ME 411 / ME 511

Biological Frameworks for Engineers

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ME 411 / 511

UNIVERSITY OF WASHINGTON

Class Organization

- HW6 due today
- *Tiny Workhorse* project
  - Reports due today
  - Presentations on Wed, Nov 27
    - 9 min with 1 min Q&A
    - Check your laptops before class
- HW7 due on Wed, Dec 4

Biological Frameworks for Engineers

ME 411 / ME 511

Kinematics
and
Spinal Biomechanics

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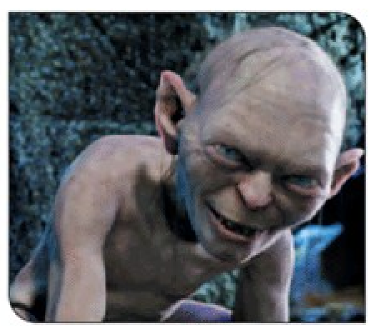
Kinematics

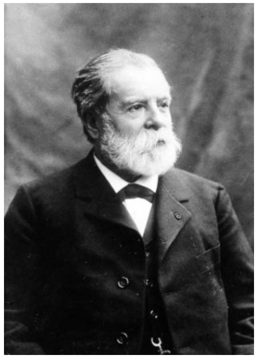
"The study of the geometry of motion"

Reasons to study kinematics:

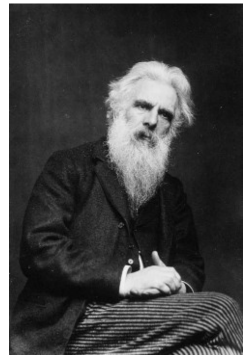
1. Understand and treat pathologies
2. Improve athletic performance
3. Ergonomics and human factors
4. Entertainment



Background and History

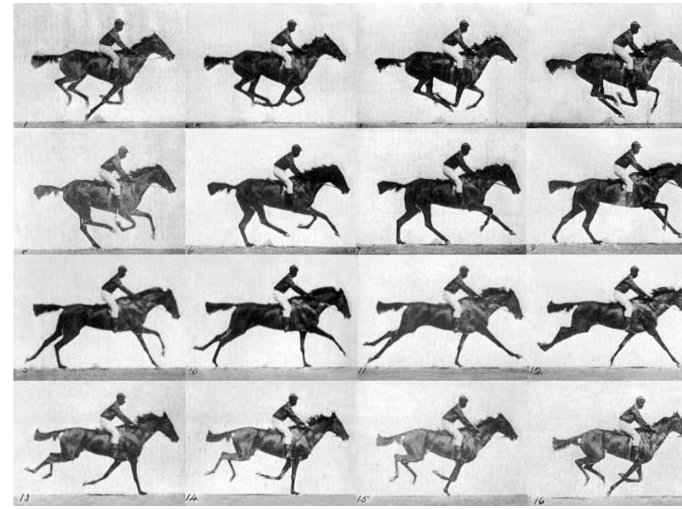


Etienne-Jules Marey



Eadward Muybridge

(1830-1903)



"The Horse in Motion"

June 15th, 1878

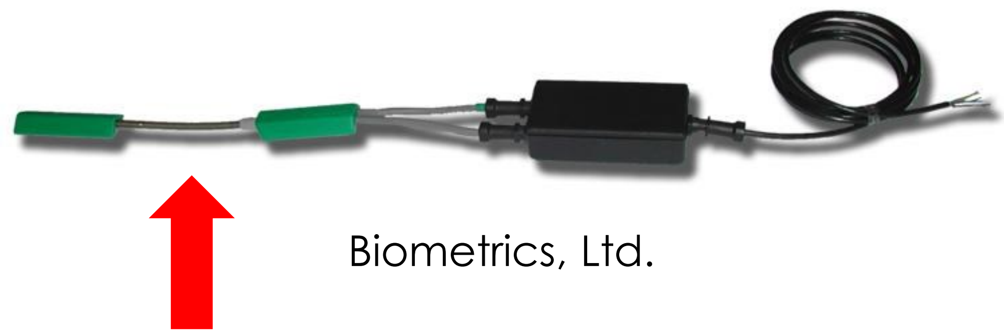
- Used cinematography for the study of human and animal movement
- Marey's "chronophotographic gun" is considered to be the forerunner of the motion picture camera

