TREATING THE SOLE: 
THE ENERGETICS OF GAIT

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OBJECTIVES

• Review the phases and mechanics of gait
• Review the prerequisites of gait
• Discuss energy expenditure in gait
• Highlight potential somatic dysfunction of the lower extremity that may negatively influence gait
• Discuss approaches to treatment of the lower leg to improve gait
WHAT ARE THE DETRIMENTAL EFFECTS OF POOR GAIT?

- Decreased ADLs
  - Financial
  - Social capitol
- Health
  - Conditioning-
    - Cardiovascular fitness
  - Fall risk
  - Mental- Sense of Self
TENSEGRITY


PREREQUISITES OF GAIT

• Equilibrium
• Locomotion
• Musculoskeletal Integrity
• Neurological Control

• Forces for gait:
  • Muscular force.
  • Gravitational force.
  • Ground reaction force.
  • Forces of momentum.
KINETICS CHAINS

• Mechanic engineering concept applied to human movement

• Combination of several successively arranged joints constituting a complex motor unit

https://s-media-cache-ak0.pinimg.com/originals/a5/e6/be/a5e6be358f42af706d6e44dae1d6aa22.jpg
KINETICS CHAINS

• Open chain system - the distal link is free to move while the more proximal links are fixed.

• Closed chain system - the distal link is fixed and the proximal end is free to move.

• Most physiologic motion involves a closed chain system, because the forces applied to the distal limb are usually weight bearing.

https://s-media-cache-ak0.pinimg.com/originals/4d/b3/65/4db365ac93998bcc4b6c1a44e6dbd26e.jpg
DEFINITION OF GAIT

• Gait: Manner of style of walking

• Gait Cycle:
  • Sequence of functions of ONE limb.
  • 1 stride = 2 steps
  • 1 gait cycle = 1 stride

• Cadence- # steps per unit time or distance
DESCRIPTORS OF GAIT

• Movement Patterns
  • Moments
  • Stability
  • Strength/Tone
• Mobility
• Flexibility
MOMENTS

- A force exerted through a lever arm $r$, where force $F$ is applied at a distance $r$ from the axis of rotation

\[ M = rF \]

Forces generated when standing with a flexed knee.

\[ M = r_a F_B = r_b F_Q = M \]
LOWER EXTREMITY MOMENTS

The four joints with the most movement during walking:

Key
- Hip
- Knee
- Ankle
- Big Toe

Displacement of center of mass (CoM) or center of Gravity (CoG)

- At this point the body would remain in equilibrium in any position.
GROUND REACTION FORCE

(A) Gravity

(B) Ground reaction force
“Are impact forces being stored particularly during midstance for maximum propulsion endurance and then released or are they being transmitted inappropriately the bone ligaments and other structures”
PATH OF CENTER OF GRAVITY

• Translatory progression of the body as a whole, produced by coordinated, rotatory movements of the body segments

• Energy efficiency aims to minimize vertical and horizontal displacement of the CoG

• Rhythmic side-to-side movement

• Path: extremely smooth sinusoidal
• Lateral displacement
  • Lateral limit: midstance
  • Average displacement: 5cm/2 in
PATH OF CENTER OF GRAVITY

- Vertical displacement
  - Highest point: midstance
  - Lowest point: double support
  - Average displacement: 5cm
STATIC DISPLACEMENT OF THE CENTER OF GRAVITY
<table>
<thead>
<tr>
<th>New Terminology</th>
<th>Old Terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Contact</td>
<td>Heel Strike</td>
</tr>
<tr>
<td>Loading Response</td>
<td>Foot Flat</td>
</tr>
<tr>
<td>Midstance</td>
<td>Midstance</td>
</tr>
<tr>
<td>Terminal Stance</td>
<td>Heel off</td>
</tr>
<tr>
<td>Preswing</td>
<td>Toe off</td>
</tr>
<tr>
<td>Initial Swing</td>
<td>Acceleration</td>
</tr>
<tr>
<td>Midswing</td>
<td>Midswing</td>
</tr>
<tr>
<td>Terminal Swing</td>
<td>Deceleration</td>
</tr>
</tbody>
</table>
MUSCULAR CONTRACTION DURING GAIT

• Concentric contraction -
  • Muscles actively shorten,
  • Generate force
  • Causes acceleration

• Eccentric contractions
  • Muscles actively elongate in response to a greater opposing force
  • Causes deceleration

Leg muscles during walking
Cadarn Learning Portal
https://www.youtube.com/watch?v=6ObNnCTV6MY#t=26.884331
## MUSCULAR FORCE

