Human Motion Control

Dept. of Mechanical Engineering
Course 2006-2007 (Wb 2407)
DirkJan Veeger

Lecture 3
Parameter estimation

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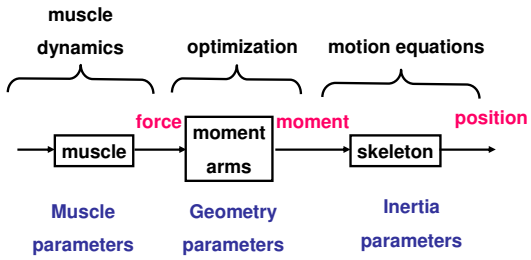
Delft University of Technology

Inverse & forward dynamics



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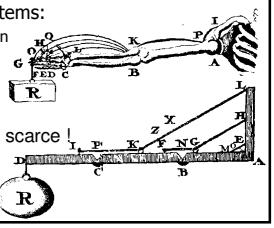
Musculoskeletal models

- Model is a simplification of the system
- Level of detail depends on the goal of the model

- One and two Degree-of-Freedom models:
  - Analyse principles of motion control
- Large-scale models of joint systems:
  - Comparison with reality: Validation
  - Recognize principles



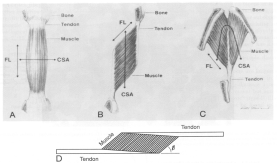
⇒ Good anatomical data are scarce !

Musculoskeletal model parameters

- Inertia parameters
  - Mass & Rotational inertia
  - Center of mass
- Geometry parameters
  - Center of rotation of joints
  - Muscle moment arms, muscle lines-of-action
    - Attachment sites:
      - Muscles
        - Fiber direction
      - Ligaments
    - Bony contours

Musculoskeletal model parameters

- Muscle parameters
  - Physiological Cross-Sectional Area (PCSA)
  - Optimal fiber length
  - Other (dynamic) parameters?
    - Fast / slow twitch
    - Tendon length and width
    - Pennation angle



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Mass & rotational inertia

- Direct: measurements at cadavers
- Indirect: by regression equations based on antropometric data 'in vivo'
- Direct: MRI (in vivo)
- Direct: surface scanning (in vivo)

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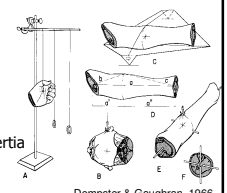
Direct measurements of cadavers

- Antropometry:
  - Total weight, bone thickness, segment length, segment circumference, percentage fat
- Disarticulation:
  - Choice of cutting plane through joints
- Measurement of segment mass
- Measurement of center of gravity
  - Pendulum
  - Balancing tables
- Measurement of principal moments of inertia
  - Oscillation time: pendulum, balancing table
  - Volume: submersion in water



Dempster & Gaughran, 1966

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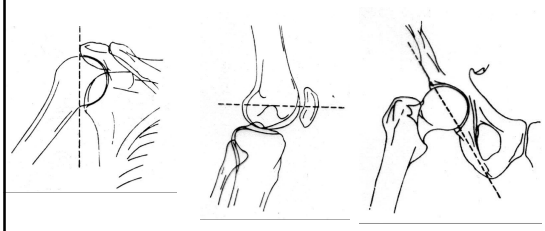
Division into segments Disarticulation



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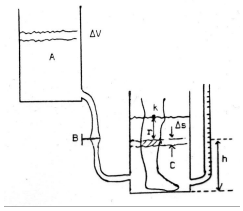
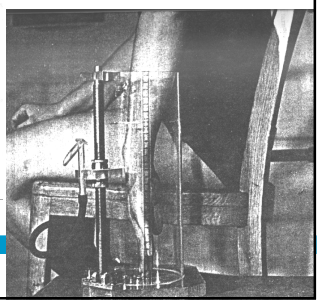
Segment mass: Submersion techniques





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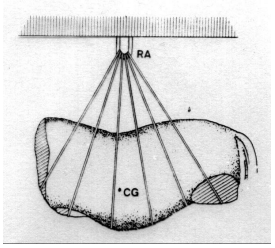
Center of gravity: Pendulum technique



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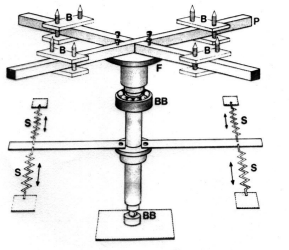
Rotational inertia: Oscillating table



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From cadavers to living humans: Regression equations

- Dependent variables:
  - Mass
  - Center of gravity (% segment length)
  - Principal moments of inertia
    - Chosen along segment axis
    - Often identical transversal moments of inertia
- Independent variables: Anthropometric data
  - Total weight, bone thickness, segment length, segment circumference, percentage fat
- Key references:
  - Clauser et al., 1969; Dempster, 1955

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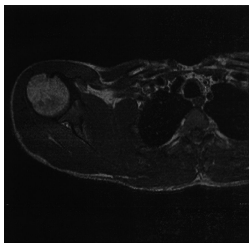
Generalization of cadaver data

