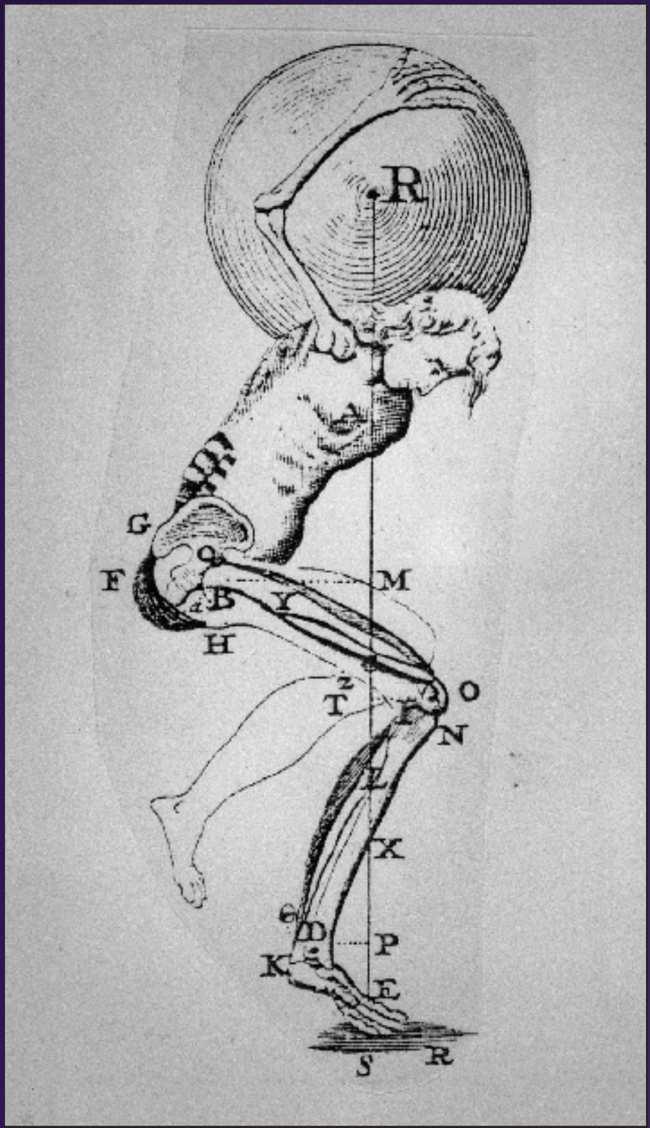


Musculoskeletal Biomechanics

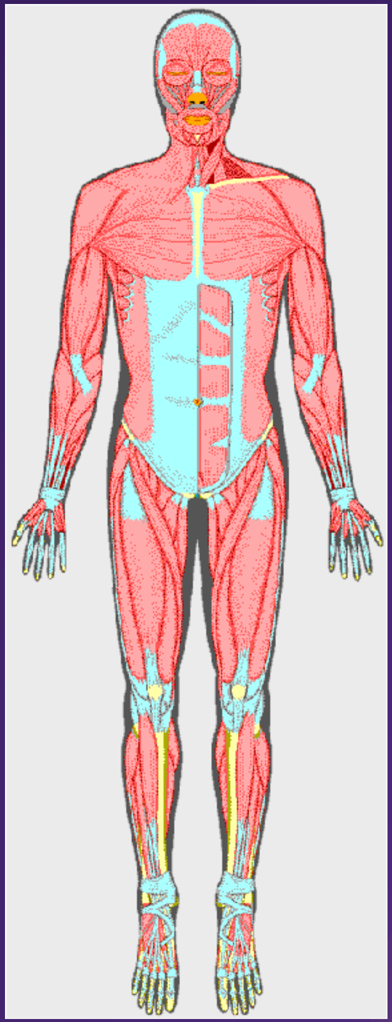
BIOEN 520 | ME 527

Session 12A

Biomechanics of Joint Systems

Review Musculoskeletal Structures…
[Sessions 9-10]

- Bone
- Ligament
- Tendon
- Cartilage (disc, meniscus/labrum)
- Muscle



Session 12A Discussion Questions...

[Q]: What are the types and function of joints?

[Q]: What are the common features of synovial (diarthrodial) joints?

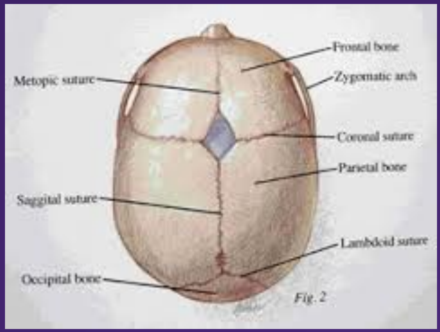
[Q]: What mechanical properties of joints are generally of interest and why?

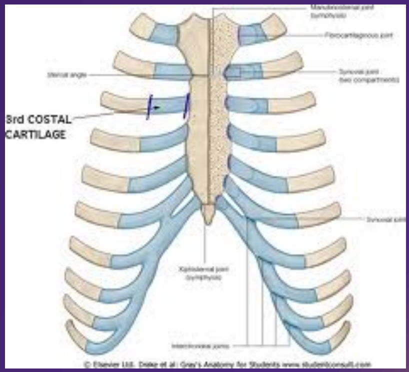
[Q]: What is the #1 joint disease and how might abnormal mechanics play a role?

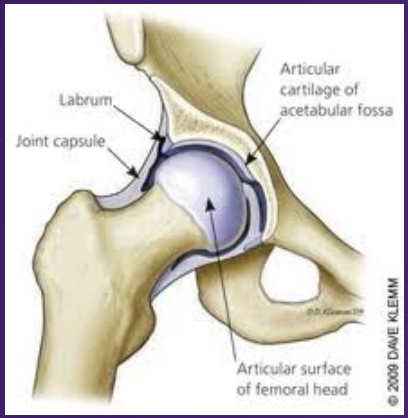
Joint Systems...

[Q]: What are the three main types (classifications) of joints?

- Fibrous
- Cartilaginous
- Synovial



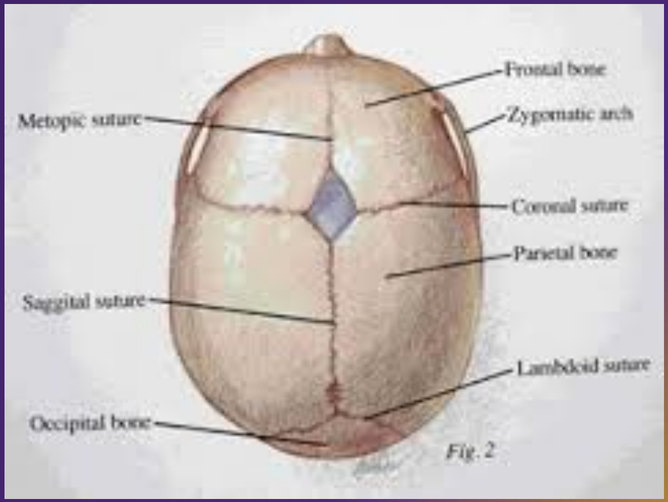




Joint Systems...

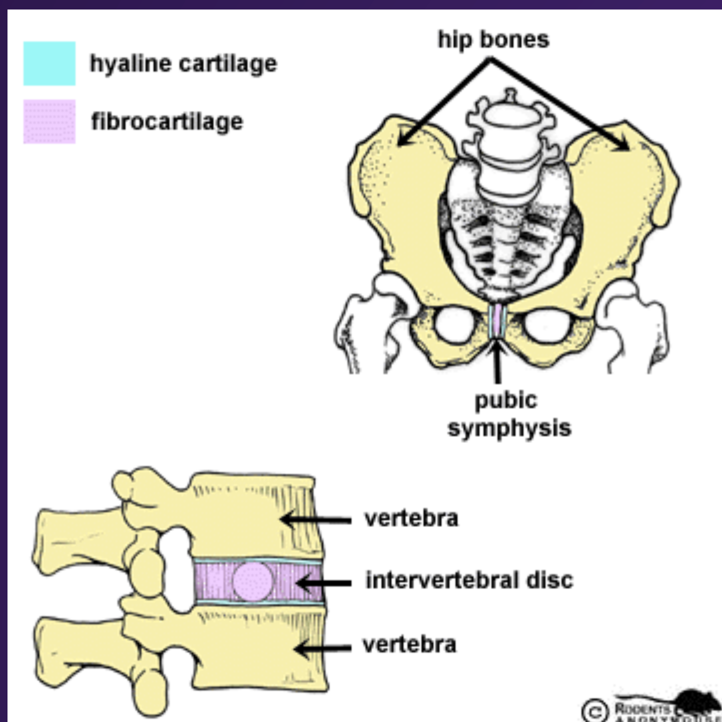
- Fibrous Joint
  - Function? To stabilize; very little movement…

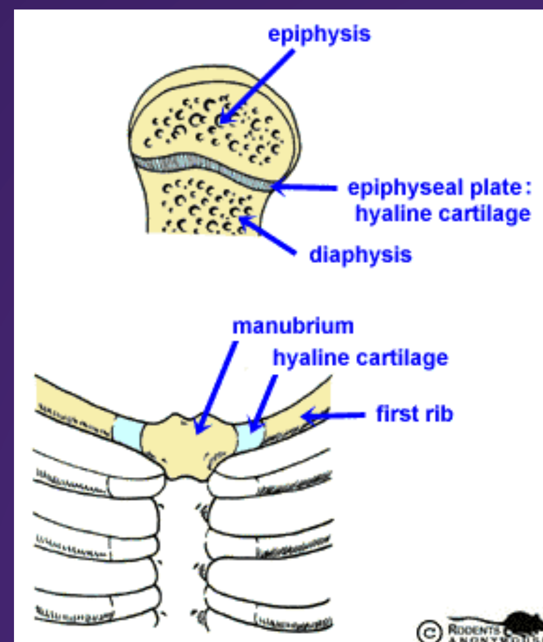
Ex: Skull suture



Joint Systems...

