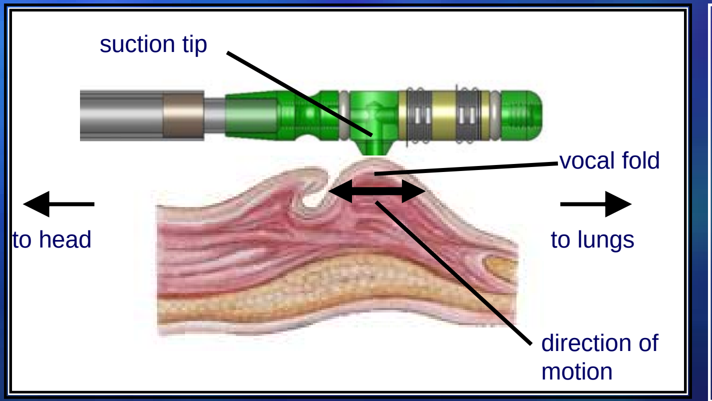


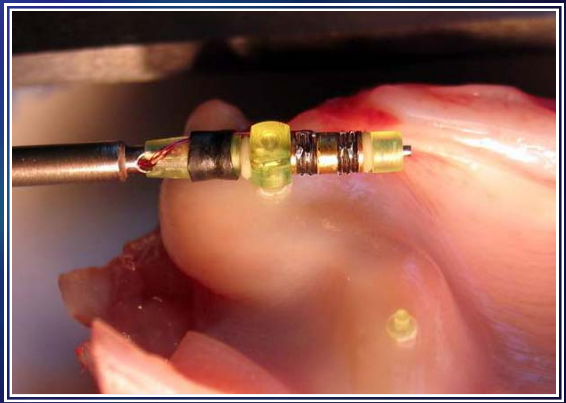
Compliance: tangential shear

- Early tests with TeMPeST
  - unsuitable for intra-operative use
- Development of VoCCI
  - imposes tangential oscillation, records reaction force
  - Scotch yoke drive to >250Hz
    - human vocal fundamental from 100-300Hz
    - 50% strain



