What are we going to cover?

• Definitions and key concepts
• Gait cycle
• Determinants of gait
• Abnormal gait and potential causes
• Energy expenditure
Pre-test #1

• In nondisabled subjects walking at self-selected normal speeds, the normal amount of time spent in double limb support is approximately:
  – A: 10%
  – B: 20%
  – C: 30%
  – D: 40%
Pre-test #2

• At mid stance, where is the ground reaction force vector located?
  – A: anterior to the ankle, posterior to the knee
  – B: anterior to the ankle, anterior to the knee
  – C: anterior to the knee, anterior to the hip
  – D: posterior to the knee, posterior to the hip
Pre-test #3

• Concentric activation of the iliopsoas muscle is essential to which phase of the gait cycle?
  – A: midstance
  – B: terminal stance
  – C: preswing
  – D: terminal swing
• Painful, arthritic hip disease is associated with the following gait abnormality?
  – A: prolonged stance phase of the affected limb
  – B: limb circumduction during swing
  – C: lateral trunk shift over affected joint during stance
  – D: shortest step length of the affected limb
Pre-test #5

A patient with a recent stroke and hemiplegia presents to your clinic and is noted to have a genu recurvatum gait pattern. Aggressive stretching has improved ankle range-of-motion, but not spasticity and gait. The most appropriate treatment is?

– A: an AFO with 5 degrees of plantarflexion
– B: Achilles tendon lengthening
– C: phenol injection to hamstrings
– D: botox injection to the gastroc-soleus muscle group
What are we going to cover?

• Definitions and key concepts
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Definitions and Concepts

- Stride length: distance between points of contact of same foot (also one gait cycle)
- Step length: distance between points of contact of opposite feet (normal is 15-20 in)
Definitions and Concepts

• Center of gravity (COG)
  – Located just anterior to S1/S2 (typically 5 cm anterior to S2)
  – Displaces horizontally and laterally while walking

• Center of pressure (COP)
  – Point where total sum of pressure acts on body
  – Located with force plate in gait labs
  – Can consider as origin of ground reaction force
Vertical displacement of CoM

Side-to-side displacement of CoM

Centre of Pressure

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(From Neumann: Kinesiology of the Musculoskeletal System, 2nd edition.)
Definitions and Concepts

★ • Base of support

- Space outlined by feet and any assistive device in contact with ground
- Falling is prevented if COG is over base of support
Definitions and Concepts

- Ground reaction force (GRF)
  - Equal in magnitude and opposite in direction to force body exerts on ground
  - Think of a line going from COP to COG
Physics Review

- Force = mass x acceleration
- Moment: (also known as torque) rotation around a fixed point in space
- Moment = Force x distance (perpendicular)
Moments

- External: forces acting outside (or external) to the joint
- Internal: forces acting inside on the joint - ie muscles
Muscle Activation

• Concentric
  – Muscle shortens
  – Think of bicep curl

• Eccentric
  – Muscle elongates
  – Often greater opposing force
  – Can think of a “negatives”
What are we going to cover?

- Definitions and key concepts
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Gait

• Gait cycle has two phases:
  – Stance phase: time in which limb is in contact with ground (60% of gait cycle)
  – Swing phase: time in which limb is in air (40% of gait cycle)

• Comfortable walking speed is 80 m/min or 3 mph
  – You can change this by either changing cadence or stride/step length
Gait

• Double limb support
  – Time in which both feet are in contact with ground
  – Beginning and end of stance phase
  – 20% of gait cycle

• Single limb support
  – Time in which opposite foot is lifted in swing
  – 80% of gait cycle

• When there is no longer double limb support = running
  – Running has float
(a) Walking

Double support (10%)

Stance (60%)

Double support (10%)

Swing (40%)

10% Loading response

30% Midstance

50% Terminal stance

Preswing

70% Initial swing

85% Midswing

Terminal swing

Stride (100%)

Heel strike

(b) Running

Stride (100%)

