

Introduction to Kinetics

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Outline

- Basic elements of kinetics
 - Force, moment, acceleration
- Kinetics of typical gait
 - Conventions, patterns
- Interpretive considerations
 - Emg, speed, remote action

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Dynamics!

- The study of the motions and the forces associated with them
 - Motions = Kinematics
 - position, orientation, time
 - "effect"
 - Forces = Kinetics
 - forces, moments, power
 - "cause"

Newton-Euler Equations

The diagram shows the Newton-Euler equations for translation and rotation, with handwritten annotations in green. A green 'X' is next to the 'Inertial Properties' label. The equations are:

$$F = m a$$
$$M = I a$$

Labels and annotations:

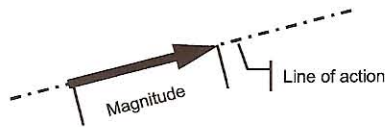
- Inertial Properties**: Points to m and I .
- Translation**: Points to a in the first equation.
- Rotation**: Points to a in the second equation, which is circled in green.
- Kinetics**: Points to F and M .
- Kinematics**: Points to a in both equations.

Basic Elements of Kinetics

- Forces
- Moments & Moment Arms (Lever Arms)
- Mass & Mass Moments of Inertia
- Power

Force

- Push or Pull
- Vector
 - Magnitude
 - Direction
- Line of Action
 - Line along which force acts



Forces at work in Gait

- Ground Reaction Force
 - Newton's 3rd law: "action-reaction principal"

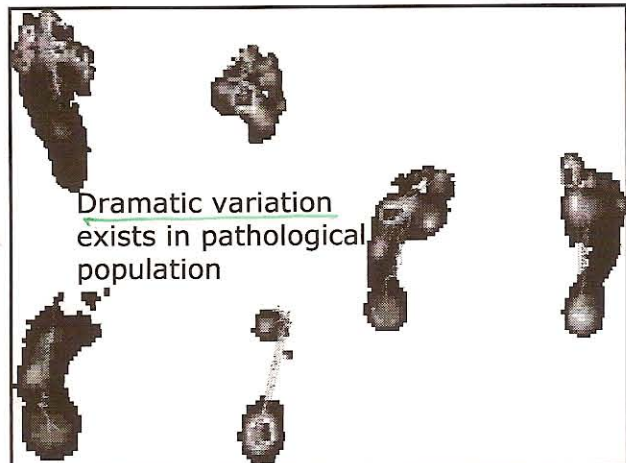


Path of GRF

- Initial contact at heel
- Rapidly moves to forefoot
- Dwells near metatarsal heads
- Moderate variation exists within typical population



dwelling!



Δ moyen de calcul →

Forces at work in Gait

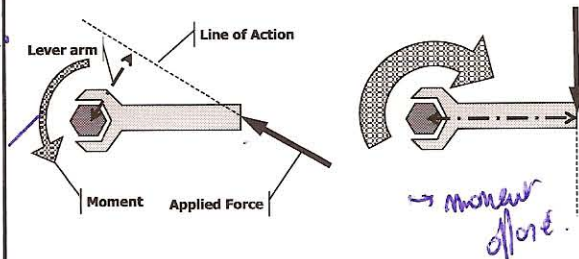
- Body segment weights
 - estimated from anthropometric studies
 - most important during swing phase
 - more important during rapid motions
 - running
 - throwing
 - etc...

Moment (Torque)

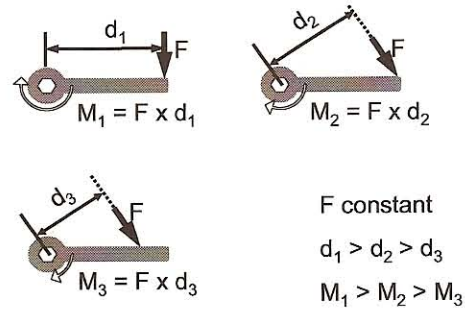
- "Vector" Twist
- Created by force (or forces)
- Calculated at a point
- Direction by Right Hand Rule
- Magnitude = Force x Lever Arm
 - Lever Arm = perpendicular distance between point and line of action of force

Moment - continued

- Think of a wrench: *cle*



Moments: planar examples



Moments at work in Gait

- Internal Joint Moments
 - the body's action
 - Knee Flexion Moment means a moment tending to flex the knee
 - represent the net action of muscle groups
 - Knee Flexion Moment can exist in the presence of knee extensor activity
 - product of muscle force and lever arm
 - perpendicular distance from muscle to joint center