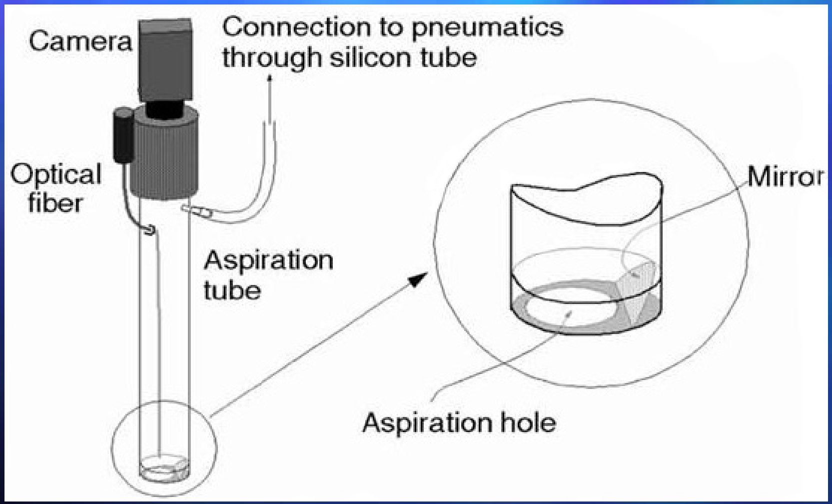


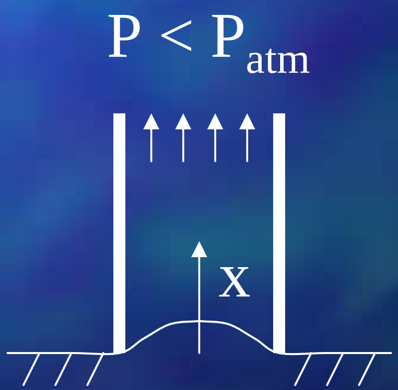


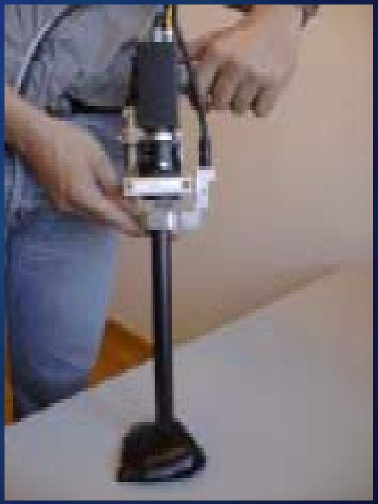


Compliance: *last one!* Aspiration testing

- ETH Zurich, Switzerland
  - Surgical simulation, prediction of cervical incompetance (loss of pregnancy)
  - human cervix in vivo, ex vivo; human liver
  - need for sterility
  - 30Hz frame rate; 3mm displacement observed; 100mbar vacuum; 12mm circular opening

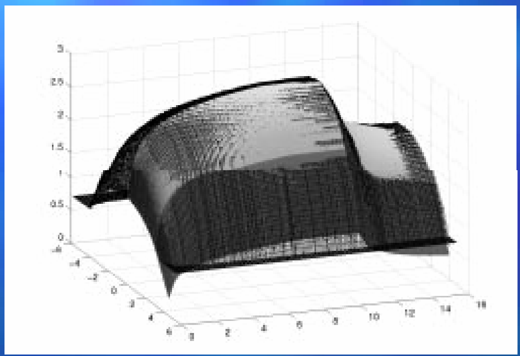


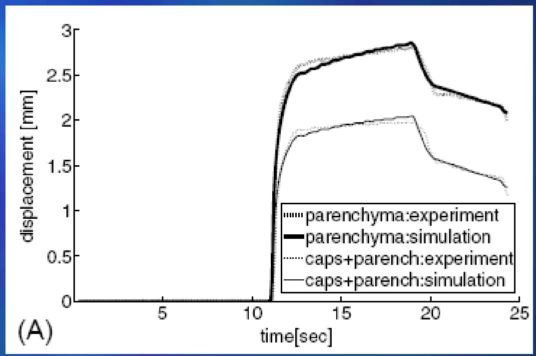


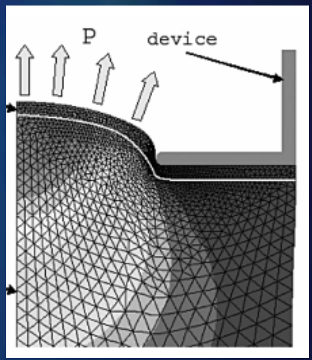


Compliance: aspiration testing

- Hollenstein et al., ISBMS'06
  - stronger pre-conditioning effect ex vivo
  - QLV model with capsule
  - parameter extraction using FEA