Pelican in Flight

Measurement Tools

Electrogoniometers

- Devices that convert joint angle to a voltage
- Advantages: Ease of use; cost
- Disadvantages: Less accurate than other systems; device placement may interfere with natural kinematics



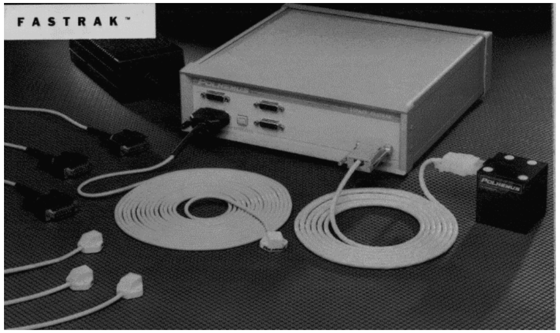
Measurement Tools

Electromagnetic Systems

• Basic components: active transmitter and passive sensor(s)

• Advantages: Highest precision and accuracy with proper set-up; do not suffer from line-of-sight problems

• Disadvantages: Precision and accuracy are affected by: metallic objects, low-frequency electronic noise, and the distance of the sensor from the transmitter



Polhemus

FASTRAK

Ascension Technology Corp.

Flock of Birds

Measurement Tools

Marker-Based Optical Motion Capture Systems

- Two types…

Passive tracking

Retroreflective markers

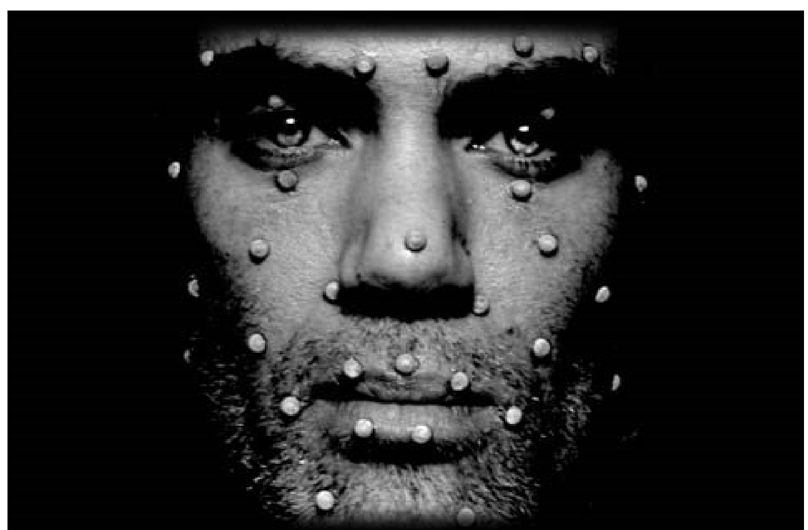
Active tracking

LED markers

Measurement Tools

Marker-Based Optical Motion Capture Systems

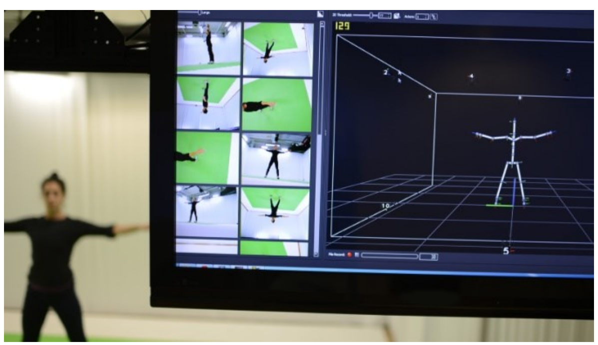
- Advantages: Highest precision and accuracy
- Disadvantages:
  - Suffer from line-of-sight problems
  - Both systems require the use of special suits and/or markers
  - Active-tracking systems require that on-board electronics be strapped to the subject



Measurement Tools

Markerless Motion Capture Systems

- The wave of the future?
- Advantages: No special suits, markers, or equipment required
- **Challenge**: Implementing tracking algorithms that can perform accurately in real-time <u>without</u> the aid of markers to provide "hints" to the software