<table>
<thead>
<tr>
<th>Initial Contact</th>
<th>Loading Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heel contact</strong></td>
<td><strong>Foot flat</strong></td>
</tr>
<tr>
<td>Hip extensors:</td>
<td>Hip extensors:</td>
</tr>
<tr>
<td>isometric</td>
<td>concentric</td>
</tr>
<tr>
<td>30° Hip flexion</td>
<td>20° Hip flexion</td>
</tr>
<tr>
<td>Knee extensors:</td>
<td>Knee extensors:</td>
</tr>
<tr>
<td>eccentric</td>
<td>eccentric</td>
</tr>
<tr>
<td>5° Knee flexion</td>
<td>15° Knee flexion</td>
</tr>
<tr>
<td>Dorsiflexors:</td>
<td>Dorsiflexors:</td>
</tr>
<tr>
<td>isometric</td>
<td>eccentric</td>
</tr>
<tr>
<td>Neutral dorsiflexion</td>
<td>5°-10° Plantar flexion</td>
</tr>
</tbody>
</table>
MUSCULAR FORCE

<table>
<thead>
<tr>
<th>Midstance</th>
<th>Terminal Stance</th>
<th>Preswing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mid stance</strong></td>
<td><strong>Heel off</strong></td>
<td><strong>Toe off</strong></td>
</tr>
<tr>
<td>Hip extensors: concentric</td>
<td>Hip flexors: eccentric</td>
<td>Hip flexors: concentric</td>
</tr>
<tr>
<td>Near neutral hip</td>
<td>10° Hip extension</td>
<td>Neutral hip</td>
</tr>
<tr>
<td>Plantar flexors: eccentric</td>
<td>10° Knee flexion</td>
<td>30° Knee flexion</td>
</tr>
<tr>
<td>Near full extension</td>
<td>5°-10° Dorsiflexion</td>
<td>15° Plantar flexion</td>
</tr>
</tbody>
</table>
STANDING GROUND REACTION FORCE

- Anterior to ankle = dorsiflexion moment
- Anterior to knee = extension moment
- Posterior to hip = extension moment
SOLE CONTACT IN GAIT

Figure 1: Gait cycle: B: heel contact; C: early foot flat; D: late foot flat; E: toe off; F: trajectory of centre of pressure during stance phase of the gait.
SOLE CONTACT IN GAIT

Figure 1: Gait cycle: B: heel contact; C: early foot flat; D: late foot flat; E: toe off; F: trajectory of centre of pressure during stance phase of the gait.
ENERGY OPTIMIZATIONS OF GAIT

I. Minimize excursion of CoG in vertical & horizontal planes

II. Significantly reduce energy consumption of ambulation
   A. Pelvic rotation
   B. Pelvic tilt
   C. Lateral Displacement of the Pelvis
   D. Knee flexion in Stance Phase
   E. Ankle Mechanisms
   F. Foot Mechanisms
A: PELVIC ROTATION

- Pelvic rotation 4°
- Forward rotation of the pelvis in the horizontal plane approx. 8 degrees
- Reduces the angle of hip flexion & extension
B: PELVIC TILT

• 5 degree dip of the swinging side (i.e. hip adduction)
• Reduces the height of the apex of the curve of CoG
C: LATERAL DISPLACEMENT OF THE HIP

• Lateral stability maintained by:
  • Gluteus medius
  • Tensor Fascia Lata
  • Upper Gluteus Maximus
• Trendelenburg test
D: KNEE FLEXION

- In stance phase approx. 15-20 degree flexion
- Shortens the leg in the middle of stance phase
- Reduces the height of the apex of the curve of CoG
E: ANKLE MECHANISM

- Lengthens the leg at heel contact
- Smoothens the curve of CoG
- Reduces the lowering of CoG
ANKLE ENERGY CONSERVATION

- Achilles Tendon
  - Between the stance phase and toe off, stretching of the Achilles tendon absorbs potential energy (PE).
ANKLE ENERGY CONSERVATION

- Achilles Tendon
  - At Toe Off, potential energy (PE) is converted to Kinetic Energy.
MOTIONS OF THE ANKLE

- Dorsiflexion (Flexion)
- Plantarflexion (Extension)
- Eversion (Valgus) (Abduction)
- Inversion (Varus) (Adduction)

SUPINATION
- = inversion
- + plantarflexion
- + adduction

PRONATION
- = eversion
- + dorsiflexion
- + abduction

- Eversion
- Inversion
MOTIONS OF THE ANKLE: TALOCRURAL ARTICULATION
A The articulating skeletal elements of the talocrural joint

c Trochlea of the right talus, superior view.
MOTIONS OF THE ANKLE: CLOSED KINEMATIC CHAIN
FOOT MECHANISM