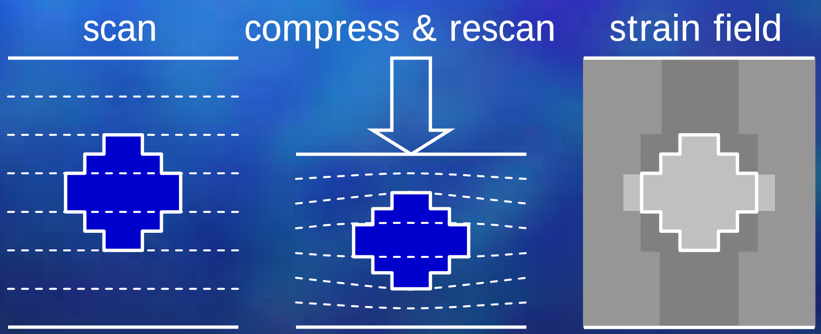


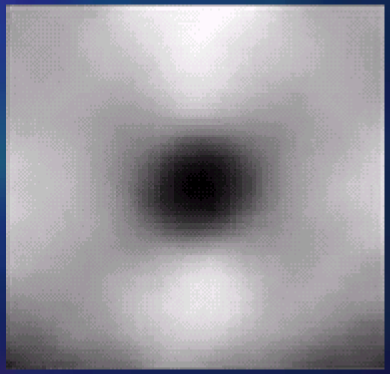
Elastography

- Imaging techniques
  - Ultrasound
    - Real-time imaging (& inversion)
    - Mechanically deform tissue / focused US shear waves
    - 2-D imaging (with a few exceptions)
    - Estimate 3-D strain tensor
  - Magnetic Resonance Imaging
    - 3-D imaging, arbitrary directions w/equal sensitivity
    - Long scanning/computation times

Elastography

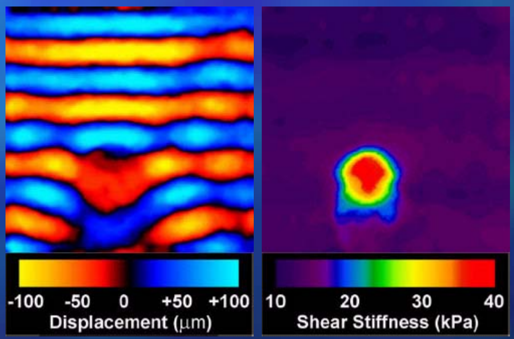
- Static deformation
  - Ultrasound: Ophir, et al., 1990
  - Magnetic Resonance Imaging: Plewes, et al. 1995
  - US: Scan pre- & post-deformation
  - Normalize, calculate strain & invert
  - Note strain artifacts





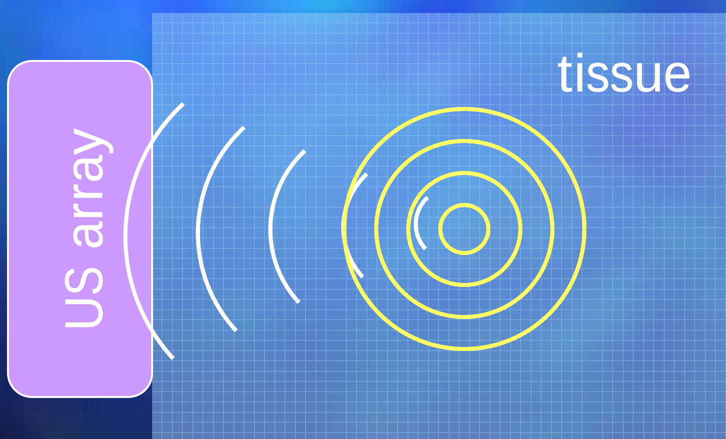
Elastography

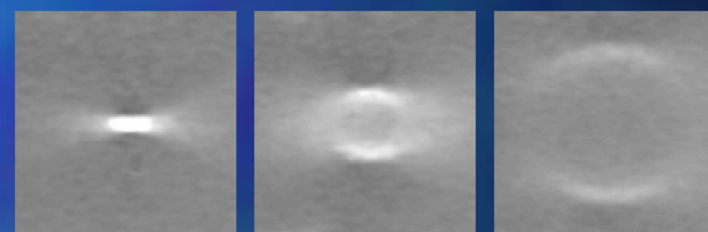
- Dynamic testing: mechanical stimulation
  - Lerner, et al., late '80s: "sonoelasticity imaging"
  - Muthupillai/Manduca/Ehman, ~'95: MRI
  - Mechanical surface vibration (normal or shear)
  - Measure local velocities/amplitude/shear wave velocity
  - Invert amplitude or direct calculation from shear wave velocity
    - $G = v_s^2\rho$ for Hookean, isotropic medium