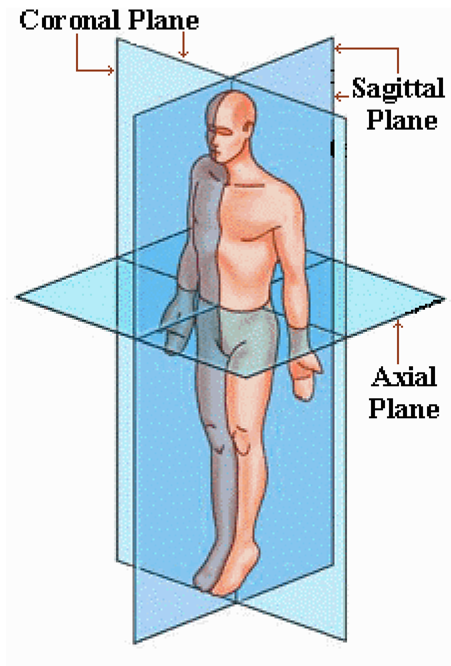
Organic Motion, Inc.

OpenStage 2

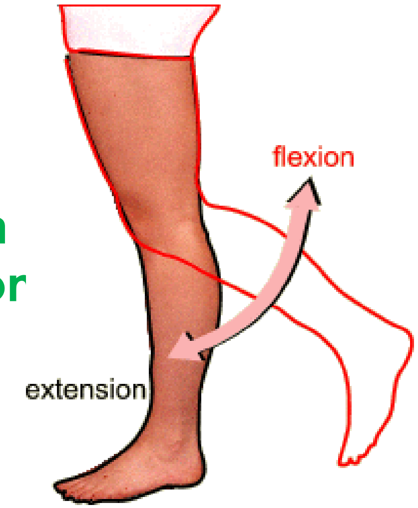
Microsoft Corp.

Kinect

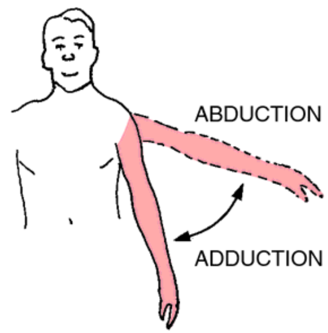
Anatomical Planes and Terms of Motion



- **Sagittal** divides the body into right and left regions
- **Coronal (Frontal)** divides the body into front and back regions
- **Transverse** divides the body into upper and lower regions

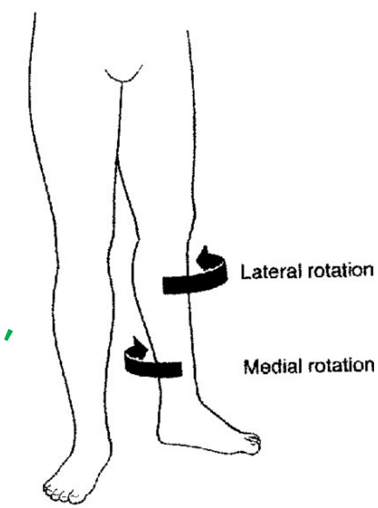


**Flexion
Extension**



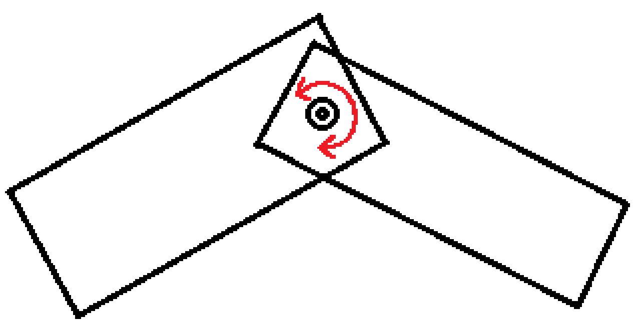
**Abduction
Adduction**

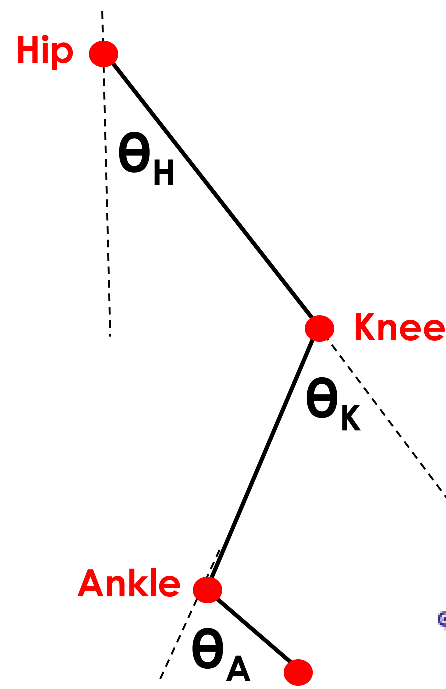
Axial Rotation (Internal/External, Medial/Lateral, CW/CCW)



