# Gait and foot

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## 왜 gait를 공부해야 할까?

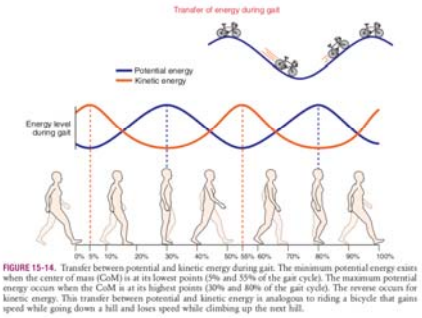



FIGURE 15-14. Transfer between potential and kinetic energy during gait. The minimum potential energy exists when the center of mass (CoM) is at its lowest points (5% and 55% of the gait cycle). The maximum potential energy occurs when the CoM is at its highest points (30% and 80% of the gait cycle). The reverse occurs for kinetic energy. This transfer between potential and kinetic energy is analogous to riding a bicycle that gains speed while going down a hill and loses speed while climbing up the next hill.

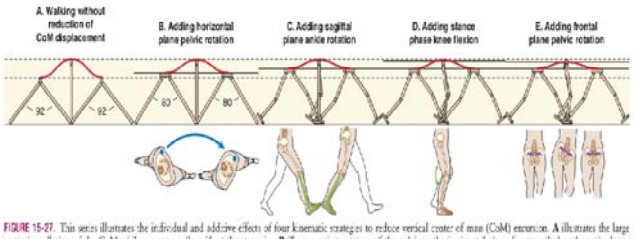
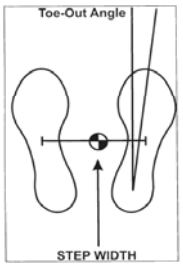



FIGURE 15-27. This series illustrates the individual and additive effects of four kinematic strategies to reduce vertical center of mass (CoM) excursion. **A** illustrates the large vertical oscillation of the CoM while a person walks *without* the strategies. **B** illustrates that rotation of the pelvis in the horizontal plane functionally lengthens the lower extremities and reduces the magnitude of the hip flexion-extension angle required for a given step length, thereby reducing the downward displacement of the CoM. **C** illustrates that further reduction of the downward displacement of the CoM is achieved by rotation of the ankle in the sagittal plane. **D** illustrates that the small amount of knee flexion present during stance reduces the functional length of the lower extremity and therefore the upward displacement of the CoM. **E** shows that the contralateral pelvic drop during stance also reduces the net overall elevation of the CoM. The angle values in **A** and **B** are for illustrative purposes only and do not represent the actual hip angles during walking.

## Temporal and Spatial Measures

Stride Duration (cycle duration, cycle period)
Stance Time (stance duration)
Swing Time (swing duration)
Single Support Time
Double Support Time
Stride Length
Step Length
Base of Support Width
Degree of Toe Out
Cadence
Velocity



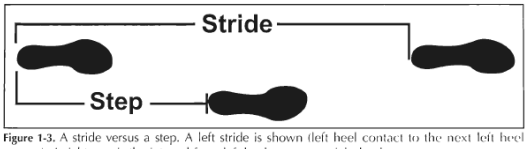




Figure 1-3. A stride versus a step. A left stride is shown (left heel contact to the next left heel contact). A right step is the interval from left heel contact to right heel contact.

- Stride
  - equivalent of a GC
  - the interval between 2 sequential initial floor contacts by the same limb
- Step
  - timing between the 2 limbs
  - There are 2 steps in each stride(or GC).

## Phases of Gait

- *traditional terminology vs Rancho Los Amigos (RLA)* system
- (*Observational Gait Analysis book)*


Figure 1-1. Divisions of the GC. The shaded bar represents the duration of stance. The clear bar is the duration of swing. Limb segments show the onset of stance with IC, end of stance by the roll-off of the toes, and end of swing as the instant before the foot contacts the ground.