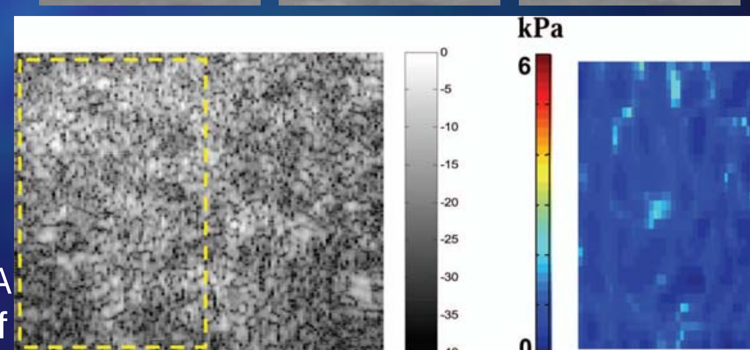


Elastography

- Dynamic testing
  - Focused ultrasound as stimulus
    - Create local impulse (or train of impulses)
    - Observe traveling shear wave with high frame rate U/S
    - Elasticity related to shear wave velocity
    - Linear viscoelastic model: displacements ~10 μm
    - Fink: Supersonic Shear Imaging: healthy human breast tissue, 1-3kPa Young's mod. (Bercoff et al., IEEE Ultrasonics Symp'03)







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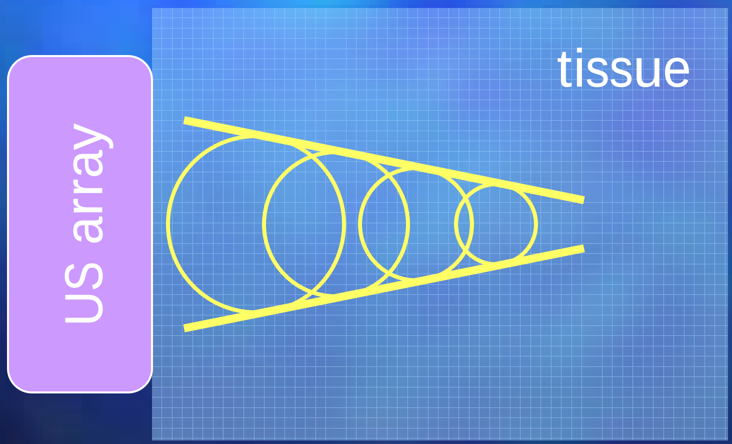
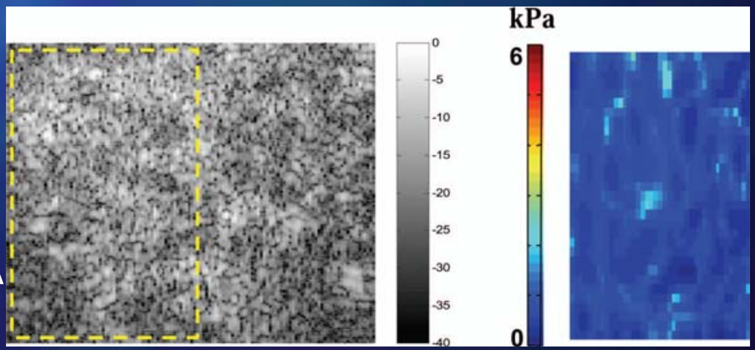
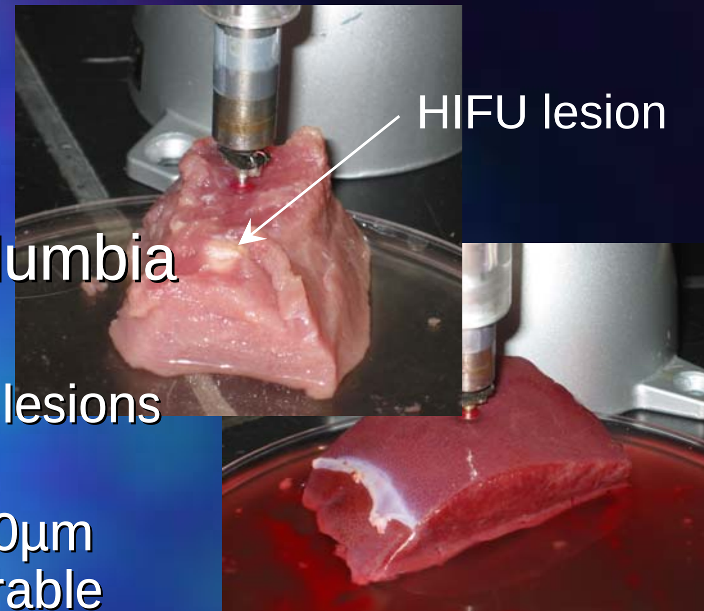
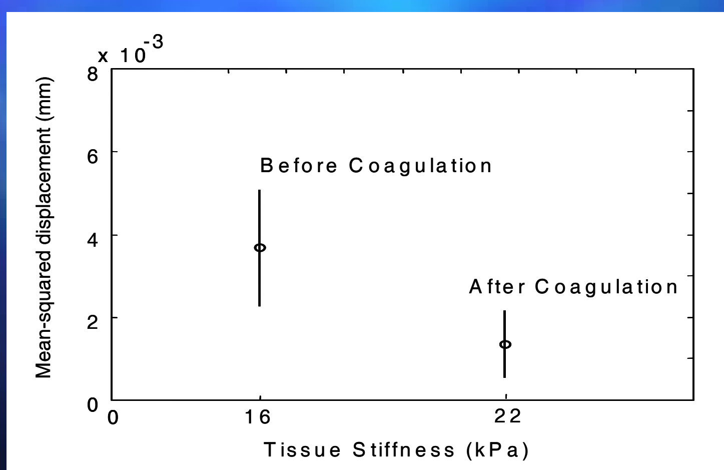