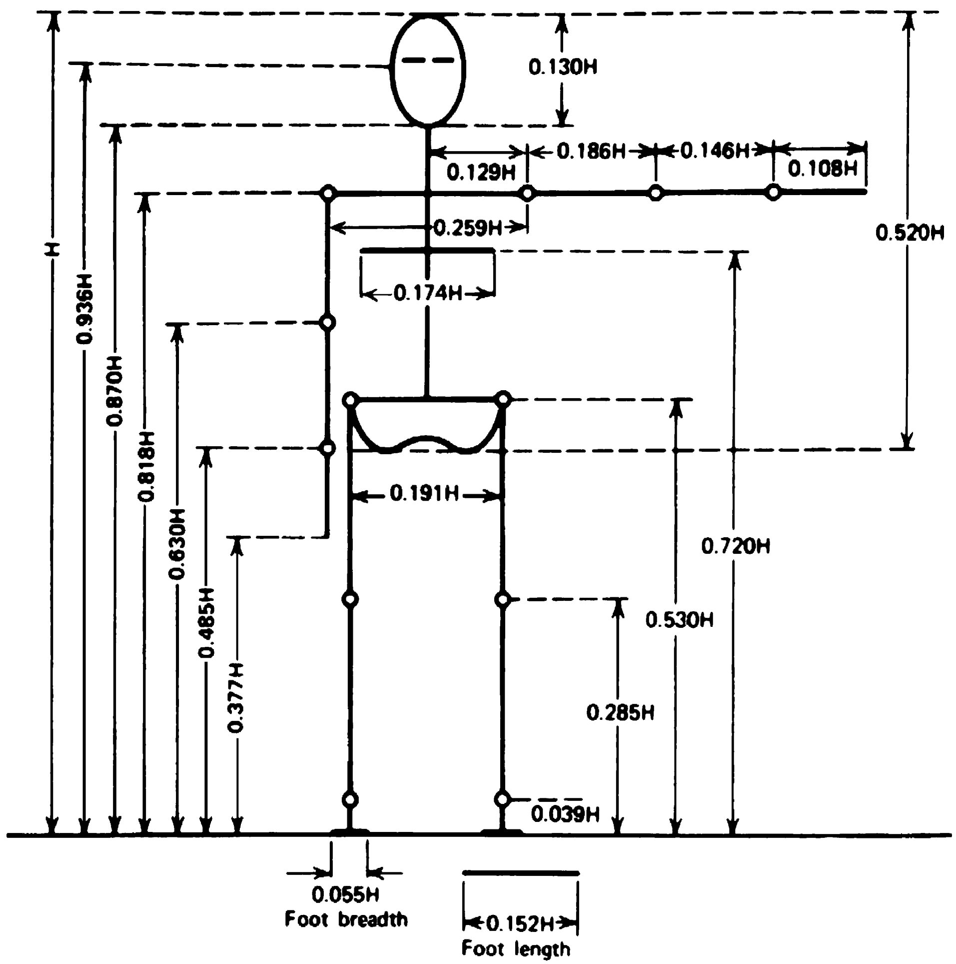
2D Kinematic Models

- Rigid segments connected with planar hinges
- Example: **Lower limb**
  - Sagittal plane motion
  - Three rigid segments: upper leg, lower leg, and foot
  - Three hinge joints: hip, knee, and ankle





Athropometric Data



All body segment lengths are expressed relative to the total height H.