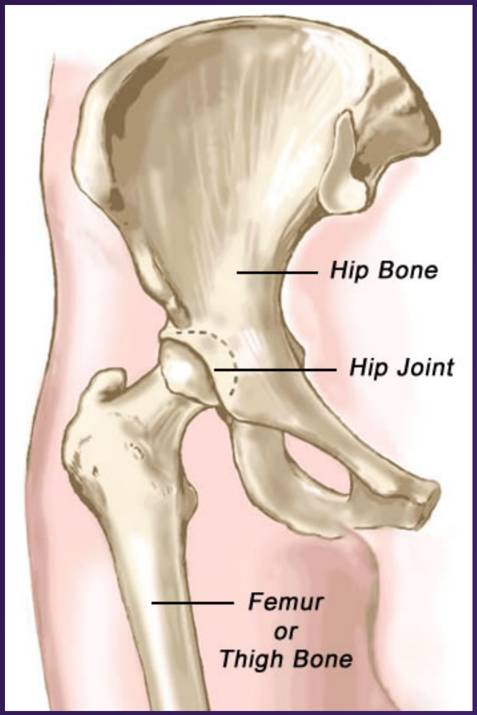
- Cartilaginous Joint
  - Function? Facilitates small relative movements...

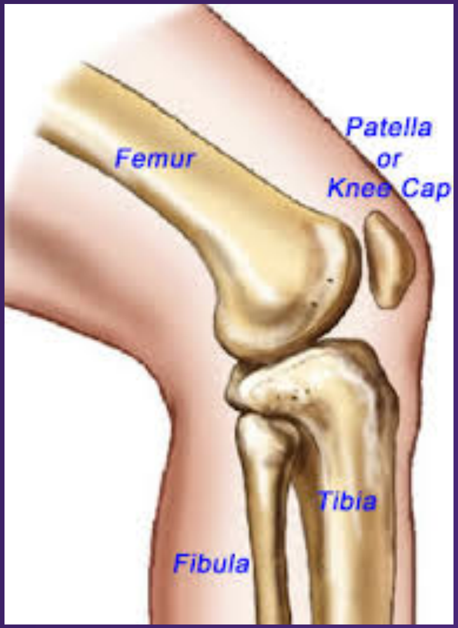




Joint Systems...

- Synovial (Diarthodial) Joint
  - Function? Enables large movements...



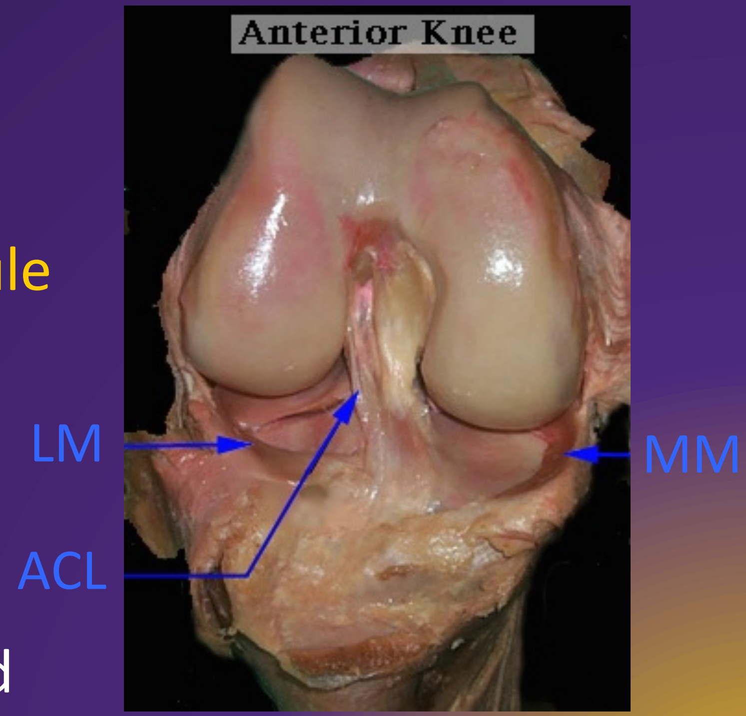


Ex: Hip, knee, elbow, shoulder, etc.

Synovial Joints…

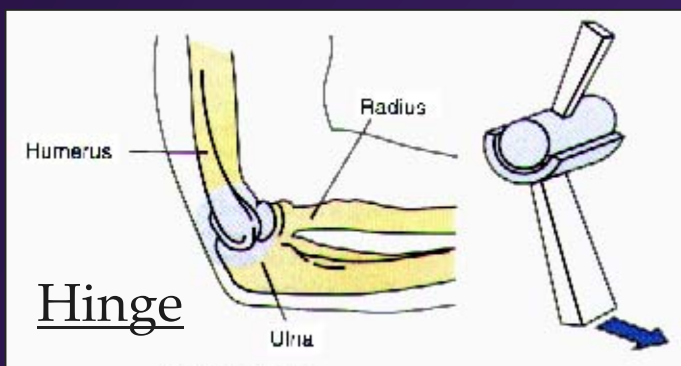
[Q]: What are common structures and features of synovial joints?

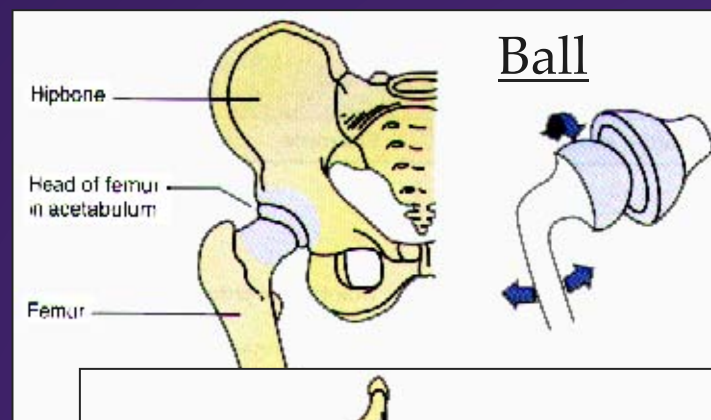
- Ends of bone lined with articular cartilage
- Encapsulated in fibrous capsule
- Capsule lined with synovium
  - Secretes synovial fluid
  - Provides nutrients/removes waste
- Stabilized with ligaments (and tendons)

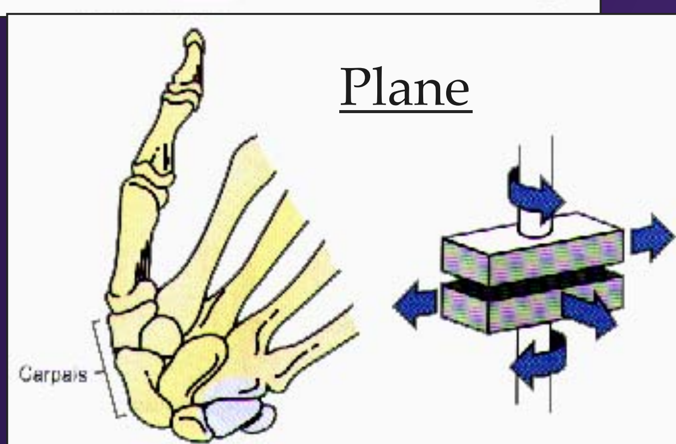


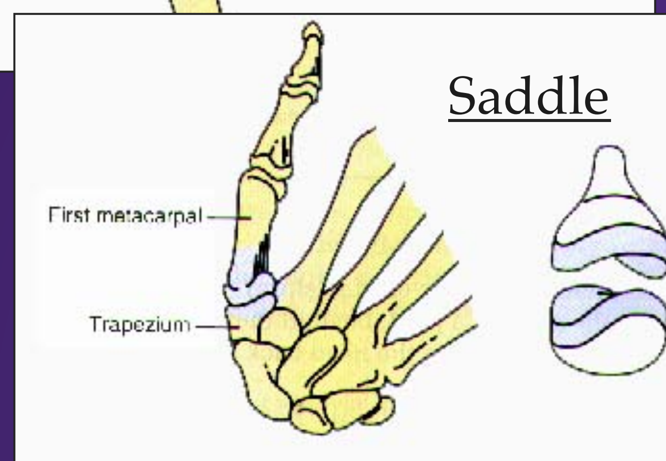
Synovial Joints…

[Q]: What are some common mechanical (functional) analogs for synovial joints?





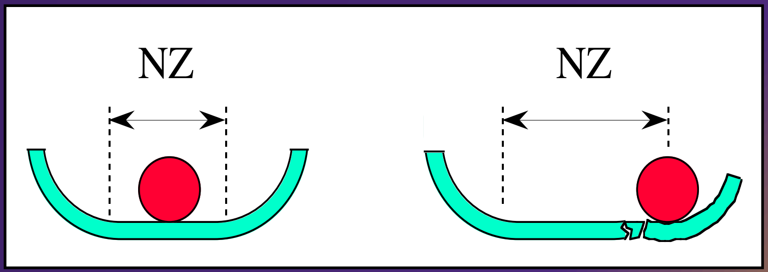




Synovial Joints…

[Q]: What mechanical properties of joints are typically of interest?