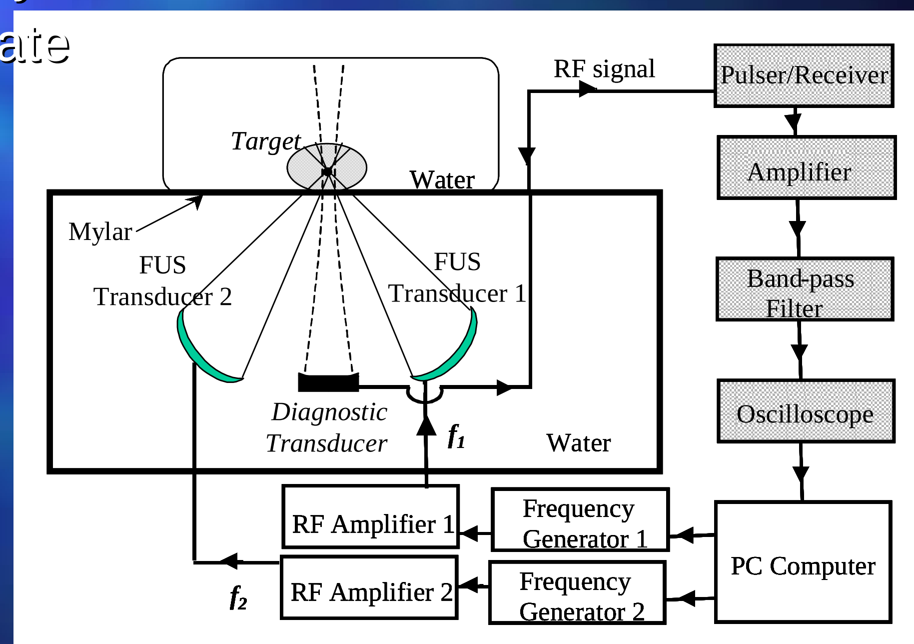


Elastography

- HMI: Konofagou, et al.; BWH/Columbia
  - *in vitro* so far
  - appl'ns: creating and characterizing lesions in tissue (e.g. tumor ablation)
  - 200 & 800 Hz harmonic force; ~5-10µm amplitude; force not directly measurable
  - *in vitro* liver & muscle to date

