Clinical biomechanics of gait

Three Requirements of Gait:

1. balance
2. weight bearing
3. forward propulsion

Outline

• terminology related to the gait cycle
• determinants of gait
• muscle activity during gait
• joint rotations, joint torques, and joint power during gait

Gait Terminology

Stride: complete cycle of locomotory movement
- sequence of right plus left steps
Step Length: distance between R and L heel strikes
- normal adult step length: 80 cm
Cadence: rhythm of locomotion
- normal adult cadence: 101-120 steps/minute
Walking Velocity = cadence * step length
- normal adult walking velocity: 1.5 m/s
Terminology and duration of the phases of a stride

- stance takes up 62% of the stride
- swing takes up the remaining 38%

Stance begins and ends with periods of double support

Limping: lengthening of stance in the contralateral (nonpainful) limb

Determinants of gait

- dictate the path through space of the whole-body COG during locomotion
- Framework for examining pathologies
- functional significance: lower the displacement of the COG; reduce energy expenditure
- location of the COG: 55% of body height, anterior to S2 vertebra
Determinants of Gait (cont)

(1) pelvic rotation
(2) pelvic tilt
(3) knee flexion during stance
(4&5) plantarflexion during heel strike and heel off
(6) lateral displacement of pelvis
(7) ankle inversion-eversion-inversion during stance
(8) lateral flexion of trunk
(9) anteriorposterior flexion of trunk

Pelvic rotation (Determinant 1)

- During normal walking, the pelvis rotates from side to side about a vertical axis.
- During the swing phase, medial rotation of ~5 deg at the weight-bearing hip advances the contralateral (swing phase) hip
- Pelvic rotation increases the step length, and smooths “trajectorial arc collisions” between R&L legs
- Walking racers use exaggerated pelvic rotation to delay transition from walking to running at high speeds

Pelvic rotation (cont)

Pelvic tilt (Determinant 2)

- The pelvis is tilted downward on the swing phase side.
- The magnitude of tilt is controlled by the hip abductors on the stance side.
- Pelvis tilt reduces the apex of the COG trajectory
- Pelvis tilt introduces the need for knee flexion during swing (so the foot can clear the ground).
- Trendelenburg gait: exaggeration of pelvic tilt due to hip abductor weakness. Pelvis descends to unsupported side; toe clearance may be impaired.
**Knee flexion during stance** (Determinant 3)

- The knee is in an extended position at heel strike, and thereafter begins to flex.
- Just prior to the middle of the stance phase (near simultaneous to heel-off), the knee extends.
- Maximum knee flexion is ~ 15 deg, and occurs at mid-stance.
- Knee flexion (a) lowers the apex of COG trajectory, and (b) assists in “shock absorption” by reducing the effective stiffness of the leg.

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**Plantarflexion during heel strike** (Determinant 4)

- At heel strike, the foot begins to plantarflex, thus lowering the ankle and approaching the full contact position of the foot.
- If the ankle were immobile, the COG would rise (dashed arrow) as if the leg were a stilt.
- Plantarflexion at the ankle lowers the trajectory of the COG (solid arrow).

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**Plantarflexion during heel off** (Determinant 5)

- At heel-off, the heel is raised by plantarflexion at the ankle.
- If the heel was not permitted to elevate, the leg would rotate forward about the ankle joint and the COG trajectory would fall abruptly (dashed arrow).
- Raising the heel off the ground by plantarflexion provides for a more horizontal COG trajectory (solid arrow).

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**Human trajectory in the sagittal plane**

Factors that raise the low point of the trajectory:

1. pelvic rotation
2. pelvic tilt
3. knee flexion during mid-stance

Factors that lower the apex of the trajectory:

1. pelvic rotation
2. pelvic tilt
3. knee flexion during mid-stance

Factors that decrease the slope of the rise:

1. plantarflexion after heel strike
2. plantarflexion during heel strike
3. knee flexion during mid-stance

Factors that decrease the slope of the dip:

1. plantarflexion after heel-off
2. pelvic tilt
3. pelvic rotation
4. knee flexion during mid-stance
Lateral displacement of pelvis (Determinant 6)

- During stance, the pelvis shifts laterally towards the stance phase limb
- This moves the COG closer to the stance leg, making it easier for the stance-side hip abductors to raise the swing leg and control pelvic tilt
- This results in horizontal (transverse plane) oscillation of the COG with an amplitude of ~5cm, and frequency one-half that of vertical (sagittal plane) movement (~1 Hz vs. 2 Hz)

Inversion-Eversion-Inversion at Ankle (Subtalar) Joint (Determinant 7)

- In the normal foot, slight inversion occurs at heel strike
- This is followed by eversion throughout the greater part of the stance phase
- At heel off, inversion again occurs
- This sequence results in shock absorption through flattening of the longitudinal arch

Pressure distribution on the plantar surface of the foot:

Abductor lurch

- Exaggerated lateral shift due to loss of hip abductors (gluteus medius, gluteus minimus) on stance side
- Pelvic tilt is opposite to “Trendelendburg gait”
- Apes have Abductor lurch

Lateral flexion of the trunk (Determinant 8)

- An ipsilateral flexion of the vertebral column to the stance phase side (in the coronal plane)
- Corresponds to lateral displacement of the pelvis towards the stance side.
Anterioposterior flexion of the trunk (Determinant 9)

- Maximum backward flexion occurs at the beginning of the support (stance) phase
- Maximum forward flexion occurs at the end of the support phase

Muscle activity during the gait cycle

- First rocker: eccentric contraction of plantarflexors and quadriceps control rate of dorsiflexion and knee flexion
- Second rocker: eccentric extensor torque controls knee flexion
- Third rocker: concentric contraction of plantarflexors causes forceful push-off
- Initial swing: eccentric extensor torque brakes knee flexion

Ankle joint: sagittal plane kinetics

- 1st rocker: eccentric dorsiflexor torque controls foot lowering
- 2nd rocker: eccentric plantarflexor torque controls dorsiflexion
- 3rd rocker: concentric plantarflexor torque causes forceful push-off
- 4th rocker: concentric dorsiflexor torque assists in toe clearance during swing

Knee joint: sagittal plane kinetics

- 1st heel strike: concentric flexor moment, byproduct of hip extension via hamstrings contraction
- 2nd beginning of second rocker: eccentric extensor moment controls knee flexion
- 3rd end of second rocker: extensor moment becomes concentric
- 4th midstance to push-off: eccentric flexor moment, byproduct of gastrocnemius contraction
- 5th third rocker: eccentric extensor torque controls knee flexion
- 6th initial swing: eccentric extensor torque brakes knee flexion
Hip joint: sagittal plane kinetics

- **1.** Heel strike: concentric hip extensor torque, limits trunk rotation and hip flexion
- **2.** Midstance to terminal stance: eccentric hip flexor torque resists increasing hip extension
- **3.** Third rocker and initial swing: concentric hip flexor raises limb and adds energy to gait cycle
- **4.** Terminal swing: concentric extensor torque accelerates thigh backwards prior to heel strike

Review questions

- What are the three requirements of gait?
- During normal gait, what variation occurs in the position of the COG in the coronal plane?
- During normal gait, what variation occurs in potential energy of the body? How is this affected by the determinants of gait?
- What factors lower the apex of the COG during gait?
- What factors raise the low point of the COG during gait?
- What factors reduce the slope of the rising and falling portions of the COG trajectory during gait?
- How does the pressure on the plantar surface of the foot vary during normal gait?
- What accounts for 80% of power generation during the gait cycle?