Biomechanics of Elderly Gait

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The situation …

• 8% of North Americans have a mobility disability (90 million in NA & Europe)
• Over 23% of elderly Canadians have a mobility disability
  – Climbs to 42.9% for people over 75 years
• Estimate of 6.7 million seniors by 2021
  – Over 1.7 million Canadian seniors with mobility disability by 2021
Factors Affecting Locomotion

- Loss of muscle mass, strength, power
  - Greater in females (25-54% lower peak power and torque)
  - Males lose 20% strength by 65 years
- Decreased joint RoM
  - 25-25% reduction up to 65 years, little change after 65 years
- Decreased reaction time
- Decreased acuity for auditory vestibular, visual, somatosensory
- Cognitive deficits
Diagnoses Contributing to Gait Disorders

- Frontal gait disorder (20-28%)
  - Normal-pressure hydrocephalus (4%)
  - Multiple strokes / Binswanger’s disease (16-28%)
- Sensory imbalance (4-18%)
  - Neuropathy (3-4%)
  - Multiple sensory deficits (18%)
- Myelopathy (16-24%)
  - Cervical spondylosis (22%)
  - Vitamin B12 deficiency (16%)
- Parkinsonism (9-12%)
  - Idiopathic Parkinson’s disease (8%)
  - Drug-induced parkinsonism
  - Progressive supranuclear palsy (2%)
- Cerebral atrophy (8%)
Diagnoses Contributing to Gait Disorders

- Tumors (2-6%)
- Depression (2%)
- Motor neuron disease (2%)
- Lumbar stenosis (2%)
- Alzheimer’s disease (4%)
- Degenerative joint disease / gouty arthritis (4-43%)
- Orthostatic hypotension (2-9%)
- Intermittent claudication (6%)
- Post-cerebrovascular accident (6%)
- Congenital deformity (6%)
- Post-orthopedic surgery (3%)
- Vertebrobasilar insufficiency (3%)
- Heart disease / heart failure (2-3%)
- Toxic/metabolic encephalopathy (2%)

Neil Alexander, 1996
**Complexity**

![Flowchart]

*Figure 1.* Algorithm for diagnosis of abnormal gait. C-spine, cervical spine; CT, computed tomography; EMG, electromyography; EOG, ethyl alcohol; L-spine, lumbar spine; MRI, magnetic resonance imaging; RPR, rapid plasma reagent; TSH, thyroid-stimulating hormone; T-spine, thoracic spine. (Modified from Rubino [2]. By permission of Mayo Foundation for Medical Education and Research.)
Stride Parameters

• Velocity decreases with age
  – Decreased stride length, cadence
• Age accounts for 30-45% of walking velocity variation
• Height a factor for decreased velocity
• Speed decreases 0.1 – 0.7% per year
• Increases stance time, double support
• Decreased stride symmetry
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Ankle

• Kinematics
  - Decreased RoM (24.9° versus 29.3°)
  - Decreased peak plantar flexion (13° versus 17°)
  - Larger “toe-out” angle

• Kinetics
  - Lower plantarflexor moment (1.44 N/m/kg versus 1.63 N/m/kg) and power (1.62-2.90 W/kg versus 3.50-4.36 W/kg)
  - Peak ankle power accounts for 52% of step length variance
  - Weaker ankle plantar flexors and dorsiflexors
Ankle

- Reduced plantar flexion power affects
  - Swing initiation
  - Trunk progression
  - Trunk stabilization

Chris A McGibbon, 2003
Knee: Kinematics

- RoM decreases (55° versus 59°)
- Extension angle at midstance increases 0.5° per decade
- Swing phase angle decreases 0.5°-0.8° per decade
- Elderly have slight knee flexion at end of swing (younger have full extension)
  - Decreases quadriceps demand for loading
  - Correlates with shorter step length
Knee: Kinetics

- Higher energy absorption between stance and swing (50% versus 16%)
- Lower peak knee absorption power
  - Could be related to walking speed
- Knee OA reduces knee power and has greater increase in hip eccentric energy expenditure (McGibbon and Krebs)
  - From hyperextending the hip (passive-elastic mechanism for advancing leg into swing)
  - Increases load on hip cartilage, can destabilize pelvis / upper body
Hip: Kinematics

- RoM increases (40° versus 32°)
- Accommodate for increased hip extension with anterior pelvic drop
- Lower hip A/P accelerations (1.54 m/s² versus 1.91 m/s²)
- Hip contractures decrease extension angle
  - Shorter step length, lower ankle power
Hip: Kinetics

- Compensation at hip produces higher
  - Concentric hip powers (active extension)
  - Angular impulse (sum of all moments)
  - Positive work
  - Partly due to decreased muscle strength of the ankle plantar-flexors and knee quadriceps group and/or hip muscle contractures

- Increased hip pull-off power
  - Can contributes 16% to elderly gait
  - Differing results in literature

- May be related to desire for high foot clearance (i.e., confidence not to trip)
Figure 4. Progression of the leg into swing phase: hip flexor strategy. As shown by the study of Judge et al. (3), elders may use the hip flexors to pull the leg into swing phase as a means of compensating for reduced ankle plantar flexor power. The diagram shows the hip flexor concentric contraction in late stance, which rotates the thigh forward and assists with leg advancement. Ankle plantar-flexion angle is reduced, possibly due to hip flexion contracture.