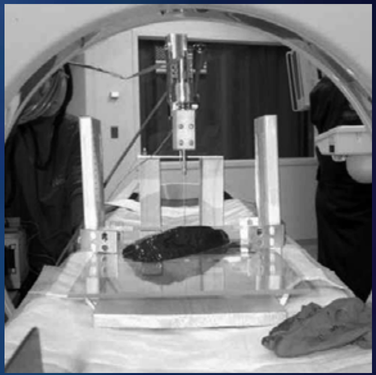


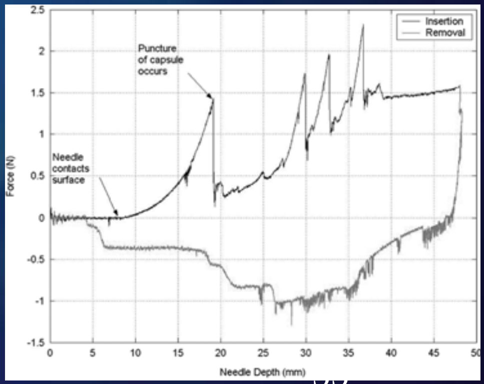




Cutting & Needle Insertion

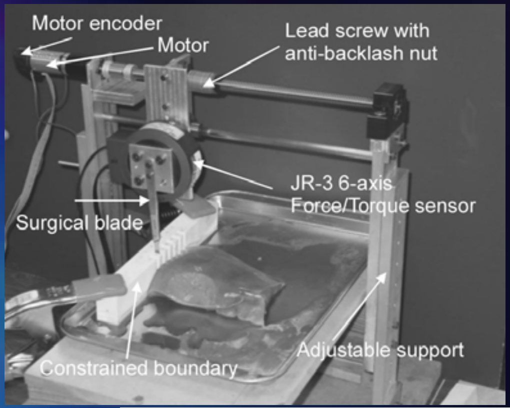
- More limited data, instruments
- Tendick (Brower et al., MMVR01)
  - measuring tool force on needle driver & scissors
  - 6-dof needle force, 1-dof cutting/spreading
  - 30Hz sampling
  - 3-0 suture through porcine stomach wall,
- Okamura, Haptics Exploration Lab, JHU
  - scissor cutting forces
    - IEEE Trans.Rob.'07, in press
  - percutaneous sim & needle insertion modeling
    - Elastic response, puncture, Karnopp friction
    - Okamura et al., IEEE TBME'04