Stance

Swing

Double float

Double float

Absorption

Propulsion

Initial swing

Midswing

Terminal swing

Initial contact

Midstance

Toe off

Midswing

Initial contact
Gait Cycle

A. Heel strike (initial contact)
B. Loading response (foot flat)
C. Midstance
D. Terminal stance (heel off)
E. Preswing (toe off)
F. Initial & Mid-swing
G. Terminal swing

Stance Phase (60%)
Push Off
Gait Cycle
Swing Phase (40%)

| Double support (10%) | Single support (40%) | Double support (10%) | Single support (40%) |
Initial Contact/Heel Strike

- Heel contacts ground
- Eccentric activity:
  - Glut max, glut med
  - Hamstrings
  - Quadriceps
  - Pre-tibial muscles
Initial Contact/Heel Strike

• GRF
  – Posterior to ankle (plantar flexion moment)
  – Posterior to knee (knee flexion moment)
  – Anterior to hip (hip flexion moment)
Loading Response

- Initial contact to opposite leg lifted off
- Weight shift occurs
- Lowest COG
- Eccentric:
  - Glut med
  - Hamstrings
  - Quadriceps
  - Pretibial muscles
Loading Response

• GRF
  – Posterior to ankle (plantar flexion moment)
  – Posterior to knee (knee flexion moment)
  – Anterior to hip (hip flexion moment)
Midstance

• From liftoff of opposite leg to point where ankles of legs aligned in frontal plane
• Highest COG
• Minimal muscle activity:
  – Glut med
  – Calf muscles
Midstance

- GRF
  - Close to going through most joints
  - Relatively quiet from muscular standpoint
  - Hip abductors firing to stabilize hip
Terminal Stance

- Time from ankle alignment to just prior to initial contact of opposite leg
- Concentric
  - Iliopsoas
  - Calf muscles
- Eccentric
  - Glut med
Terminal Stance

- **GRF:**
  - Anterior to ankle (dorsiflexion moment)
  - Progresses to posterior to knee (knee flexion moment)
  - Posterior to hip (hip extension moment)
Pre-swing

- From initial contact of opposite leg to just prior to lift off
- Unloading weight
- Concentric:
  - Iliopsoas
  - Calf muscles
- Eccentric:
  - Quadriceps
Pre-swing

• GRF:
  – Anterior to ankle (dorsiflexion moment)
  – Progresses to posterior to knee (knee flexion moment)
  – Posterior to hip (hip extension moment)
★ Initial and Mid Swing

• Initial: lift off to maximal knee flexion
• Mid: max knee flexion to vertical tibia
• Concentric:
  – Iliopsoas
  – Pretibial muscles
• Eccentric:
  – Hamstrings
  – Quadriceps (initial only)
Terminal Swing

- From vertical tibia to just prior to initial contact again
- Concentric:
  - Pretibial muscles
- Eccentric:
  - Hamstrings
What are we going to cover?

- Definitions and key concepts
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Determinants of Gait

- Pelvic rotation
- Pelvic tilt
- Knee flexion in stance phase
- Foot mechanics
- Knee mechanics
- Lateral displacement of pelvis

*These factors help minimize excursion of COG to maximize forward progression with least expenditure of energy*
★ Pelvic Rotation

- Pelvis rotates medially/anteriorly on swinging leg side
- Essentially lengthens that limb as it prepares to accept weight
- Helps keep limbs lengthened at lowest point of COG to try to prevent sudden drop in COG
★ Pelvic Tilt

• Pelvis on side of swinging leg (opposite to weight bearing leg) is lowered 4-5 degrees
• Lowers COG at midstance
Knee Flexion in Stance

- Knee flexes 15-20 degrees at heel contact → loading response
- Lowers COG and reduces vertical elevation at midstance (would be highest point)
- Decreases energy expenditure
- Also absorbs shock of impact of heel strike
Foot Mechanisms

- Plantar-flexion at heel strike smoothens curve of falling pelvis
- Associated with controlled plantar-flexion in first part of stance
Knee Mechanisms

- Knee extends at mid-stance
- Coincides with ankle plantar-flexion and foot supination to restore length to leg
- Diminishes fall of pelvis at opposite heel strike
★ Lateral Pelvis Displacement

• Displaces towards stance limb
• Helps keep COG above base of support
What are we going to cover?