• Lengthens the leg at toe-off as ankle moves from dorsiflexion to plantar flexion
• Smoothens the curve of CoG
• Reduces the lowering of CoG
MOTIONS OF THE FOOT: SUBTALAR JOINT
MOTIONS OF THE FOOT
MOTIONS OF THE FOOT

- Tibia
- True ankle joint
  - Medial malleolus
  - Deltoid ligament
  - Lateral malleolus
  - Tibialis posterior
- Subtalar joint
  - Flexor digitorum longus
  - Flexor hallucis longus
  - Med. plantar ncr and vessels
  - Quadratus plantae
  - Abductor hallucis
  - Lat. plantar ncr and vessels
  - Flexor digitorum brevis
- Calcaneous
  - Peronaeus brevis
  - Peronaeus longus

ANKLE
- Dorsiflexion (Flexion)
- Plantarflexion (Extension)

TOES
- Extension

HINDFOOT
- Eversion (Valgus) (Abduction)
- Inversion (Varus) (Adduction)

SUPINATION
- Inversion + plantarflexion + adduction

PRONATION
- Eversion + dorsiflexion + abduction

FOREFOOT
- Abduction (Valgus)
- Adduction (Varus)

FOREFOOT
- Eversion
- Inversion
MOTIONS OF THE FOOT

ANKLE
- Dorsiflexion (Flexion)
- Plantarflexion (Extension)

TOES
- Extension
- Flexion

HINDFOOT
- Supination
  - Inversion
  - Plantarflexion
  - Abduction

PRONATION
- Eversion
- Dorsoflexion
- Adduction

FOREFOOT
- Abduction
- Adduction
- Eversion
- Inversion
MOTIONS OF THE FOOT

**Figure 42-23** Combined motions (left foot): Inversion versus eversion, supination versus pronation.
MOTIONS OF THE FOOT: PROPULSION

- **Phalanx**
- **Metatarsal**
- **MTP joint**

**ANKLE**
- Dorsiflexion (Flexion)
- Plantarflexion (Extension)

**HINDFOOT**
- Eversion (Valgus) / Abduction
- Inversion (Varus) / Adduction

**SUPINATION**
- Inversion
- Plantarflexion
- Adduction

**PRONATION**
- Eversion
- Dorsiflexion
- Abduction

**FOREFOOT**
- Abduction (Valgus)
- Adduction (Varus)

**TOES**
- Extension
- Flexion

**Stages of Gait**
- **Heel Strike**
- **Midstance**
- **Propulsion**
MOTIONS OF THE FOOT: PROPULSION

- MTP joint requires flexibility $45^0$
- Rigidity leads to early heel lift
- Decreased stretch of Achilles tendon
- Decreased potential to kinetic energy
<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Chain Type</th>
</tr>
</thead>
</table>
| Swing Phase     | • Foot is off the ground  
• Distal end is free to move  
• Calcaneus/midfoot/forefoot moves on tibia/talus  
• Abduction of foot | Open Chain      |
| Stance Phase    | • Foot is on the ground  
• Proximal end moves on fixed distal end  
• Tibia/Talus move on fixed foot  
• Internal rotation of the leg | Closed Chain    |
<table>
<thead>
<tr>
<th></th>
<th><strong>Pronation</strong></th>
<th><strong>Supination</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Swing Phase</strong></td>
<td>Open Chain</td>
<td>Calcaneal eversion</td>
</tr>
<tr>
<td></td>
<td>Calcaneus moves on talus</td>
<td>Adduction</td>
</tr>
<tr>
<td></td>
<td>Abduction</td>
<td>Plantar flexion</td>
</tr>
<tr>
<td></td>
<td>Dorsiflexion</td>
<td></td>
</tr>
<tr>
<td><strong>Stance Phase</strong></td>
<td>Closed Chain</td>
<td>Calcaneal inversion</td>
</tr>
<tr>
<td></td>
<td>Talus moved on calcaneus</td>
<td>Adduction</td>
</tr>
<tr>
<td></td>
<td>Calcaneal eversion</td>
<td>Plantar flexion</td>
</tr>
<tr>
<td></td>
<td>Talar adduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dorsiflexion</td>
<td></td>
</tr>
</tbody>
</table>
TORQUE OF THE LEG TRANSFERS INTO THE FOOT

- Internal rotation absorbs gravitational energy
- Release that on toe off as you go back to external rotation
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TORQUE OF THE LEG TRANSFERS INTO THE FOOT

- Internal rotation absorbs gravitational energy
- Release that on toe off as you go back to external rotation
ENERGY CONSERVATION

- Architecture recycles energy, up to 60%
  - Gait Impairments
  - Frail & Comorbidities
  - Amputation
- Architecture absorbs external shocks.
- Designed to adapt to navigate uneven surfaces, or run flat out.