Athropometric Data

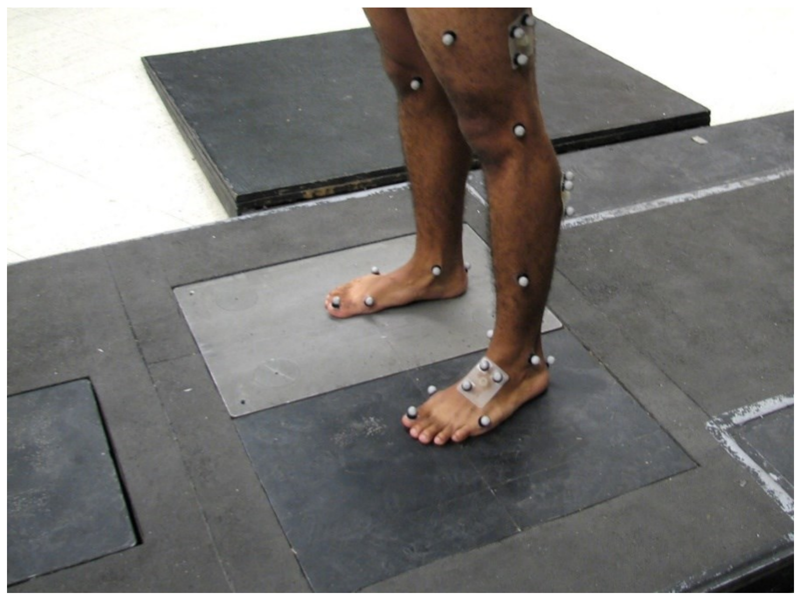
Table 10.2. Anthropometric data on segment mass, location of center of mass, radius of gyration and density. Segment masses are expressed relative to total body mass; locations of the centers of mass are expressed relative to the limb segment length (see Fig. 10.21 for definitions of limb segments); the radii of gyration are expressed relative to the segment length, about three points, namely the center of gravity (C of G) for the segment, the proximal end of the segment, and the distal end of the segment. Note that the radii of gyration are for rotation about the z axis (see Fig. 10.17). Collected from various sources in Winter [7]. Reprinted with permission of John Wiley & Sons, Inc.

Segment	Definition of segment length	Segment weight/total body weight	Center of mass/ segment length		Radius of gyration/ segment length			Density (g/cm^3)
			Proximal	Distal	C of G	Proximal	Distal	
Hand	Wrist axis/knuckle II middle finger	0.006	0.506	0.494	0.297	0.587	0.577	1.16
Forearm	Elbow axis/ulnar styloid	0.016	0.430	0.570	0.303	0.526	0.647	1.13
Upper arm	Glenohumeral axis/elbow axis	0.028	0.436	0.564	0.322	0.542	0.645	1.07
Forearm and hand	Elbow axis/ulnar styloid	0.022	0.682	0.318	0.468	0.827	0.565	1.14
Total arm	Glenohumeral joint/ulnar styloid	0.050	0.530	0.470	0.368	0.645	0.596	1.11
Foot	Lateral malleolus/head metatarsal II	0.0145	0.50	0.50	0.475	0.690	0.690	1.10
Shank	Femoral condyles/medial malleolus	0.0465	0.433	0.567	0.302	0.528	0.643	1.09
Thigh	Greater trochanter/ femoral condyles	0.100	0.433	0.567	0.323	0.540	0.653	1.05
Foot and shank	Femoral condyles/medial malleolus	0.061	0.606	0.394	0.416	0.735	0.572	1.09
Total leg	Greater trochanter/medial malleolus	0.161	0.447	0.553	0.326	0.560	0.650	1.06
Head and neck	C7-T1 and 1st rib/ear canal	0.081	1.000	–	0.495	1.116	–	1.11
Shoulder mass	Sternoclavicular joint/glenohumeral axis		0.712	0.288				1.04
Thorax	C7–T1/T12–L1 and diaphragm[a]	0.216	0.82	0.18				0.92
Abdomen	T12–L1/L4–L5[a]	0.139	0.44	0.56				
Pelvis	L4–L5/greater trochanter[a]	0.142	0.105	0.895				
Thorax and abdomen	C7–T1/L4–L5[a]	0.355	0.63	0.37				
Abdomen and pelvis	T12–L1/greater trochanter[a]	0.281	0.27	0.73				1.01
Trunk	Greater trochanter/glenohumeral joint[a]	0.497	0.50	0.50				1.03
Trunk, head, neck	Greater trochanter/glenohumeral joint[a]	0.578	0.66	0.34	0.503	0.830	0.607	
Head, arm, trunk	Greater trochanter/glenohumeral joint[a]	0.678	0.626	0.374	0.496	0.798	0.621	
Head, arm, trunk	Greater trochanter/middle rib	0.678	1.142		0.903	1.456		

[a] These segments are presented relative to the length between the Greater Trochanter and the Glenohumeral Joint.