Internal vs. External Moments

- Different Sign
- Similar magnitude for "slow" motions
- Internal Moments reflect what anatomy "does" ***

Contributing factors

- Internal
 - Ground Reaction Force, Geometry, Segment Weight, Motion
- External
 - Ground Reaction Force, Geometry

Inverse Dynamics

- Marker trajectories \Rightarrow segment planes/coordinate systems
- Segment planes/coordinate systems \Rightarrow joint motions
- Motions & inertial properties & GRF \Rightarrow joint moments
- Joint moments & joint motions \Rightarrow joint powers

assemble

Sign Conventions for Kinetics

- Sagittal Plane
 - Extension Moments > 0
 - Flexion Moments < 0
- Coronal Plane
 - Abduction Moments > 0
 - Adduction Moments < 0
- Transverse Plane
 - External Rotation Moments > 0
 - Internal Rotation Moments < 0

Opposite to Kinematics

Work, Energy and Power

- Power
 - rate at which work is done
 - ability to generate timed force
 - overall picture of kinematic and kinetic function
- $\text{Power} \approx \text{Moment} * \text{Angular Velocity}$

↓
Slope of kinematic curve

rate

Sign of Power

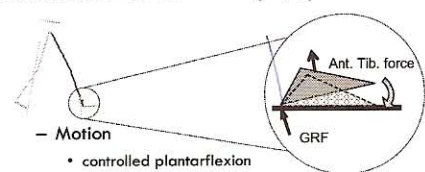
- Power Generation > 0
 - moment and motion (not angle) in same direction
 - increase of joint flexion/extension rate
- Power Absorption < 0
 - moment and motion in opposite directions
 - decrease of joint flexion/extension rate

Outline

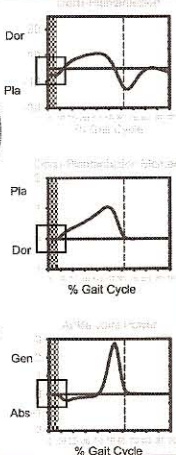
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A Few Examples

Ankle: initial contact (2%)

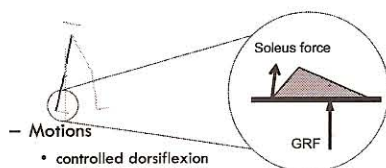


- Motion
 - controlled plantarflexion
- Moments
 - External:
 - GRF behind ankle joint \Rightarrow plantarflexion moment
 - Internal:
 - anterior tibialis on \Rightarrow internal dorsiflexion moment
- Power
 - very small absorption



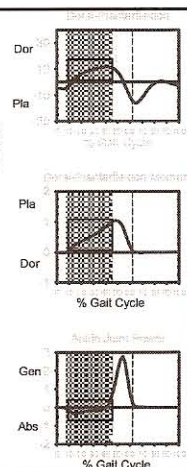
net moment

Ankle: mid-stance (38%)

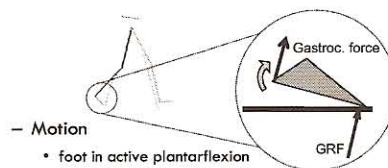


- Motions
 - controlled dorsiflexion
- Moments
 - External:
 - GRF moves in front of ankle \Rightarrow dorsiflexion moment
 - Internal:
 - soleus on giving \Rightarrow plantarflexion moment
- Power
 - Small, sustained power absorption

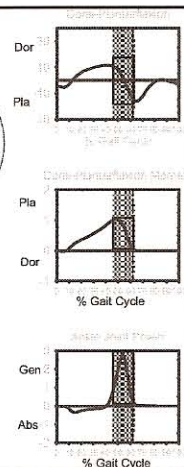
\rightarrow Net work / moment off



Ankle: toe-off (56%)

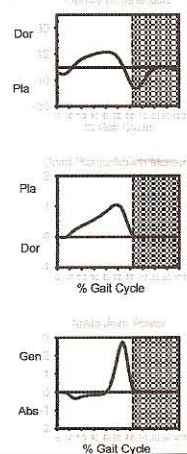


- Motion
 - foot in active plantarflexion
- Moment
 - External:
 - GRF at toe \Rightarrow large dorsiflexion moment
 - + forward propulsion component
 - Internal:
 - Gastrocnemius active \Rightarrow large plantarflexion moment
- Power
 - large generation: "push-off"