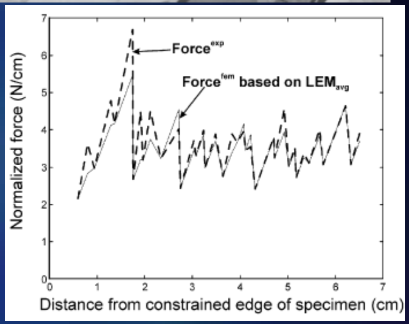


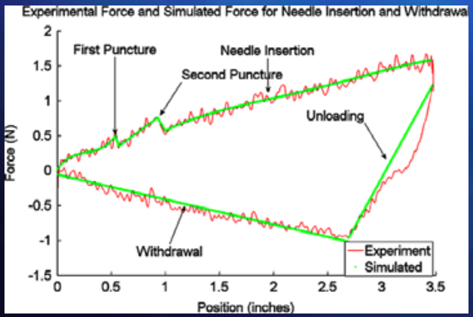


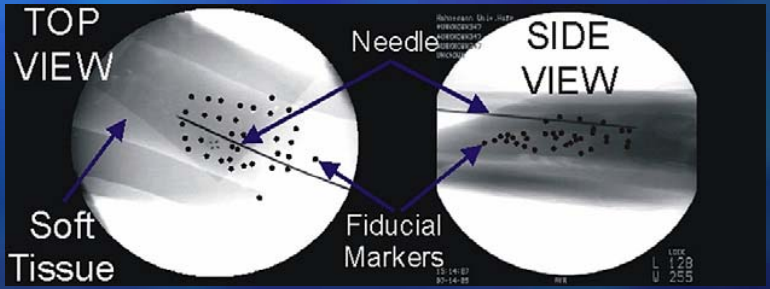
Cutting & Needle Insertion

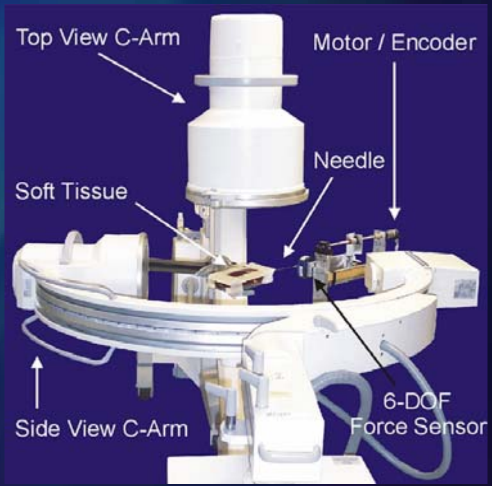
- Desai, RAMS Lab, U.Maryland
  - single blade cutting
    - varying cutting speed, blade angle
    - developed model predicting elastic slope, fracture model
    - Chanthasopeehpan et al., TBME'07a,b
  - needle insertion
    - fluoro imaging of tissue, needle, internal fiducials
    - position/force tracking, porcine tissue in vitro
    - generated simulation w/haptics of needle insertion