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Causes of Abnormal Gait

• Focal weakness
  – Example: dorsiflexion weakness

• Joint contractures
  – Example: tight heel cord

• Pain
  – Example: hip osteoarthritis

• Neurological conditions
  – Examples: stroke, Parkinson disease, CP
Why is it important?

• Targeted strengthening, stretching programs
• Prosthetics and orthotics
• Botox/phenol
• Joint injections (for painful joints)
• Assistive devices
• Surgical considerations
Trendelenburg

- Cause: weak hip abductors, loss of pelvis stabilization
- Uncompensated: contralateral pelvis drops during stance
- Compensated: lateral trunk lean over stance leg to keep COG over stance leg
Trendelenburg

Uncompensated

Compensated
Weak Dorsiflexors

- Foot slap seen in mildly to moderately weak muscles
- With more severe, creates an effectively longer limb
- Compensate with:
  - Steppage gait - accentuated hip and knee flexion to clear limb
  - Circumduction - swing leg advances in semi-circular pattern
  - Hip hiking - pelvis elevates during swing
- Other causes of long limb: plantar-flexor spasticity, equinus deformity, stiff knee, weak hamstrings
Genu Recurvatum

• Excessive knee extension in stance

• Causes:
  – Weak, short, or spastic quadriceps
  – Compensated hamstring weakness
  – Plantar-flexor spasticity
  – Achilles tendon contracture

• Treatment (examples):
  – Manage plantar-flexor tone, bracing, stretching, strengthening
<table>
<thead>
<tr>
<th>Gait Pathology</th>
<th>Probable Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Foot strike to foot flat</td>
<td></td>
</tr>
<tr>
<td>– Foot slap</td>
<td>Moderately weak dorsiflexors</td>
</tr>
<tr>
<td>2. Foot strike through midstance</td>
<td></td>
</tr>
<tr>
<td>– Genu recurvatum</td>
<td>Weak, short, or spastic quadriiceps; compensated hamstring weakness; Achilles tendon contracture; plantarflexor spasticity</td>
</tr>
<tr>
<td>– Excessive foot supination</td>
<td>Compensated forefoot valgus deformity; pes cavus; short limb; uncompensated external rotation of tibia or femur</td>
</tr>
<tr>
<td>– Excessive trunk extension</td>
<td>Weak hip extensor or flexor; hip pain; decreased knee ROM</td>
</tr>
<tr>
<td>– Excessive trunk flexion</td>
<td>Weak gluteus maximus and quadriceps</td>
</tr>
<tr>
<td>3. Foot strike through toe off</td>
<td></td>
</tr>
<tr>
<td>– Excessive knee flexion</td>
<td>Hamstring contracture; increased ankle dorsiflexion; weak plantar flexor; long limb; hip flexion contracture</td>
</tr>
<tr>
<td>– Excessive medial femur rotation</td>
<td>Tight medial hamstrings; antverted femoral shaft; weakness of opposite muscle group</td>
</tr>
<tr>
<td>– Excessive lateral femur rotation</td>
<td>Tight hamstrings; retroverted femoral shaft; weakness of opposite muscle group</td>
</tr>
<tr>
<td>– Increased base of support</td>
<td>Abductor muscle contracture; instability; genu valgum; leg length discrepancy</td>
</tr>
<tr>
<td>– Decreased base of support</td>
<td>Adductor muscle contracture; genu varum</td>
</tr>
<tr>
<td>4. Foot flat through heel off</td>
<td></td>
</tr>
<tr>
<td>– Excessive trunk lateral flexion</td>
<td>Ipsilateral gluteus medius weakness; hip pain (see below)</td>
</tr>
<tr>
<td>(Trendelenburg gait)</td>
<td></td>
</tr>
<tr>
<td>– Pelvic drop</td>
<td>Contralateral gluteus medius weakness</td>
</tr>
<tr>
<td>– Waddling gait</td>
<td>Bilateral gluteus medius weakness</td>
</tr>
<tr>
<td>5. Midstance through toe off</td>
<td>Compensated forefoot or rearfoot varus deformity; uncompensated forefoot valgus deformity; pes planus; decreased ankle dorsiflexion; increased tibial varum; long limb; uncompensated internal rotation of tibia or femur; weak tibialis posterior</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>– Excessive foot pronation</td>
<td></td>
</tr>
<tr>
<td>– Bouncing or exaggerated plantar flexion</td>
<td></td>
</tr>
<tr>
<td>– Insufficient push-off</td>
<td></td>
</tr>
<tr>
<td>– Inadequate hip extension</td>
<td></td>
</tr>
<tr>
<td>6. Swing phase</td>
<td></td>
</tr>
<tr>
<td>– Steppage gait</td>
<td>Severely weak dorsiflexors; equinus deformity; plantarflexor spasticity</td>
</tr>
<tr>
<td>– Circumduction</td>
<td>Long limb; abductor muscle shortening or overuse</td>
</tr>
<tr>
<td>– Hip hiking</td>
<td>Long limb; weak hamstring; quadratus lumborum shortening</td>
</tr>
</tbody>
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What are we going to cover?