- Joint forces and moments… (physiologic and non-physiologic)
- Joint range of motion and stiffness…
- Joint kinematic corridors… (normal vs. pathologic)
- Joint stability…



Ching (1992)

Synovial Joints…

[Q]: Why are joint mechanics (forces) important?

- Joint forces are large… (can be several times body weight even during minor activities)
- Understanding of joint forces needed for:
  - Total joint replacement
  - Injury prevention
  - Rehabilitation programs
  - Tissue Engineering
- Abnormal joint forces may play a role in degenerative joint disease…

Synovial Joints…

[Q]: What's the #1 joint disease?

Ostoeoarthritis (OA)

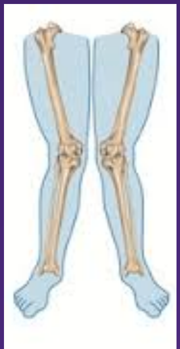
- Arthritis is a condition marked by joint stiffness, inflammation, and pain… [Disrupted collagen network / reduced PG content]
- Affects >27M in US @ cost >$186B…*
- Comes in two "flavors": Osteo and Rheumatoid…

* Kotlarzet al. (2009)

Synovial Joints…

[Q]: How might abnormal mechanics play a role in OA?

- Trauma and body weight are among the leading risk factors…
- Valgus (knock-kneed) deformity causes a 5-fold increase in risk for OA progression in lateral compartment…
- Varus (bow-legged) deformity causes a 4-fold increase in risk for OA progression in medial compartment…

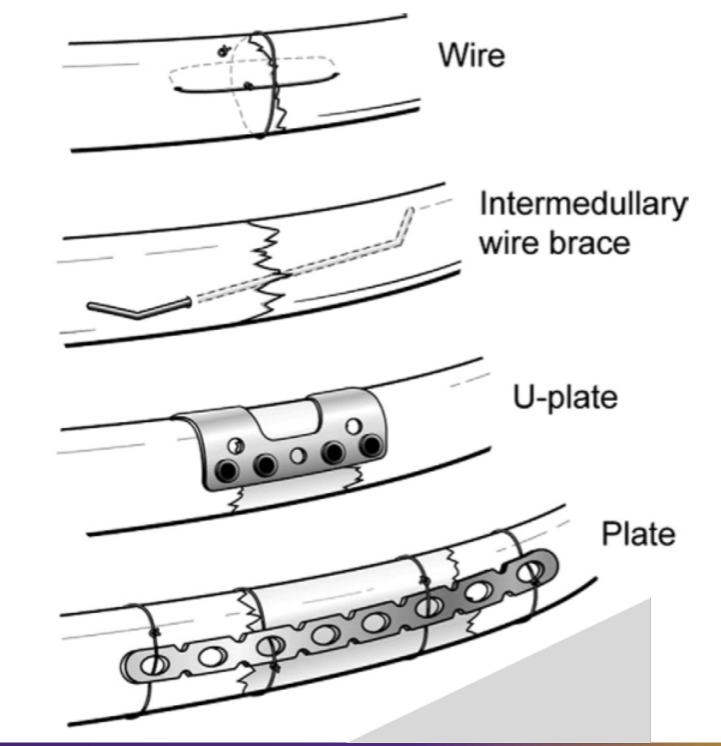


Sharma et al. (2001)

Example #1: Functional Loads of the Ribs and Sternum (Costal Cartilage)

Characterize the thoracic environment to improve the design of rib fixation devices...

- Rib fractures...
  - Most common chest injury
  - Complicated fracture patterns
- Forces...
  - Very little is known about physiologic loads



Lew (2010)

Ex #1: Functional CC Loads

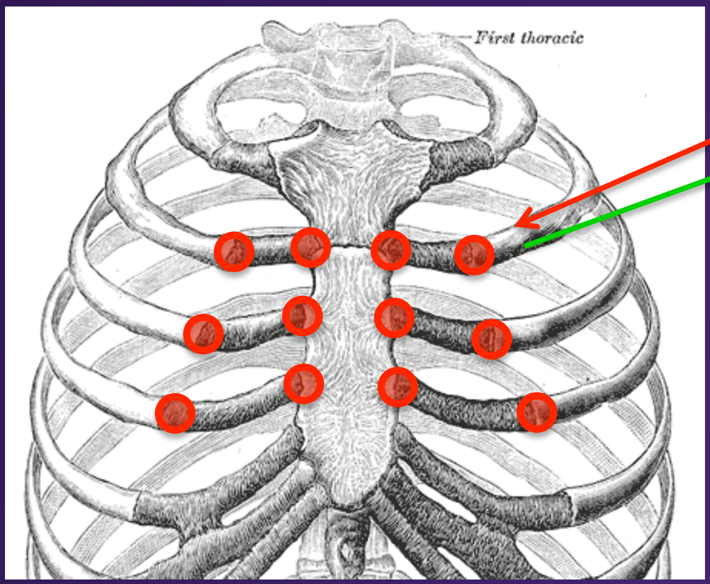
Objective: Determine the loads between the ribs and sternum (costal cartilage).

- 3-Step process...
  - Measure physiologic strains across CC → ***In vivo* test using optical tracking**
  - Estimate loads based on published elastic moduli → **Literature review**
  - Verify modulus by testing human samples → ***In vitro* CC test**

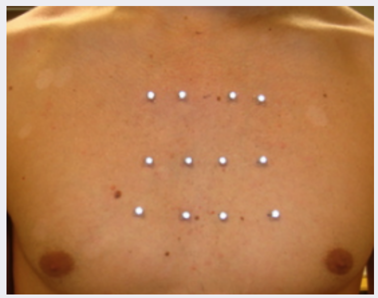
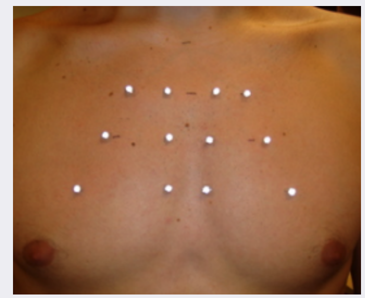
Lew (2010)

Ex #1: Functional CC Loads

Method: Use optical tracking to measure strains

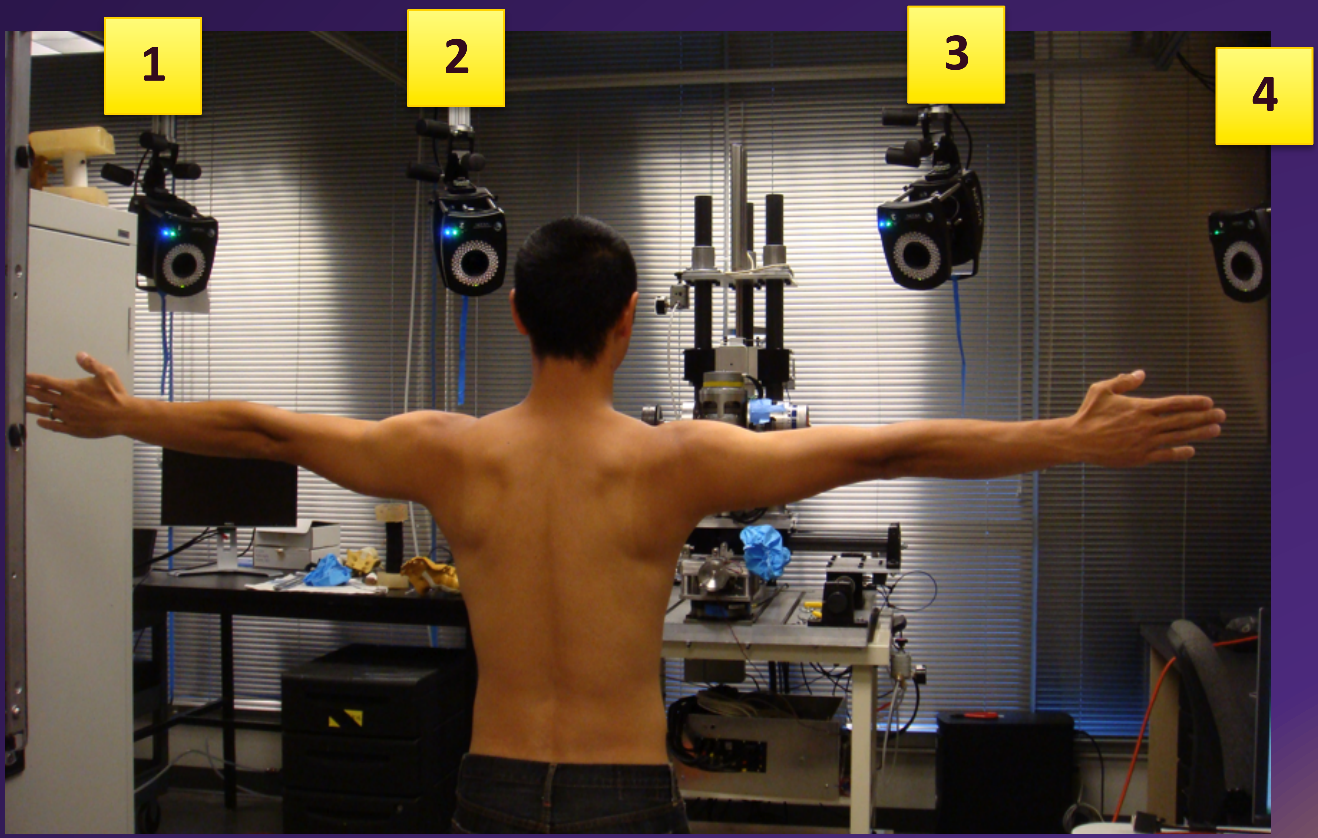


Ex #1: Functional CC Loads

Subject 002	Subject 003	Subject 004	Subject 005
BMI: 21.31	***BMI: 20.60***	***BMI: 22.5***	***BMI: 23.57***
			