3D Kinematic Models

- A coordinate system is defined for EACH segment of interest
- Typically, the coordinate system is defined such that each coordinate direction has some anatomical significance



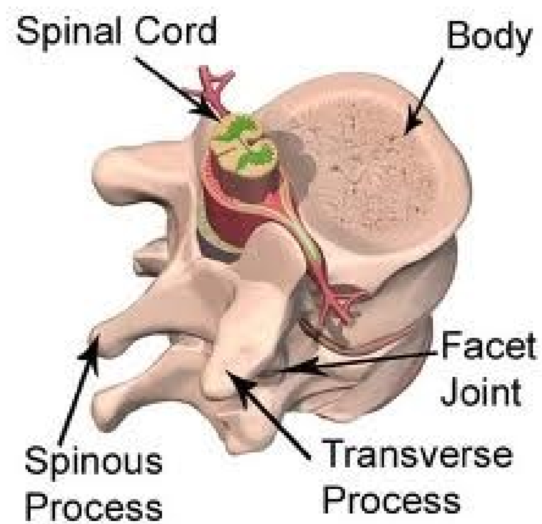
3D Kinematic Models

STEPS

1. For each segment, identify the <u>anatomical landmarks</u> that will be used to define the coordinate system
2. Track the landmarks during motion
   - Option #1: Directly attach markers to the landmarks
   - Option #2: Attach markers to the segment and record the position of the landmarks with respect to the markers
3. Reconstruct the 3D positions of the landmarks during motion
4. Using the landmarks, define a coordinate system for each segment
5. Calculate the 3D displacements/rotations between the segments

Spinal Anatomy

- The spine is divided into three major sections
- The intervertebral joint is a 3-joint system (disc + 2 facet joints)



Functional spinal unit (FSU)

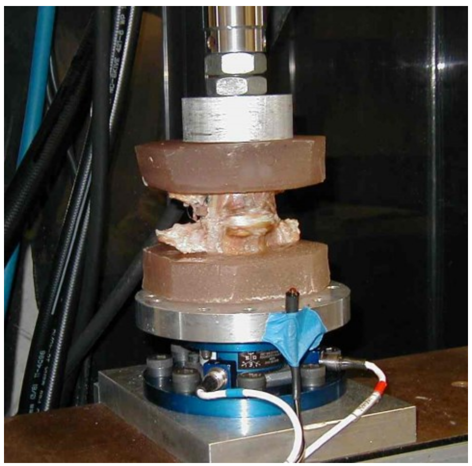
Reasons to Study Spinal Biomechanics

1. Basic science: What is the mechanical behavior of the spine in its "normal" condition?
2. Clinical: How is the mechanical behavior of the spine affected by injury, disease, or surgical intervention?
3. Device design
    - Motion-limiting devices
    - Motion-preserving devices (e.g. disc and facet joint replacement systems)

Medtronic, Inc.