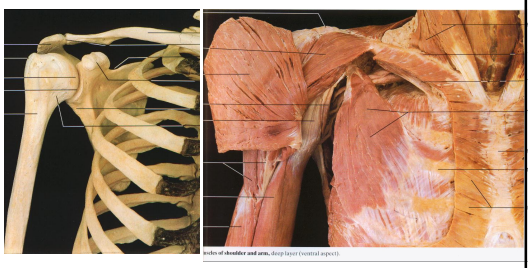
- Weight cadavers < 5th percentile of young people
- Old people, loss of weight during disease
- Small number of cadavers

⇒ Mismatch between motion recording data and musculoskeletal data !!
⇒ Lack of data !!

Segment mass and rotational inertia: Magnetic Resonance Imaging (MRI)



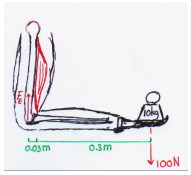
Geometry of musculoskeletal system cadaver measurements



Geometry data

- Cadaver measurements
  - Center of rotation of joints
  - Muscle moment arms/lines-of-action
    - dl/dθ method
    - Attachment sites:
      - Muscles
        - Fiber direction
        - bony contours
      - Ligaments
- MRI measurements
  - Centroid method

Muscle moment arm



- External moment: 100 x 0.3 = 30 Nm
- Muscle force: 30 / 0.03 = 1000N
- Joint reaction force: 1000 - 100 = 900N

Muscle moment arm Line-of-action

- 'dl/dθ' method
- 'straight-line' method
- 'centroid-line' method
- 'bony contour' method

'dl/dθ' method

- $\dot{l} = \frac{dl}{d\theta}.\dot{\theta}$ (chain rule)
- virtual work: $F.\dot{l} = M.\dot{\theta}$

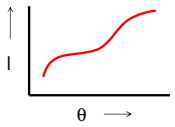
$$F.\frac{dl}{d\theta}.\dot{\theta} = M.\dot{\theta}$$

$$F.\frac{dl}{d\theta} = M$$

$$\frac{dl}{d\theta} = r$$ r: moment arm

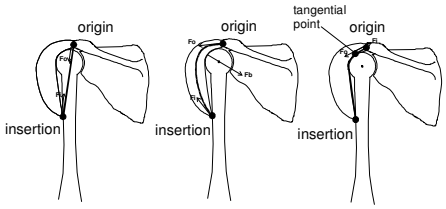
l: muscle length
θ: joint angle
F: muscle force
M: joint moment

'dl/dθ' method



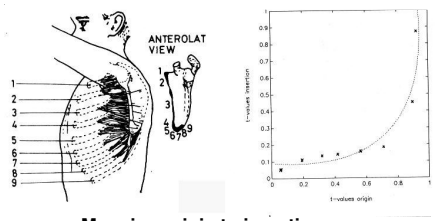
- moment arm is derivative of joint angle - muscle length relation
- relation can be determined in cadaver measurements
- not applicable in joint with multiple DOF, or with muscles crossing multiple joints.

Moment arms



straight line **centroid line** **bony contour**

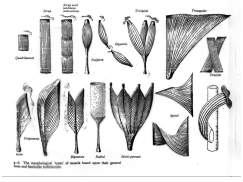
Muscle architecture: Multiple muscle lines of action



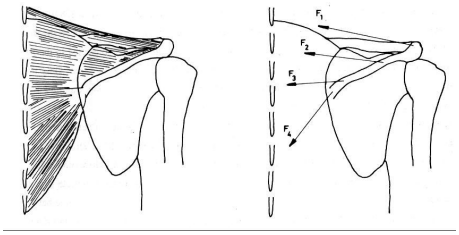
Mapping origin to insertion

Muscle function

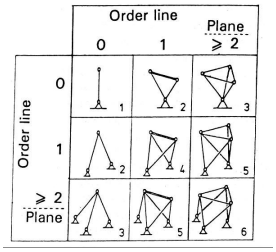
- Actuator in a mechanical system
- Transition of neural signals to forces
- Transition of chemical energy to mechanical energy and heat



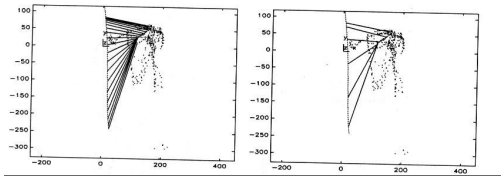
How many force vectors?



Number of muscle lines-of-action



Example: Trapezius muscle



Physiological Cross-Sectional Area (PCSA)

- PCSA measured perpendicular to muscle fibers
- PCSA ~ force
- Muscle force: Includes pennation angle

- Measurements of PCSA:
  - Direct measurements of surface perpendicular to muscle fibers
    - Cadaver study
    - MRI
  - PCSA = Muscle volume/optimum fiber length