Subject 006	Subject 007	Subject 008
BMI: 22.24	***BMI: 24.95***	***BMI: 21.62***
		

Ex #1: Functional CC Loads



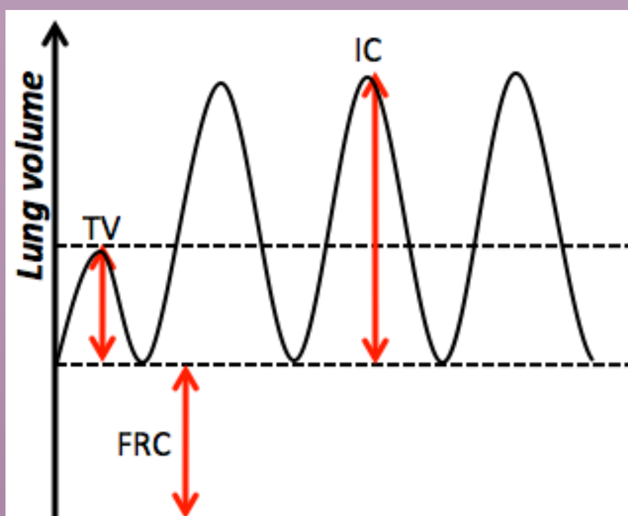
Chest kinematics

- VICON MX13 system
- Resolution = 0.05 mm/pixel
- Data collected at 60 Hz

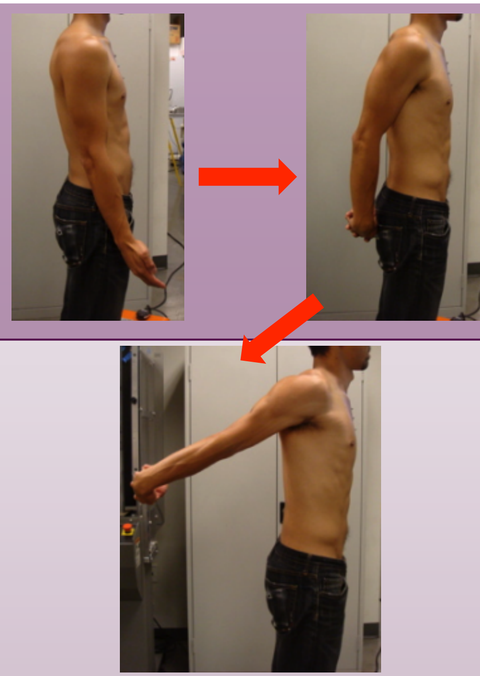
Ex #1: Functional CC Loads

Methods: Respiratory and stretching exercises

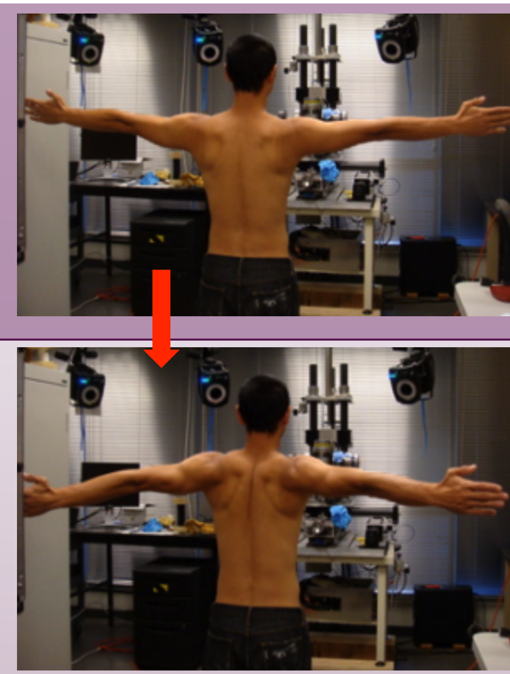
Inspiratory capacity (IC)



Chest stretch 1 (S1)



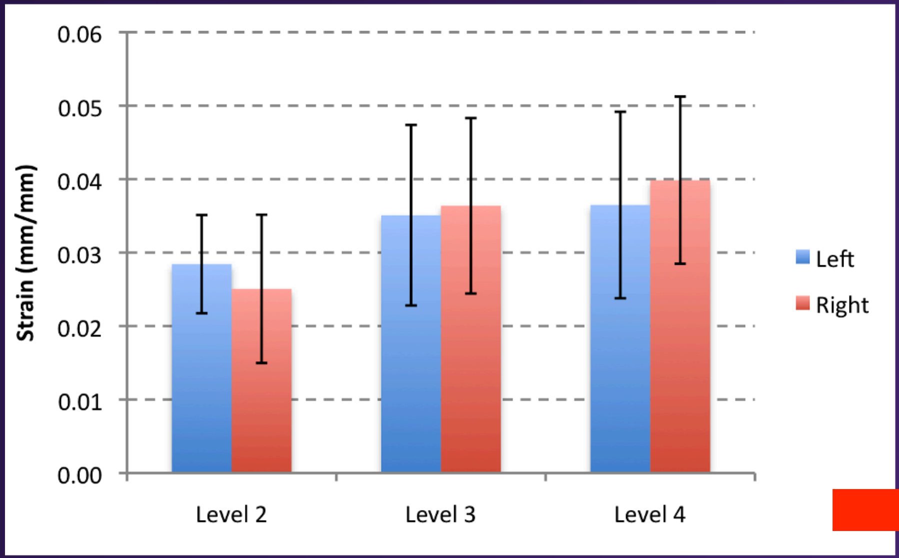
Chest stretch 2 (S2)

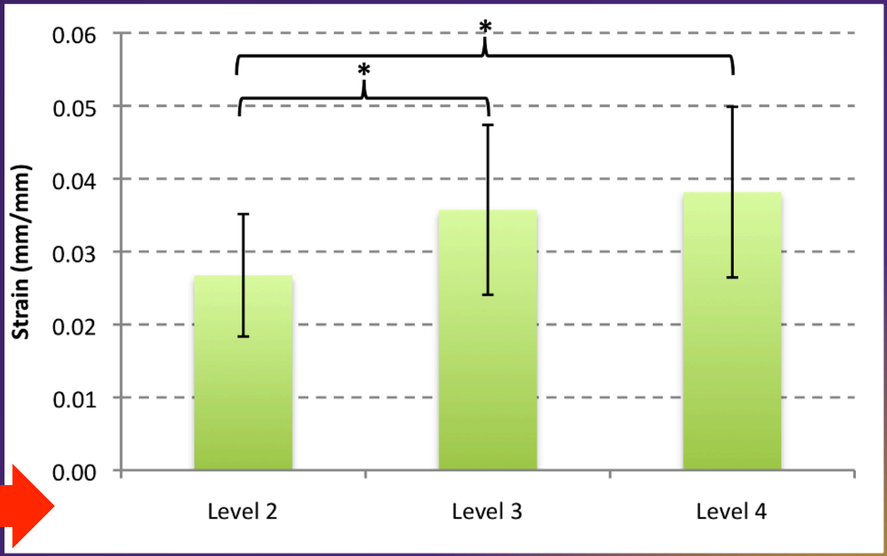


Ex #1: Functional CC Loads

Results: Average left and right data sets

- No statistical difference between left and right results ($p > 0.05$)
- So, used average of right and left