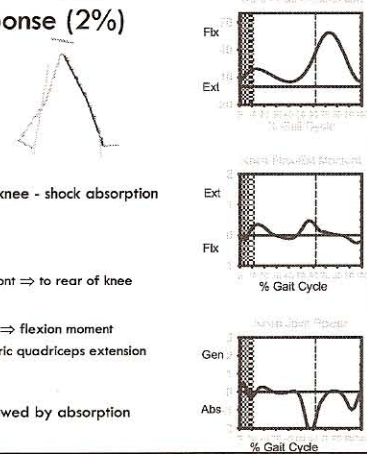
Ankle: swing phase

- Motion
 - active dorsiflexion
 - slight plantarflexion prior to heel strike
- Moment
 - External:
 - weight of foot \Rightarrow small plantarflexion moment
 - Internal:
 - Anterior tibialis holding foot up \Rightarrow small dorsiflexion moment
- Power
 - very small



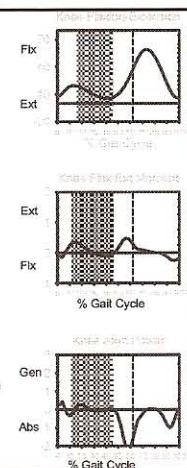
Knee: loading response (2%)

- Motion
 - Controlled flexing of knee - shock absorption
- Moment
 - External:
 - GRF moves from front \Rightarrow to rear of knee
 - Internal:
 - Hamstrings initially \Rightarrow flexion moment
 - followed by eccentric quadriceps extension
- Power
 - initial generation followed by absorption



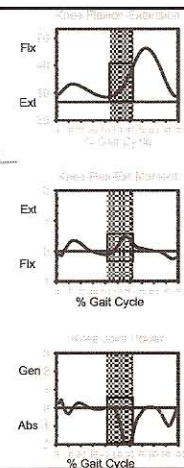
Knee: mid-stance (38%)

- Motion
 - active extension followed by restraint of extension
- Moment
 - External:
 - GRF stays near knee center
 - Internal:
 - initial extension followed by gastrocnemius mediated flexion moment limiting hyperextension
- Power
 - generation early, then slight absorption



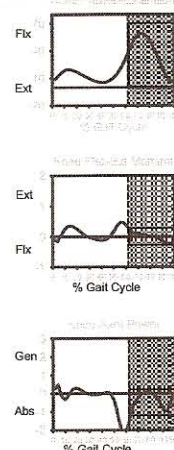
Knee: late stance (56%)

- Motion
 - Ankle and Hip add to knee flexion
 - pushed from below, pulled from above
- Moment
 - External:
 - GRF behind knee \Rightarrow flexion moment
 - Internal:
 - extension moment controls flexion momentum
- Power
 - large absorption



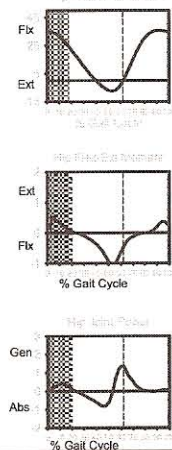
Knee: swing phase

- Motion
 - slowing flexion followed by extension
- Moment
 - External:
 - segment weight only
 - Internal:
 - mostly passive extension
 - late flexion moment from hamstrings prevents hyperextension at terminal swing
- Power
 - continued absorption early and again late



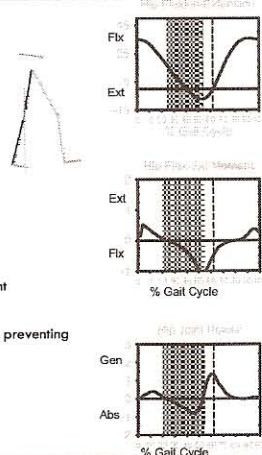
Hip: early stance (10%)

- Motion
 - active extension of hip
- Moment
 - External:
 - GRF starts in front then passes near hip \Rightarrow small flexion moment
 - Internal:
 - large extension moment from hamstrings
- Power
 - generation burst



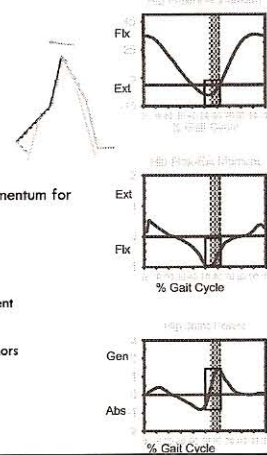
Hip: mid-stance (38%)