• Definitions and key concepts
• Gait cycle
• Determinants of gait
• Abnormal gait and potential causes
• Energy expenditure
• With any deviation of gait, energy demands to return to normal ambulatory function are high
  – This is true to some extent for all gait deviations
• Wheelchair propulsion is 9% increase in energy
• Crutch walking requires more energy
  – Would benefit from strengthening these muscles:
    • Lat dorsi, triceps, pec major, quadriceps, hip extensors, hip abductors
Energy Expenditure of Different Amputation Levels

<table>
<thead>
<tr>
<th>Level of Amputation</th>
<th>Increased Metabolic Cost Above Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syme’s</td>
<td>15%</td>
</tr>
<tr>
<td>Traumatic TT (BKA)</td>
<td>25%</td>
</tr>
<tr>
<td>Traumatic TF (AKA)</td>
<td>68%</td>
</tr>
<tr>
<td>Vascular TT (BKA)</td>
<td>40%</td>
</tr>
<tr>
<td>Vascular TF (AKA)</td>
<td>100%</td>
</tr>
</tbody>
</table>

TT = transtibial
TF = transfemoral
### Energy Expenditure of Different Traumatic Amputations

<table>
<thead>
<tr>
<th>Level of Amputation (Correlates with traumatic amputee)</th>
<th>Increased Energy Expenditure above normal</th>
</tr>
</thead>
</table>
| BKA                                                   | 20%–25%  
(Short BKA—40%  
Long BKA—10%)                                   |
| BKA + BKA                                             | 41% (Gonzalez 1974)                        |
| AKA                                                   | 60–70%                                    |
| AKA + BKA                                             | ↑ 118% net cost (Traugh 1975)              |
| AKA + AKA                                             | >200%  
(260% Huang 1979)                            |
Post-test #1

- In nondisabled subjects walking at self-selected normal speeds, the normal amount of time spent in double limb support is approximately:
  - A: 10%
  - B: 20%
  - C: 30%
  - D: 40%
Post-test #2

• At mid stance, where is the ground reaction force vector located?
  – A: anterior to the ankle, posterior to the knee
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  – C: anterior to the knee, anterior to the hip
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• Concentric activation of the iliopsoas muscle is essential to which phase of the gait cycle?
  – A: midstance
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  – D: terminal swing
Post-test #4

• Painful, arthritic hip disease is associated with the following gait abnormality?
  – A: prolonged stance phase of the affected limb
  – B: limb circumduction during swing
  – C: lateral trunk shift over affected joint during stance
  – D: shortest step length of the affected limb
Post-test #5

- A patient with a recent stroke and hemiplegia presents to your clinic and is noted to have a genu recurvatum gait pattern. Aggressive stretching has improved ankle range-of-motion, but not spasticity and gait. The most appropriate treatment is?
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