A  The ligaments of the right foot, medial view

Illustrator: Karl Wesker

Schumike et al. THEMIE Atlas of Anatomy • General Anatomy and Musculoskeletal System © THIEVE 2007 • All rights reserved. Usage subject to terms of use. • www.thieme.com/tao

Thieme
SOLE CONTACT

• Normal Gait transfers force throughout the foot

• There should be free distribution of weight amongst the bones of the foot
ENERGY CONSERVATION:
PLANTAR CALCANEONAVICULAR LIGAMENT (SPRING LIGAMENT)

• During the Stance Phase:
  Flattening of the arch
  ➔ stretching of the Spring Ligament
  ➔ absorbs the energy of forward motion.
GAIT & ENERGY CONSERVATION: PLANTAR CALCANEONAVICULAR LIGAMENT (SPRING LIGAMENT)

• At Toe Off:

  Spring ligament rebounds
  → converts the stored energy to kinetic energy

• Helps to absorb shock associated with ambulation.
POTENTIAL LOWER EXTREMITY SOMATIC DYSFUNCTION NEGATIVELY INFLUENCING GAIT

- Joint restrictions
- Ligamentous injury or restriction
- Muscular imbalance
POTENTIAL SOMATIC DYSFUNCTION INFLUENCING GAIT: JOINT RESTRICTIONS

• Elevated pelvis gait: a hiking or elevation of the pelvis on the swing side if various joints have motion limitation from any cause.
  • Tibia/talus
  • Subtalar joint
• Early heel lift: If plantar flexion is absent, there is no push-off and the heel and forefoot come off the floor together.
  • Rigidity of the foot may alter normal mechanics: Midfoot, MTP
POTENTIAL SOMATIC DYSFUNCTION INFLUENCING GAIT: LIGAMENTOUS

Inversion Ankle Sprain
- External Rotation of the Tibia
  - Foot Supination
  - Inversion
- Posterior Fibular Head

- Tendency to have a recurrent ankle sprain

Eversion Ankle Sprain
- Internal Rotation of the Tibia
  - Foot Pronation
  - Eversion
- Anterior Fibular Head

Right shoulder depression
Thoracic and lumbar scoliosis
Pelvic asymmetry
Hip Adduction
Genu Valgum
Foot Pronation
POTENTIAL SOMATIC DYSFUNCTION INFLUENCING GAIT: MUSCLE IMBALANCE

• Muscle weakness
  • Increased motion of the CoG
  • Causes increases exertion to compensate
    • Gluteus medius gait: a shift of the body toward the deficient side, indicating a weakness of that gluteus medius muscle. +Trendelenburg sign in the upright position.
    • Gluteus maximus gait: the trunk and pelvis are hyperextended backward over both hips to maintain the center of gravity behind the involved hip joint.
POTENTIAL SOMATIC DYSFUNCTION INFLUENCING GAIT: MUSCLE IMBALANCE

• Muscle hypertonicity
  • Decreases flexibility on the affected side
    • Psoas, adductors, gastrocnemius/soleus
  • Inhibits antagonistic muscles from proper contraction
    • Adductors and hamstrings
APPROACHES TO TREATMENT

- Muscle strengthening
  - Concentric training
  - Eccentric training
- Joint mobilization
  - ART
- Ligamentous strain
  - BLT/LAS
- Muscle inhibition
  - MFR
  - DIR
- Fascial release
  - MFR
  - FDM
SUMMARY

• Gait is multiplanar as is our evaluation
• Requires Musculoskeletal Integrity
• Goal is to minimize energy expenditure
  • Decreased movement of the CoG
  • Efficiently transfer energy through kinetic chains
• Treatment
  • Exercise prescription
  • Orthotics
  • Manipulation to return integrity
THANK YOU
REFERENCES

• Bahler, A. The Biomechanics of the Foot. Clinical Prosthetics and Orthotics 1986; 10(1) pp 8-14


• Versteeg CS, Ting LH, Allen JL. Hip and ankle responses for reactive balance emerge from varying priorities to reduce effort and kinematic excursion: A simulation study. J Biomech. 2016 Oct 3;49(14):3230-3237