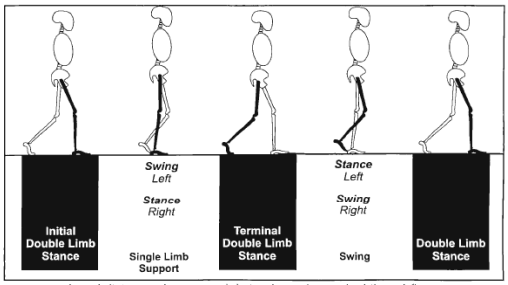



**Figure 1-2.** The subdivisions of stance and their relationship to the bilateral floor contact pattern. Vertical dark bars are the periods of double limb stance (right and left heel). Horizontal shaded bar is SLS (single stance). Total stance includes 3 intervals: the initial double stance, SLS, and the next (terminal) double stance. Note that right SLS is the same time interval as left swing. There is a left SLS during right swing. The third vertical bar (double stance) begins the next GC.

Table 1-1

*Floor Contact Periods**

| | *Generic* | *82 m/min* |
|---|---|---|
| Stance | 60% | 62% |
| Initial double stance | 10% | 12% |
| Single limb support | 40% | 38% |
| Terminal double stance | 10% | 12% |
| Swing | 40% | 38% |

*Generic timing (expressed as % gait cycle) compared to the customary normal speed of walking, 82 m/min (1.36 m/s). (Adapted from Pathokinesiology Service and Physical Therapy Department. *Observational Gait Analysis*. 4th ed. Downey, CA: Los Amigos Research and Education Institute, Inc, Rancho Los Amigos National Rehabilitation Center; 2001.)

- running
  - stance gets much shorter and swing gets slightly shorter as speed increases
  - as speed increases, the *proportion of the cycle devoted to* stance decreases and the proportion of the cycle devoted to swing increases.

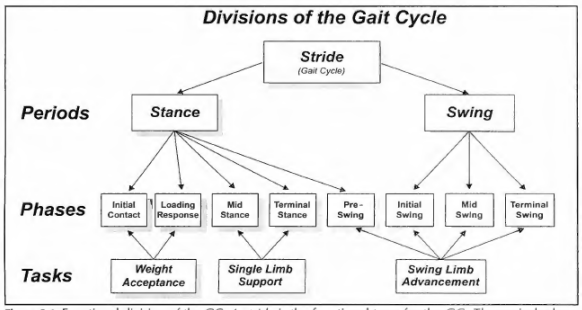



**Figure 2-1.** Functional division of the GC. A *stride* is the functional term for the GC. The periods show the basic division of the GC by foot contact. Each phase is determined by limb postures. The tasks show the grouping of the phases by the functions to which they contribute.

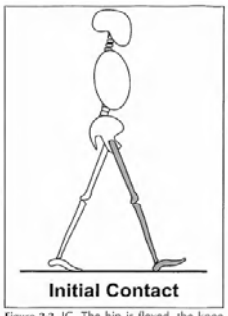



Figure 2-2. IC. The hip is flexed, the knee is extended, and the ankle is dorsiflexed to neutral. Floor contact is made with the heel. Shading indicates the reference limb. The other limb (clear) is at the beginning of pre-swing.

- Initial contact
  - The instant time when the foot contacts the ground
  - begin stance with a heel rocker.
  - beginning of double limb support interval(both extremities in contact with the surface)

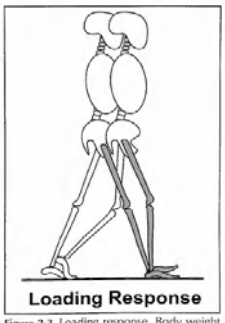



Figure 2-3. Loading response. Body weight is transferred onto the forward limb (shaded). Using the heel as a rocker, the knee is flexed for shock absorption. A brief arc of ankle plantar flexion (PF) interrupts the heel impact, but the heel rocker is preserved until the end of the phase.