- Motion
 - restrained extension of hip
- Moment
 - External:
 - GRF behind hip \Rightarrow extension moment
 - Internal:
 - growing flexion moment from psoas preventing hyperextension
- Power
 - prolonged absorption



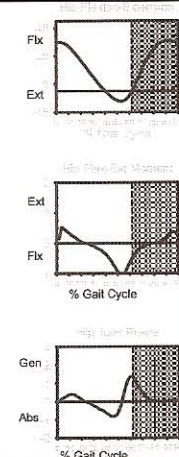
Hip: late-stance

- Motion
 - active flexion of hip generating momentum for swing
- Moment
 - External:
 - GRF behind hip \Rightarrow extension moment
 - Internal:
 - sustained flexion moment from flexors
- Power
 - large generation burst: "pull off"



Hip: Swing Phase

- Motion
 - active hip flexion early, restrained late
- Moment
 - External:
 - segment weight \Rightarrow extension moment
 - Internal:
 - early psoas activity \Rightarrow flexion moment
 - late hamstrings activity (slowing flexion) \Rightarrow extensor moment
- Power
 - early (continued) generation



Outline

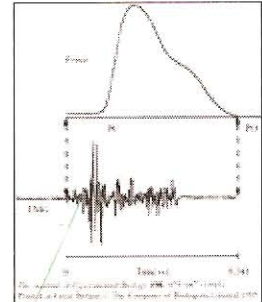
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 - EMG
 - 2-joint muscles
 - remote action
 - speed

Interpreting Kinetics

EMG considerations

Electro-mechanical delay

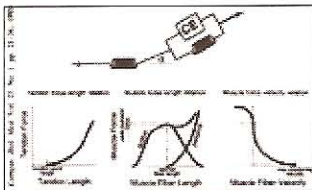
- Force generation lags behind electrical signal by 30 – 100 ms
- Complex phenomenon depending on numerous factors
 - Rate/intensity?
 - Tendon slack/joint angle?
 - Fatigue?
 - Etc...



Journal over 188 1885

Force-Length and Force-Velocity

- Muscle force generation depends on length and velocity (lengthening rate)
- Commonly expressed via Hill-type models

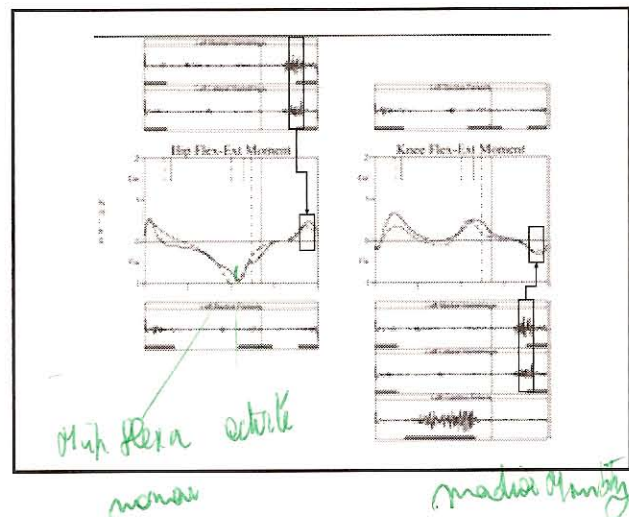
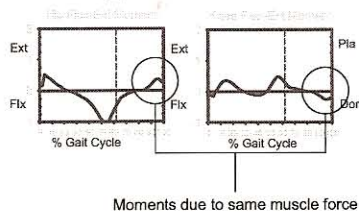


Interpreting Kinetics

Two Joint Muscles

Two joint muscle action

- Hamstrings
 - Knee Flexor and Hip Extensor
 - Consider late swing phase



High flexa exterk
moment

maximal activity

Interpreting Kinetics

Remote Actions

Remote Actions

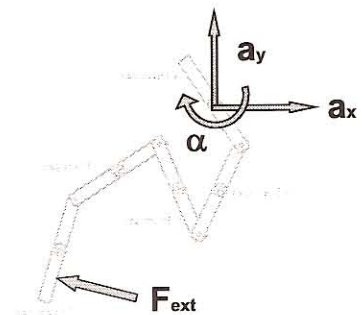
● Example:

- “plantarflexion – knee extension couple”
- Soleus (anatomical ankle plantarflexor)...can induce Knee Extension

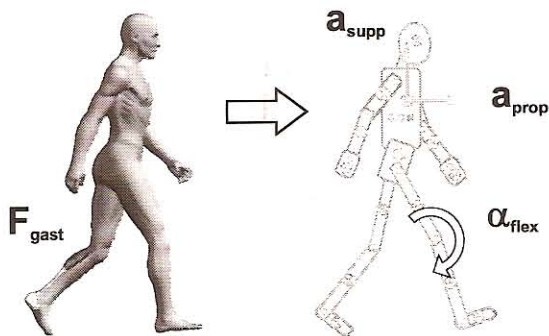
How do we explain this?