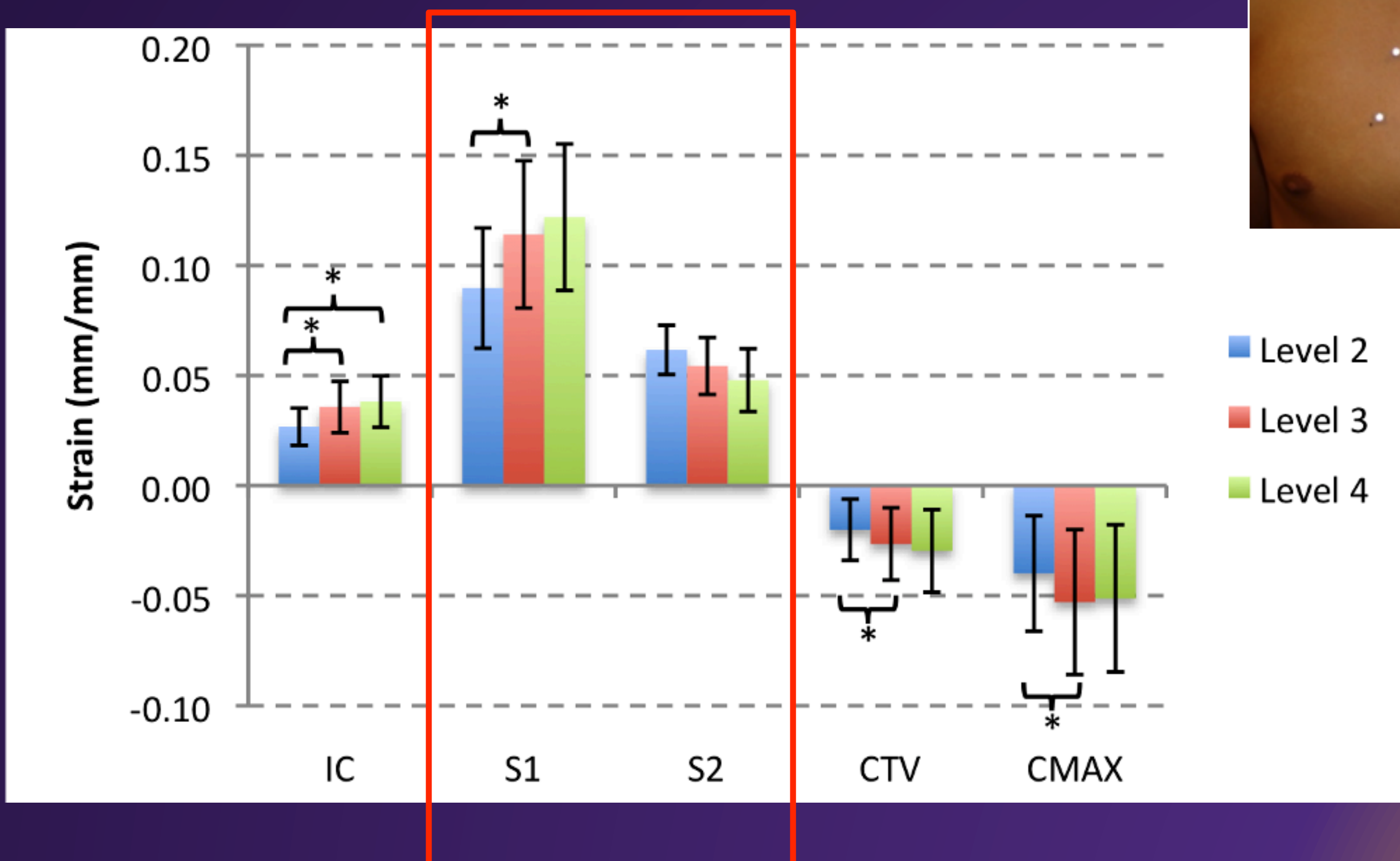


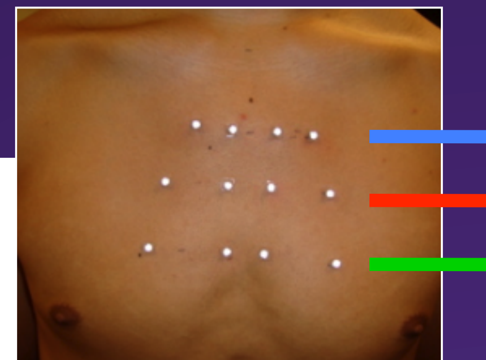


Average left/right

Ex #1: Functional CC Loads

Results: Strain

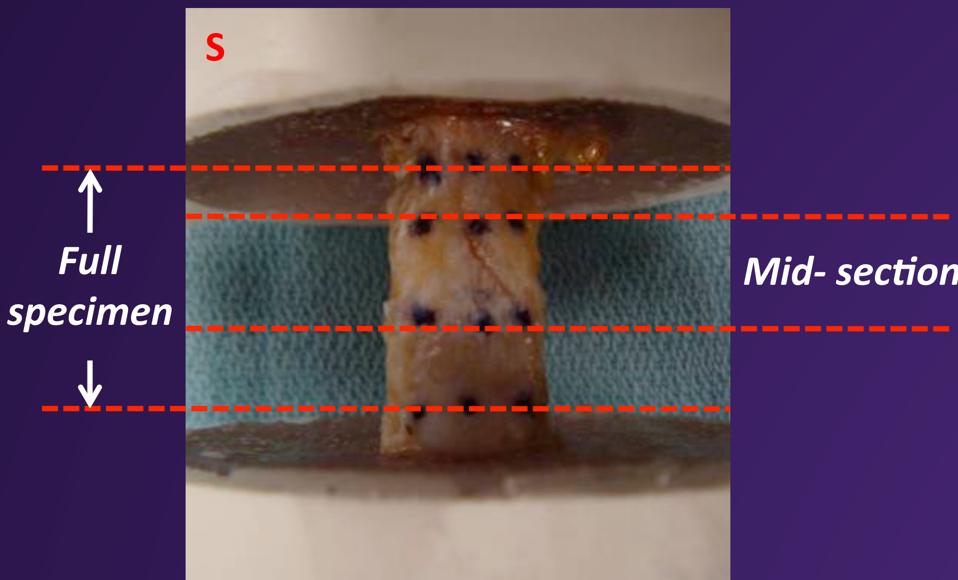




Largest strains observed for S1 (9-12%)

Ex #1: Functional CC Loads

In Vitro CC testing



(Anterior)

Ex #1: Functional CC Loads

Force estimated using Hooke's law: **$\sigma = E\varepsilon$**

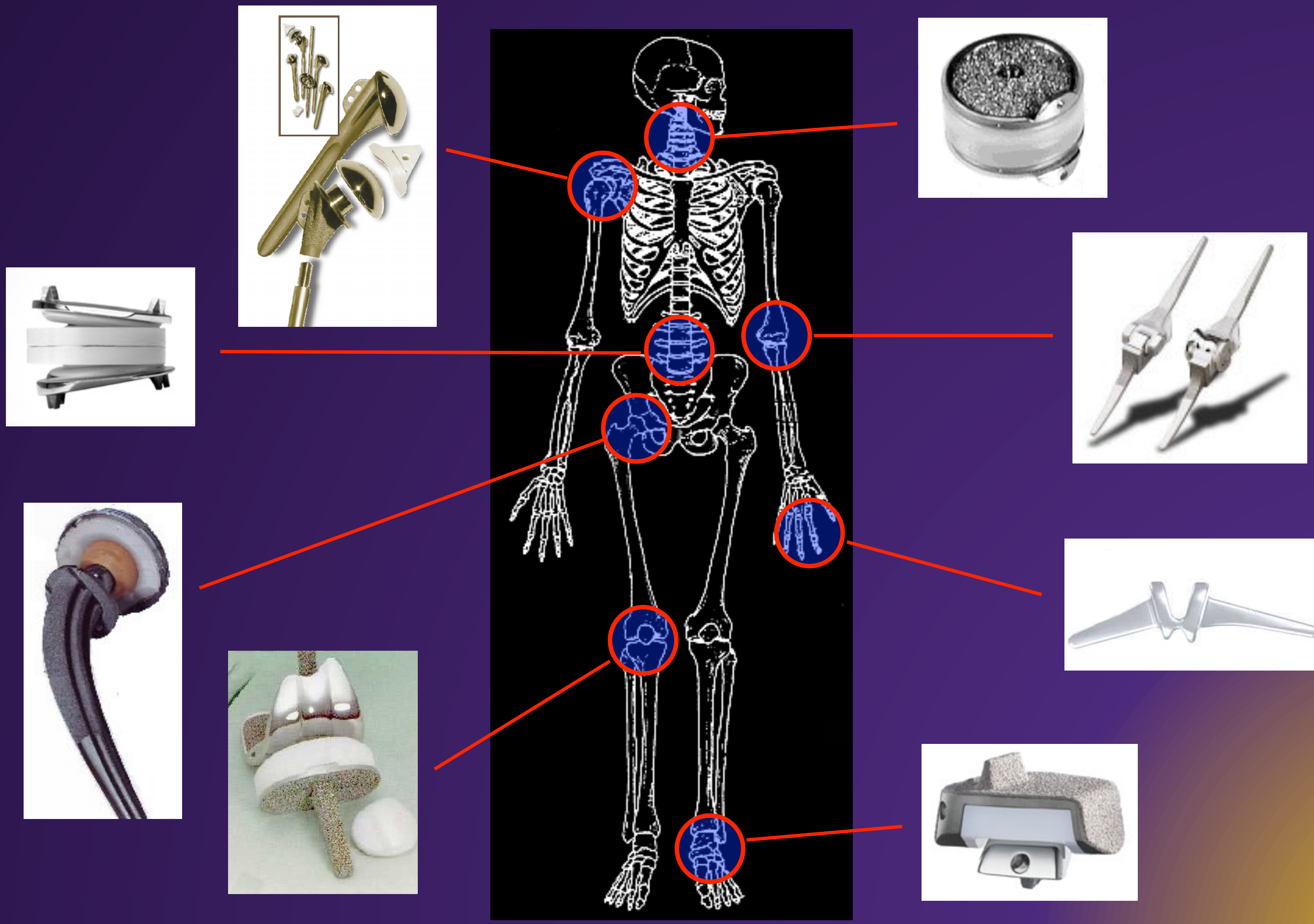
- Across 3rd rib level
- Range of forces computed using physiologic strains, and moduli from:
  - (i) Guo *et al* (for males, 18-25 y.o.)
  - (ii) E_{mid}
  - (iii) E_{full}

	Force (N)		
Strain (mm/mm)	*Guo et al*, E = 12.0 MPa*	*Mid-section*, E = 29.6 MPa*	*Full specimen, E = 11.7 MPa*
0.03	23.5	63.3	25.0
0.05	39.2	105.6	41.7
0.10	78.4	211.1	83.4