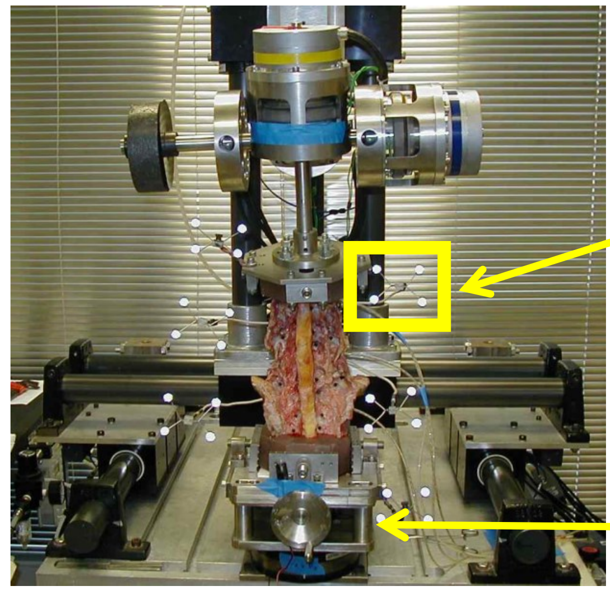
BRYAN Cervical Disc System

Mechanical Testing of the Spine



Materials Testing System

- Tension/compression
- Shear



Reflective marker set for motion capture system

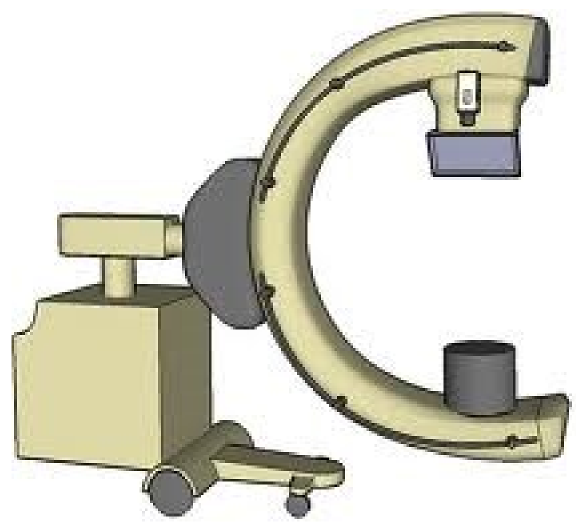
Six-axis load cell

Spine Simulator

- Bending

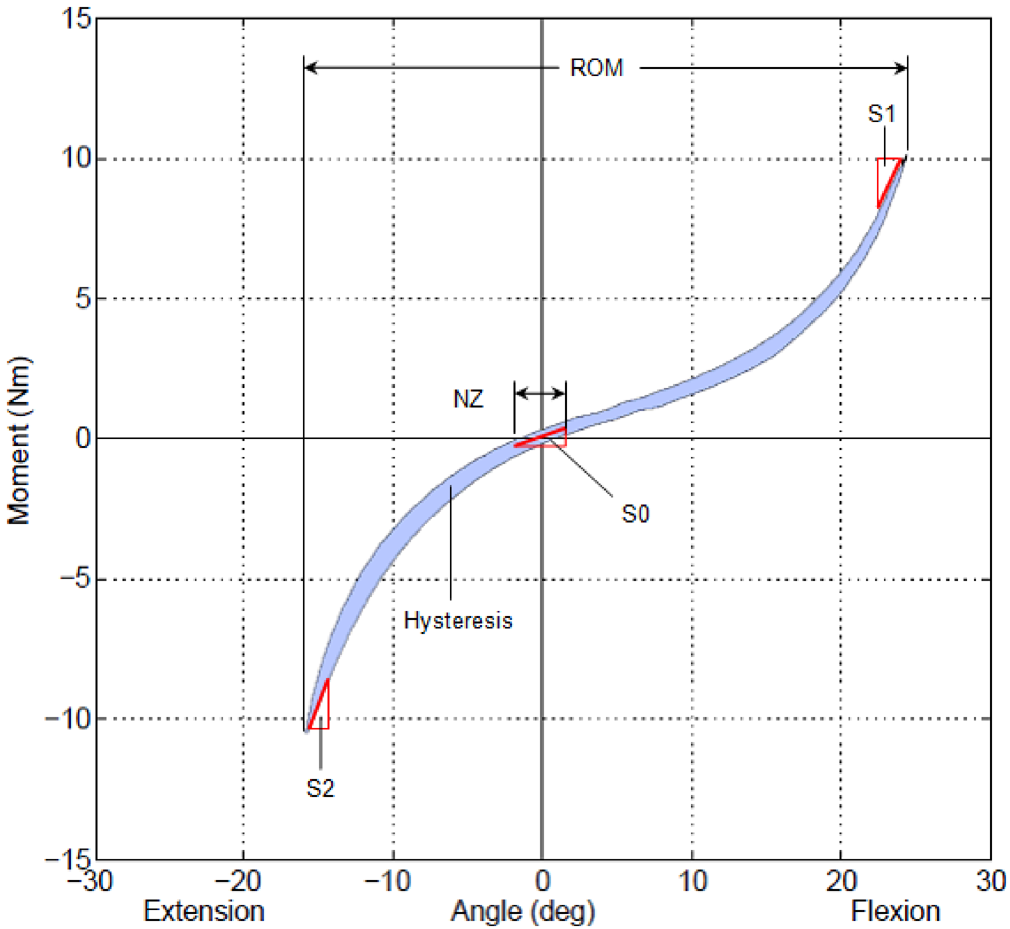
Video

- Full lumbar spine (L1-Sacrum)
- Flexion-extension test (+/- 10 Nm)
- Continuous x-rays taken with a C-arm x-ray machine



C-arm

Mechanical Testing of the Spine



Moment-Angle Plot

Metrics

- ROM = Range of motion
- NZ = Neutral zone
- S0, S1, S2 = Stiffness
- Hysteresis

Questions?