Induced Acceleration Analysis

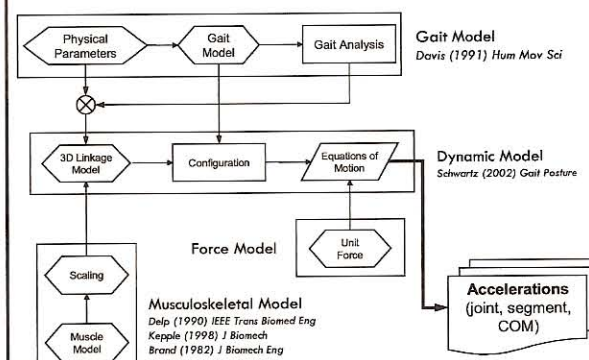
Induced Acceleration = elementary mechanics principles



Applied to a Biomechanical System

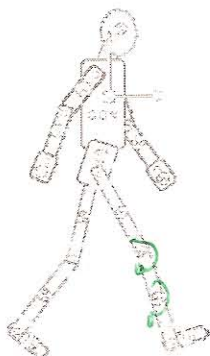


An Inverse Dynamics Approach



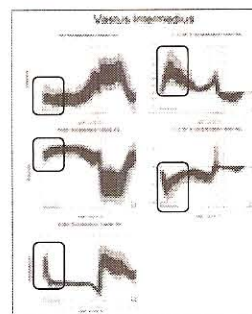
Find Peak Stance-Phase Support

- Support: vertical acceleration of COM
- Propulsion: horizontal acceleration of the COM
- Joints: rotational accelerations
 - Ipsi- and contralateral sides



Example: Vastus Intermedius

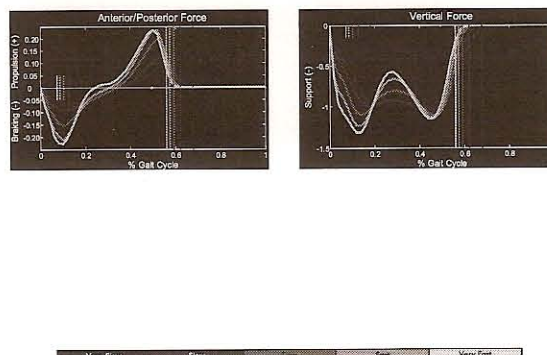
- Anatomical definition: Uni-articular knee extensor
- Strong hip extensor and plantarflexor
- Provides significant support and braking



Interpreting Kinetics

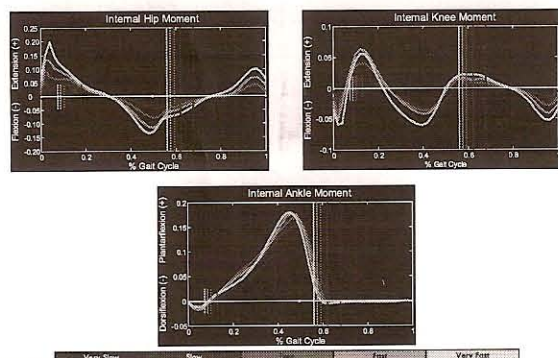
Effects of Speed

Ground Reaction Force (dimensionless)

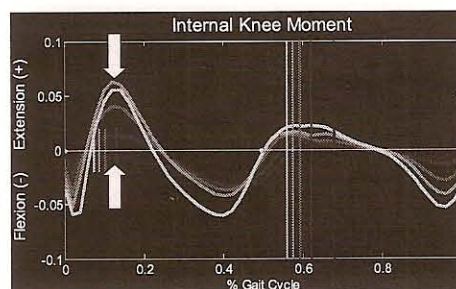


↑ vitesse ? →

Sagittal Plane Moments (dimensionless)



Knee Moment Loading Response Moment



Δ valeurs dépendent de la v. time