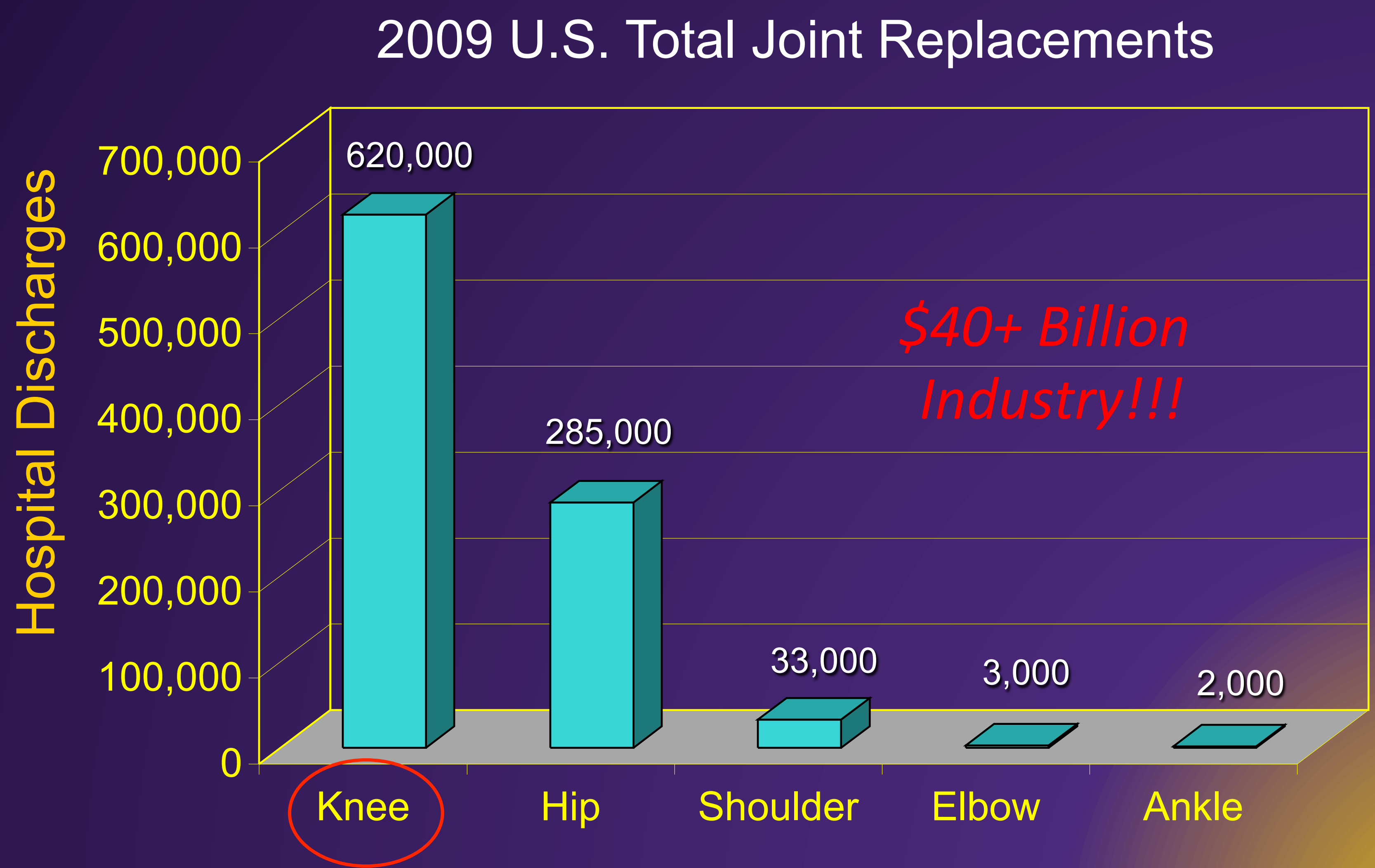
* indicates mid-section cross-sectional area was used

Ex #2: Joint Replacement…

Which is the most common???



Ex #2: Joint Replacement…

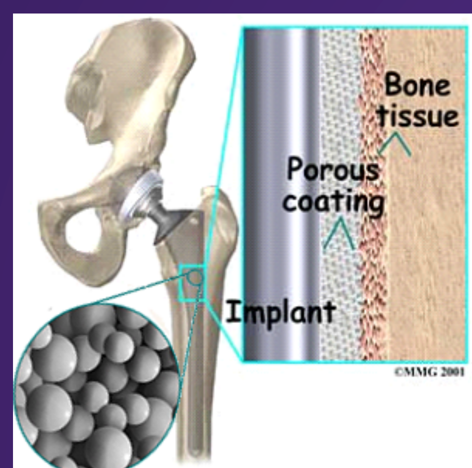


Healthcare Cost & Utilization Project Database (http://www.ahrq.gov/data/hcup/)

Ex #2: Joint Replacement…

- Design
  - Modular systems…

- Durability
  - Increased strength and wear…
- Biocompatibility
  - Porous In-growth…



Case Study #1: Component Placement…

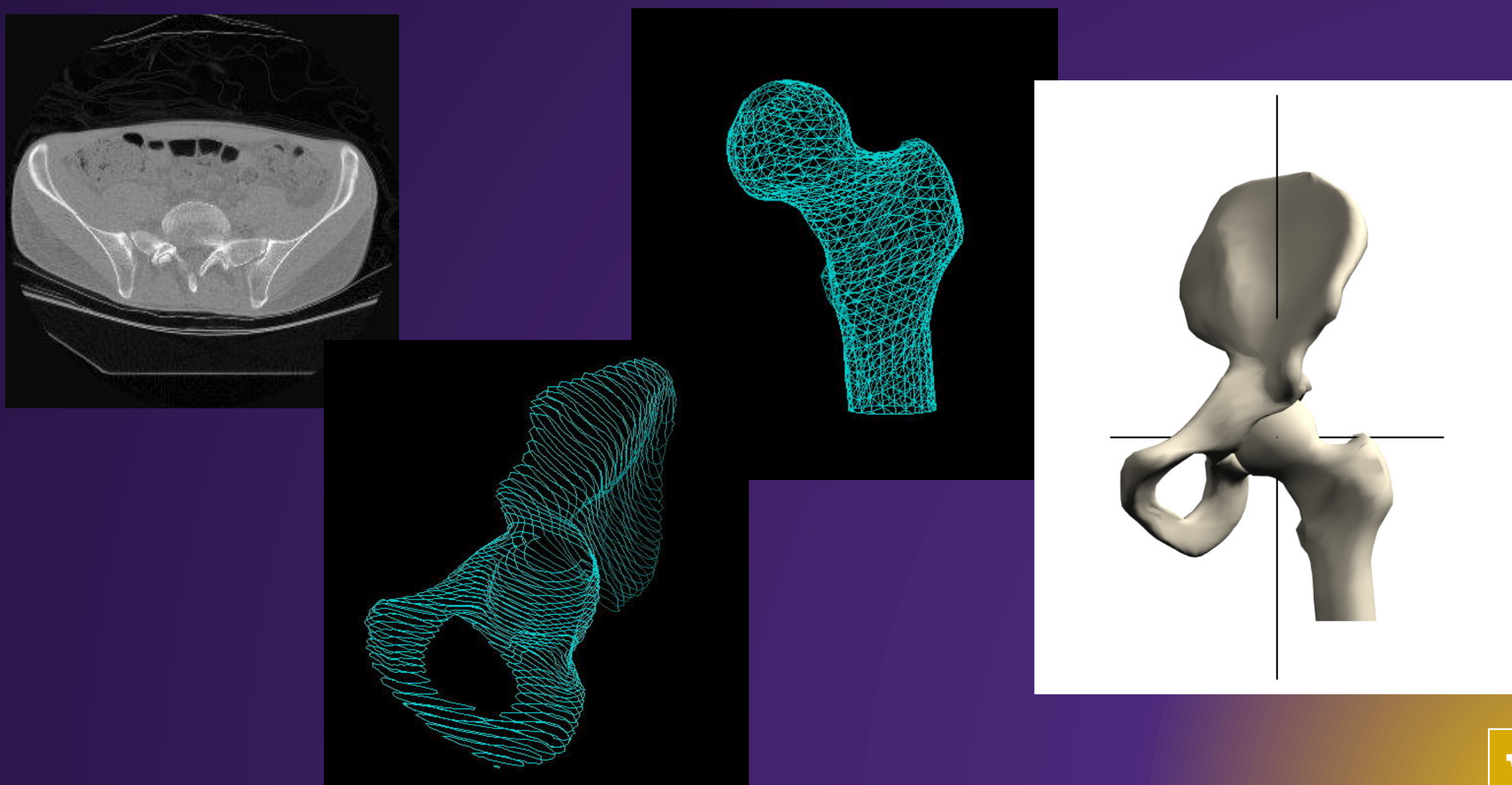
Exactech and Depuy

- Drs. Robinson and Barrett (2002)
- Dislocations: 7-11%
- Effect of component design and placement on range of motion…

Alberton et al. (2004), Robinson et al.(1997)