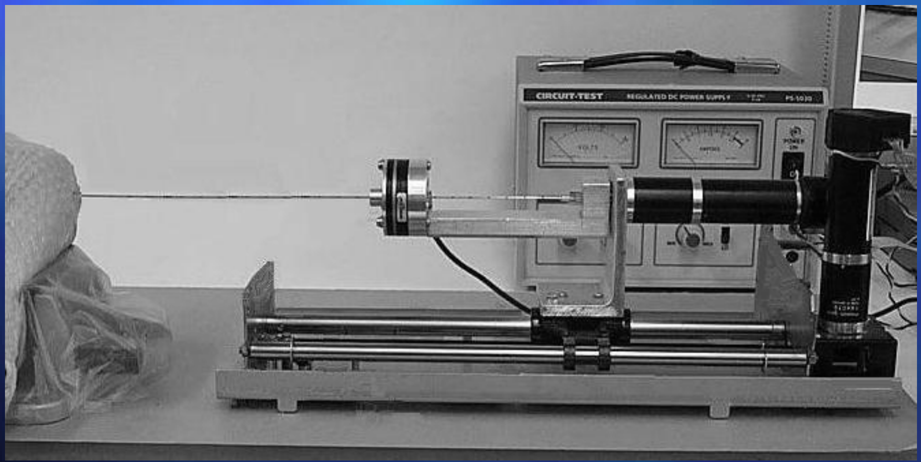


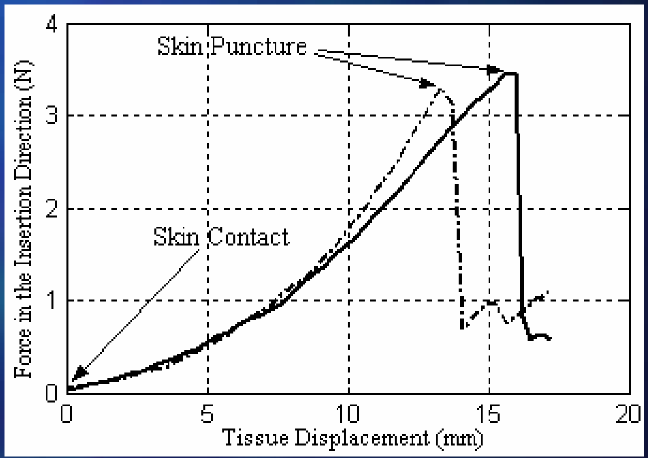




Cutting & Needle Insertion

- U.Western Ontario, Canada
  - Abolhassani, ProcEMBS'04
  - bevelled needle insertion for prostate brachytherapy
  - axial/rotational instrument, 6-DoF force sensing
  - turkey tissue model, insertion rate testing
  - Excellent survey paper: Abolhassani et al., MedEng&Phys'07





Summary

- Wide range of techniques
  - compliance testing
    - compression, tension, indentation, torsion, aspiration
    - quasi-static to 100Hz—full range of surgical strain rates
    - extremely small to large deformations
  - elastography, coming up, some clinical uses
    - small deformations have questionable application to surg. sim.
    - current applications for diagnostic purposes
  - topology-altering testing
    - needle insertion, scalpel, scissors
    - limited available data

  - growing body of *in vivo* data, including *human*
    - still need more organs, improved constitutive models (& parameters), healthy vs. other conditions...

And a few other notes...

- AIMS: Advanced Initiatives in Medical Simulation
  - 501(c)(6) non-profit consortium (“lobby group”)
  - promotes medical simulation for improving patient safety, reducing errors, ensuring competency, reducing costs...
  - improve awareness, unify the “message”, secure resources
  - Enhancing SIMULATION Act, 2007 (H.R.4321)
    - (**S**afety **I**n **M**edicine **U**tilizing **L**eading **A**dvanced Simulation **T**echnologies to **I**mprove **O**utcomes **N**ow)
    - reps Forbes (R-VA), Kennedy (D-RI)
- SAVE THE DATE: 5th Annual AIMS Conference & Exhibition
  - May 6-7, 2008, Washington, DC
  - attended by industry, academia, members of congress
- www.medsim.org

And a few other notes...

AIMS
Educating America about the Value of Medical Simulation
Advanced Initiatives in Medical Simulation

- AIMS: Advanced Initiatives in Medical Simulation

HR4321 calls for:
- federal funding for Centers of Excellence for med sim R&D
- support for solving challenges in med sim
- grants for academic sites to acquire simulators
- support to develop curricula integrating simulation
- grants to accreditation organizations for standards development
- federal med sim coordinating council
- $50,000,000 for FY'08, sums as necessary for FY'09-'12

- SAVE THE DATE: 5th Annual AIMS Conference & Exhibition
  - May 6-7, 2008, Washington, DC
  - attended by industry, academia, members of congress
- www.medsim.org

And a few other notes...

- ISBMS'08: International Symposium on Computational Models for Biomedical Simulation
  - July 7-8, 2008. London, UK
  - www.imperial.ac.uk/medicine/isbms08
  - Topics of Interest:
    - anatomical modeling; hard & soft biomechanics; physiological models; validation; simulators; haptics; GPU-based sim; etc.
  - 12 March 2008: full papers due (8 page max)
  - successor to IS^{4}TM'03 (INRIA), ISMS'04 (CIMIT), ISBMS'06 (ETH)

And a few other notes...

- IMSH'08: International Meeting on Simulation in Healthcare
  - January 13-16, 2008. San Diego, CA
  - www.ssih.org
  - Users, developers, stakeholders in mannequin & computer-based simulators, VR systems, standardized patients, task trainers
  - This year: 1st Technology Track workshop series
    - physical sim development; software-based sim (Harders); cross-platform issues (tissue props, realism, etc.); contact between end users and academic/industrial developers

Questions & further information

www.medicalsim.org

www.cimit.org

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