Figure 5. Progression of the leg into swing phase: hip extensor strategy. Alternatively, elders may use the hip extensors, in addition to enhancing trunk stability, to assist in advancing contralateral leg into swing phase as a means of compensating for reduced ankle plantar flexor power. The diagram shows the hip extensor concentric contraction in late stance, which rotates the pelvis backward, and assists with forward thigh rotation and leg advancement. Existence of this strategy is supported by the studies of Kerrigan et al. (5) and DeVita and Hortobagyi (1), which show increased hip extensor moment/power in elders.
Figure 6. Progression of the leg into swing phase: hip eccentric strategy. Elders with lower-extremity dysfunction, such as knee OA, may require different neuromuscular compensations than in healthy elders. Limited knee mobility may cause exaggerated or prolonged hip extension that also limits ankle plantar-flexion. The loss of mechanical advantage of hip flexors for concentric contraction, and tight hip flexors due to contracture, may result in a passive-elastic mechanism that aids in leg advancement.
Head / Torso

- Greater head A/P accelerations (0.62 m/s² versus 0.48 m/s²)
  - Young able to attenuate head movement by 72%, elderly by 58%
  - … or is head used for posture control?
General Kinetics/Kinematics

- Lower A/P push-off force (1.93 N/kg vs 2.19 N/kg)
- Higher A/P & M/L limb accelerations over 60 years
- Dementia
  - Shortened step length, increased double-support time, increased step-to-step variability
  - Time to walk 30 ft predictor for “persistent state” of cognitive decline
- Gait instability increases with age
- Energy cost of walking increases with age
  - No direct correlation between energy cost and instability (energy cost due to multiple factors)
- At max pace, elderly increase hip power but not ankle power (young increase peak power at all joints)
Foot Pressure

- Lower pressures at heel, midfoot, hallux (Morag, Cavanagh, 1999)
- Lower pressures medial & lateral calcaneal areas, all medial areas
  - Elderly weight-bear on lateral side
  - From treadmill study

Hessert, et al., 2005
Stair descent

- “Controlled fall”
- Lower ankle stiffness from initiation to heel-off
- More time spent in foot-flat, entire single support phase
- Greater M/L body CoG displacement and velocity
- Less confidence = slower speed
- Less foot clearance
- Implications for P&O devices that limit ankle RoM
Falls

- Leading cause of accidental death for elderly over 75 years
- 33% of elderly are fall prone
- 53% of falls due to tripping
- By 2020, cost of fall-related injuries will reach 32.4 billion in USA
Figure 13. Strandberg and Lanshammar (1981) suggested a slipping distance of 0.1 m to be the likely threshold for a fall (dotted line). Recent work has shown much higher threshold values (thick line based on Brady et al., 2000), where recovery rate reduces from approximately 75% at 0.2 m to just over 10% at 0.6 m. These results are very similar to the observation made elsewhere (square and triangle, Pavo et al., 2000). The differences may result from the discrepancies in the methodology. It may be further hypothesized that the recovery rate will be further reduced among the older adults (thin line).
Falls

• Heel contact skid velocity higher (1.15 m/s versus 0.87 m/s), even with slower walking speed
  - Increases slip potential
  - Related to delayed and reduced hamstring muscle activation

• Delayed or prolonged muscle activation key element for unsafe gait
  - Elderly have increased electromechanical delay (time from EMG to force production)

• Longer gait termination time
Fallers: Biomechanical Profile

- Abnormal stride parameters
  - Slower walking speed, stride length
  - Unequal stepping, timing, broad base of support
- Smaller, more variable 1st step
- Impaired lower extremity RoM
- Use assistive device (cane, walker, etc.)
- Take more steps to turn 360°
- Greater lateral sway
- Balance decrease precedes changes in gait?
Fallers: Biomechanical Profile

- Fallers have higher peak hip extension moment in stance.
- Fallers have lower peak:
  - hip extension moment
  - knee flexion moment in preswing
  - Knee power absorption in preswing
Fig 1. Sagittal plane joint moments and powers at the hip, knee, and ankle for elderly nonfaller controls (dashed line, \( n = 23 \)) at comfortable walking speed and for elderly fallers at comfortable (solid bold line) and fast (solid thin line) walking speeds \( (n = 16) \). *Persistent statistically significant faller-related difference at both comfortable and fast speed. †Statistically significant faller-related difference that did not persist at fast walking speed.
Fallers: Biomechanical Profile

- Delayed onset for push-off plantar flexion power is a good predictor of falls?
  - Combination of deficient dorsiflexors and continued contraction of plantarflexors
Fallers: Biomechanical Profile

- Problems accommodating to postural perturbations (elderly and Parkinson's)
  - Problems compensating for absent or disrupted sensory information
  - Longer neural processing & response times
  - Disorganized muscular responses / altered response strategy
  - Muscular strength for correction insufficient
  - Increased threshold for movement detection
Elderly: Obstacle avoidance

- Slower crossing strategy
- More rigid posture
  - Shorter stride length, decreased peak hip moments
  - Needed to compensate for decreased ability to control upper torso movement
- Increased variability = increased risk of obstacle contact
- Difficulty stepping over 8cm high obstacles
Elderly: Obstacle avoidance

- Different strategies
  - Increased limb elevation to ensure foot clearance
  - Decreased swing velocity over obstacle (compensate for torso control)

- Increased errors at faster speed
Psychosocial Implications

- Elderly with “cautious gait” tend to be
  - More depressed
  - More anxious
  - Greater fear of falling
  - Lower scores on “Mini-Mental State Exam”
- Assesses cognitive mental status

<table>
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<th>Table 4: Balance and postural control measures</th>
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<td>Patients (n = 25)</td>
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<td>ABC (%)</td>
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<td>No. of falls over the last year</td>
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| Tandem stand |<table>
| Able | 1 (4%) |
| Unable | 24 (96%) |
| Tandem walk |<table>
| Able | 0 |
| Unable | 25 (100%) |

*ABC: Activities-specific Balance Confidence scale. Note: a lower score on the ABC reflects greater fear of falling; TUG: Timed Up and Go; UPDRS: Unified Parkinson’s Disease Rating Scale*
References

References