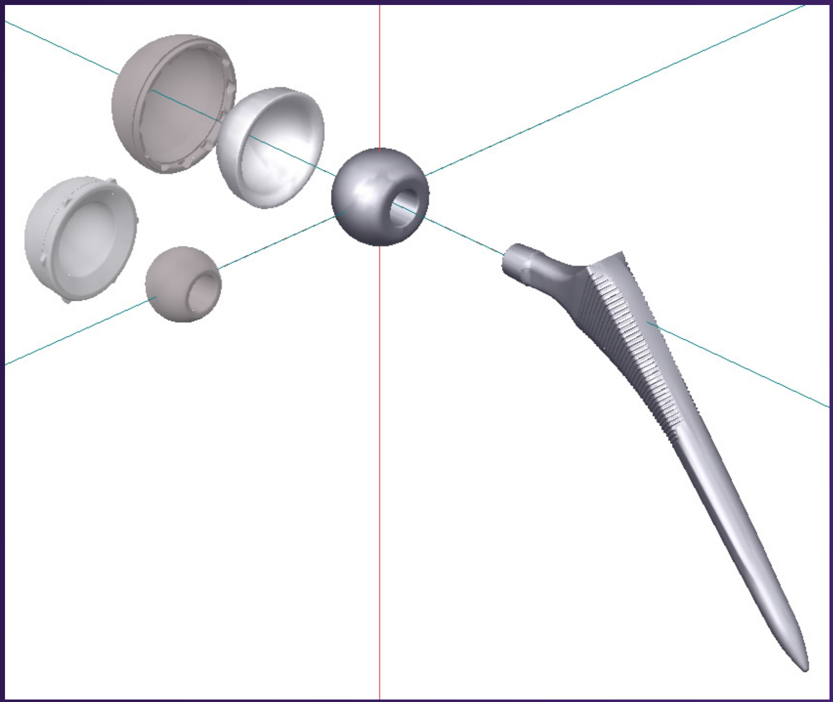
Case Study #1: Component Placement…

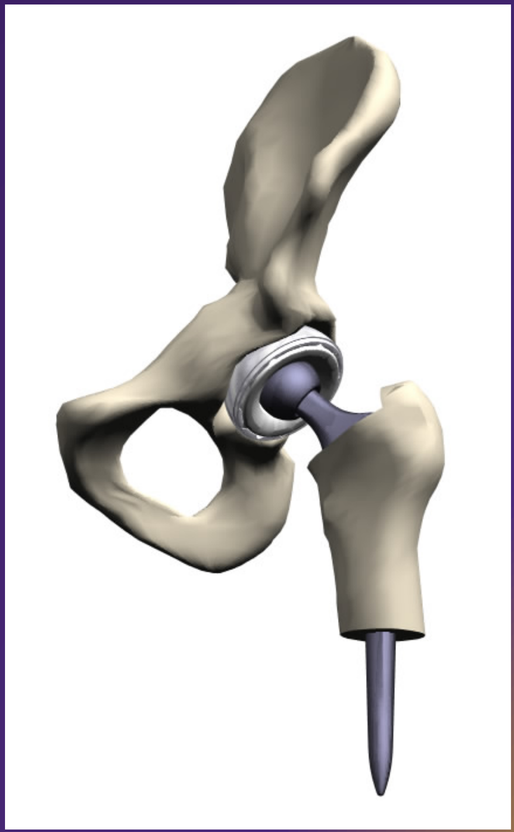
3-D models of hemipelvis and femur created from CT scans of a normal male…



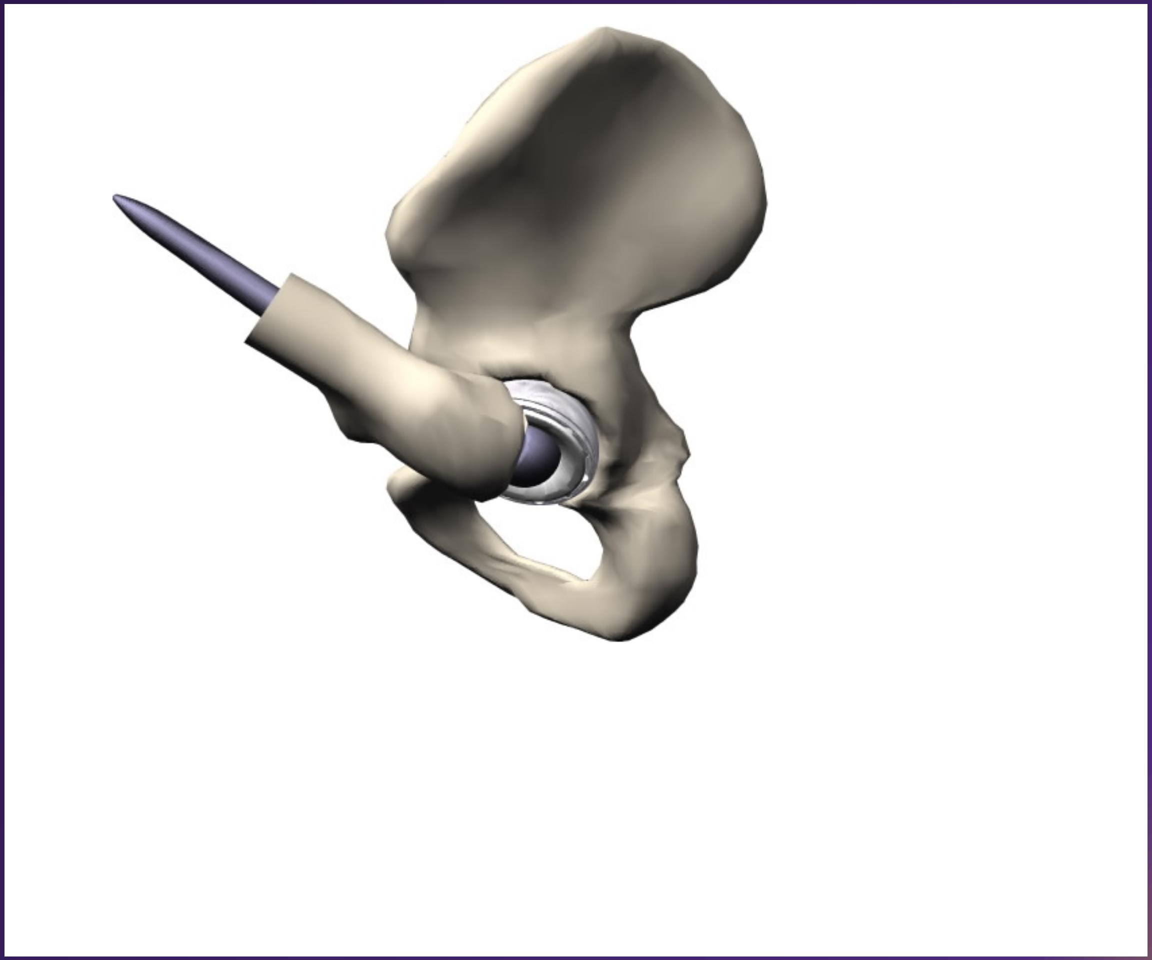
Case Study #1: Component Placement…

3-D models of acetabular cup and femoral stem obtained from manufacturer and implanted *in silico*…

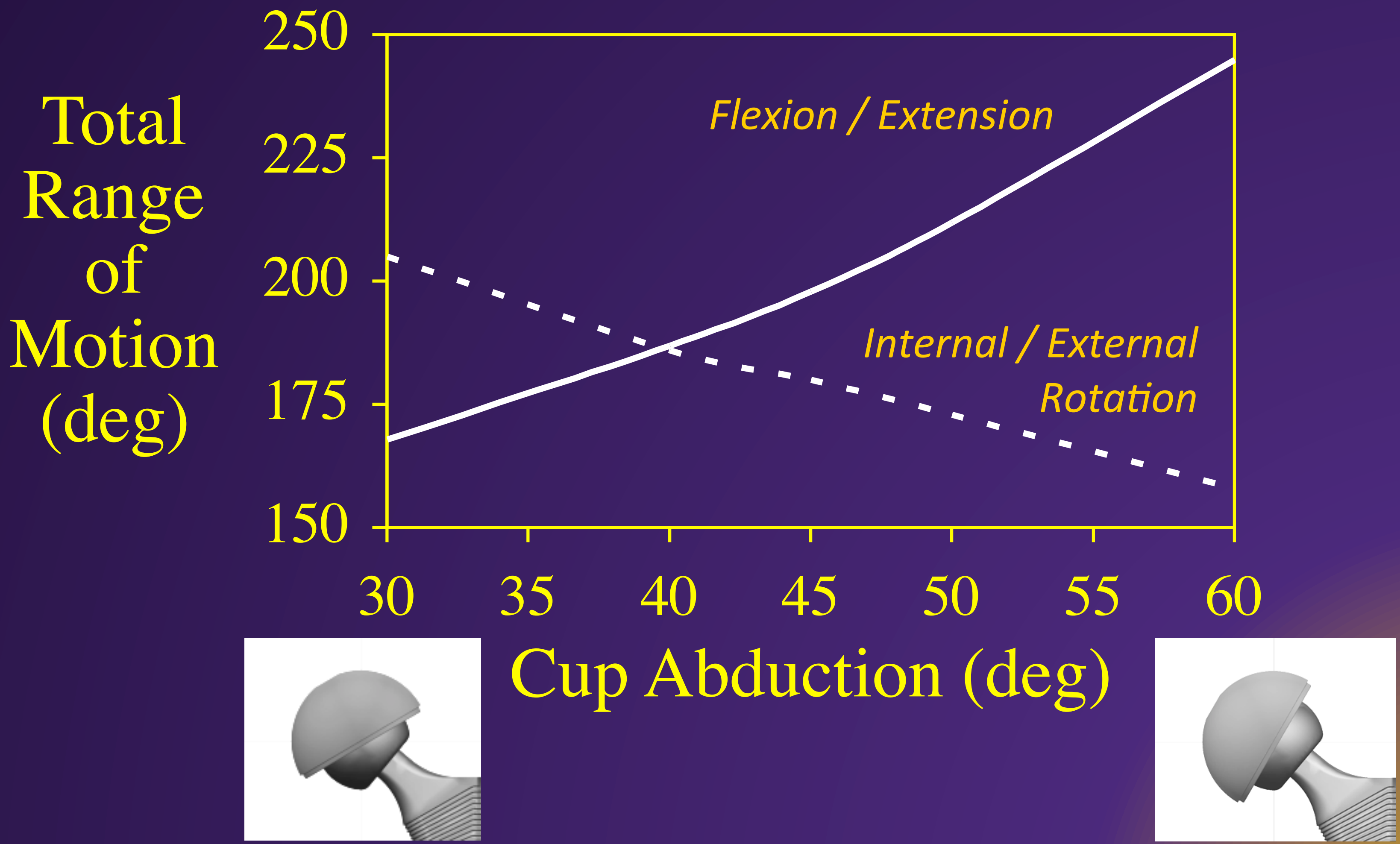




Case Study #1: Component Placement…



Case Study #1: Component Placement…



Case Study #2: Detecting Loose Implants…

Failed Total Ankle Replacements

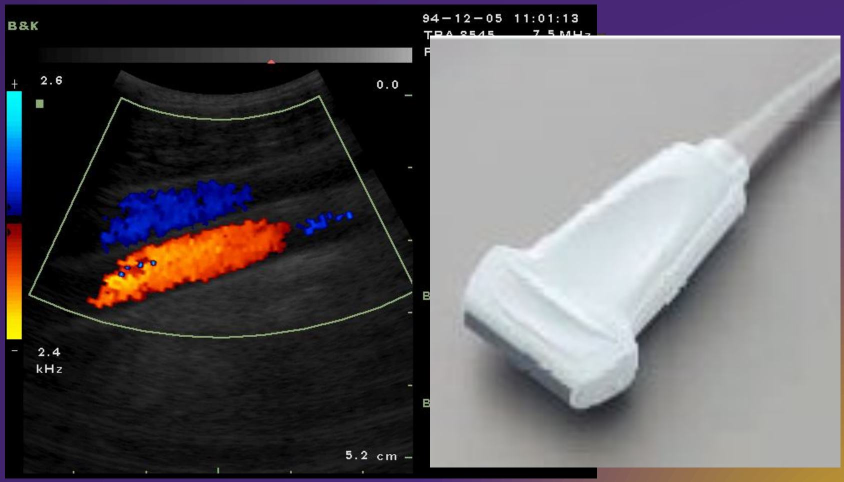
- HMC does >60 revisions/year
- Leading cause: Loose talar component
- How can we detect osteointegration level?

Case Study #2: Detecting Loose Implants…

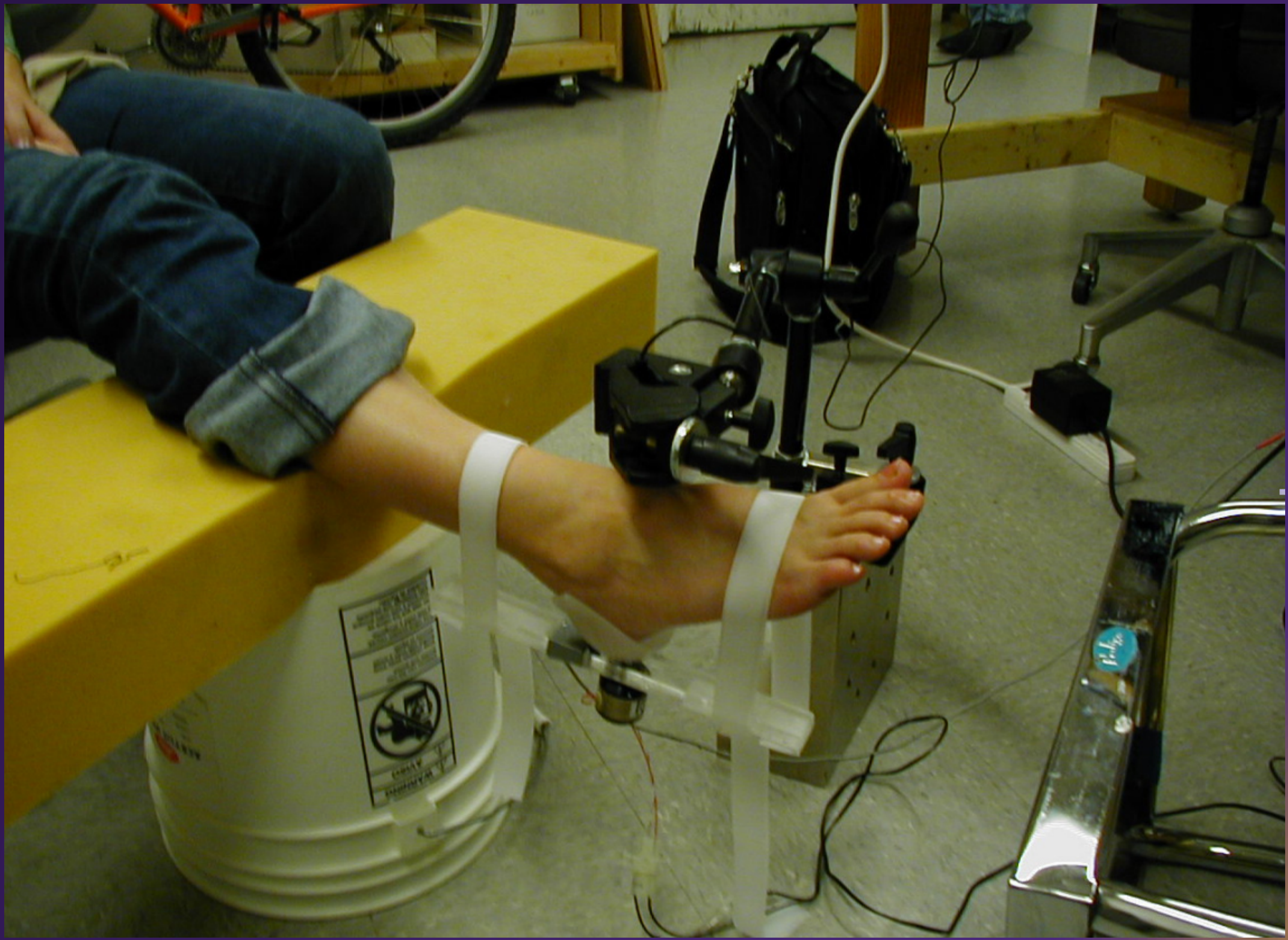
Vibrometry?

- Step 1: Shake

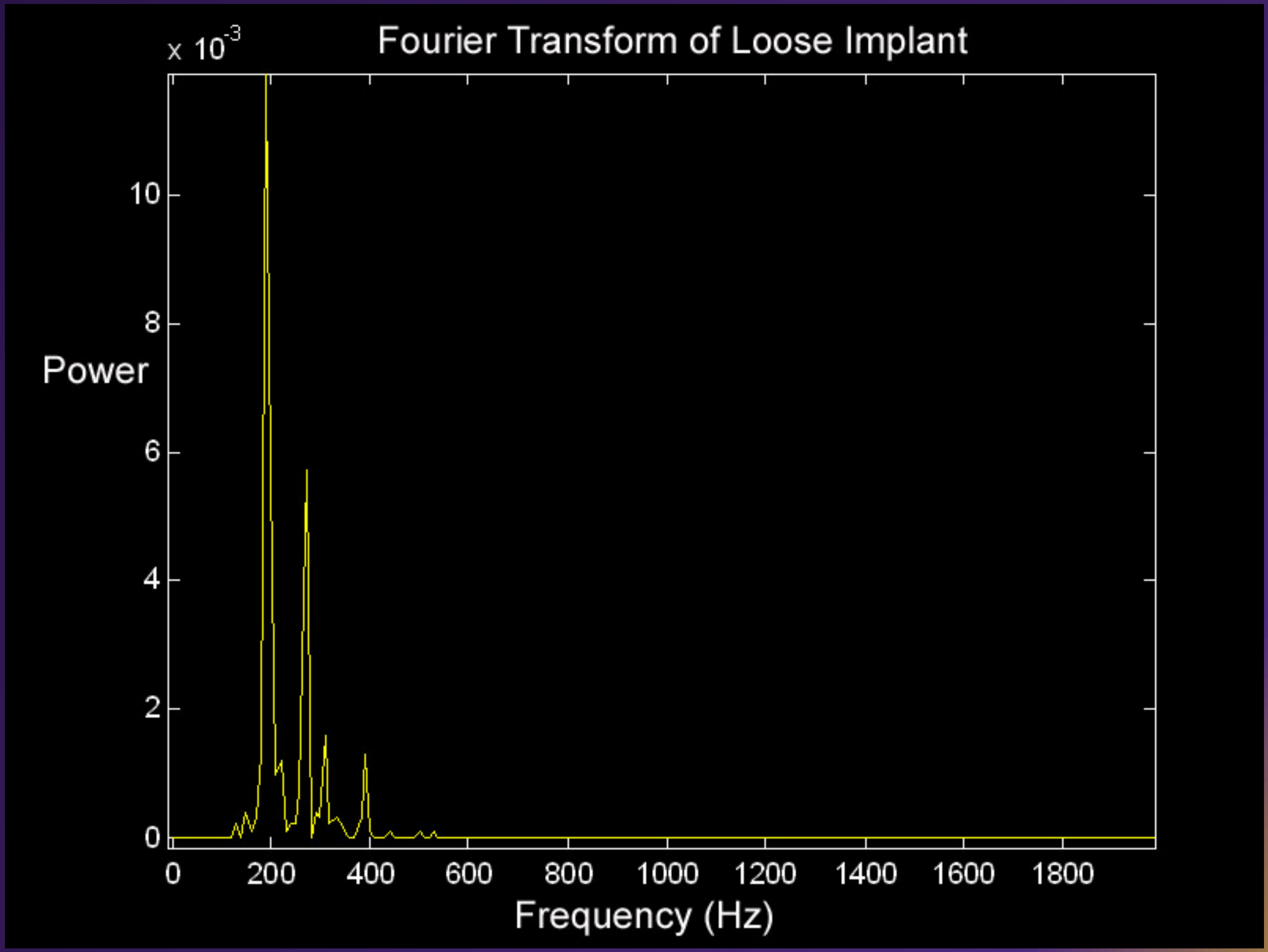
- Step 2: Listen



Case Study #2: Detecting Loose Implants...



Case Study #2: Detecting Loose Implants…



Case #2: Detecting Loose Implants…