- Loading response
  - initial double stance period
  - begins with initial contact
  - until the other foot is lifted for swing.
  - Shock is absorbed as weight is rapidly transferred on the outstretched limb
  - Interval : 0-10% of GC

- Three Rockers
  - These concepts are presented in Dr. Perry's book entitled *Gait Analysis.*

- ***1.*** **HEEL ROCKER.**
- **2. ANKLE ROCKER.**
- **3. FOREFOOT ROCKER.**
- 4. TOE ROCKER

- ***1.*** **HEEL ROCKER.**
  - Lasts from initial contact to the time of foot flat.
  - Its function is to translate the vertical component of the ground reaction force into forward progression of the tibia through the link provided by the eccentric action of tibialis anterior.

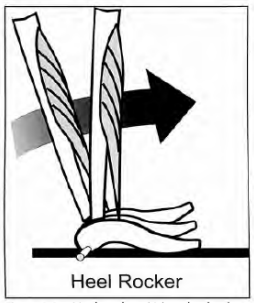



**Figure 3-21.** Heel rocker. Using the heel as the fulcrum (rod designates motion axis), the foot rolls through a short arc of PF. Pretibial muscles decelerate foot drop and draw the tibia forward, preserving the heel rocker until the end of loading response.

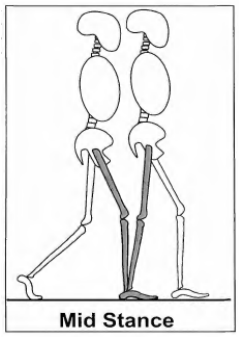



Figure 2-4. Mid stance. In the first half of SLS, the limb (shaded) advances over the stationary foot by ankle dorsiflexion (OF) (ankle rocker) while the knee and hip extend. The opposite limb (clear) is advancing through its mid swing phase.

- Mid stance
  - single support period.
  - It begins as the other foot is lifted form the ground
  - continues until the body weight is aligned over the forefoot(tibia of swing leg apporaches vertical)
  - when your momentum moves your mass forward(other limb swing) and slightly up(to the top of the pendulum)
  - Interval = 10-30% of GC

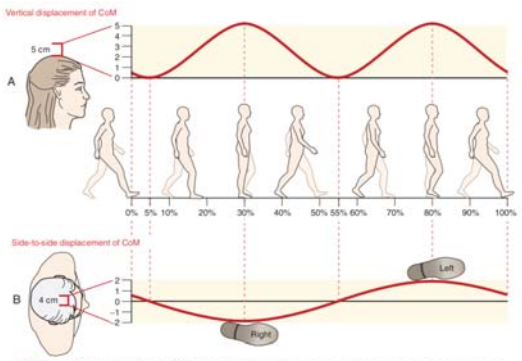



**FIGURE 15-13.** Center of mass (CoM) displacement during gait. The vertical and the side-to-side displacements of the CoM are illustrated in **A** and **B,** respectively. The CoM is at its lowest and most central position, in the side-to-side direction, in the middle of double-limb support (5% and 55% of the gait cycle)–a position of relative stability with both feet on the ground. Conversely, the CoM is at its highest and most lateral position at mid stance (30% and 80% of the gait cycle)–a position of relative instability. During single-limb support, the trajectory of the CoM is never directly over the base of support. This fact is illustrated in **B,** with the vertical projection of the CoM always located between the footprints.

- **2. ANKLE ROCKER.**
  - Lasts from the time of foot flat to heel rise. Its function is to control the rate of forward progression of the body as the tibia rotates at the ankle joint over the fixed foot under the eccentric control of the triceps surae.

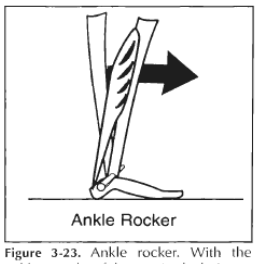



**Figure 3-23.** Ankle rocker. With the ankle as the fulcrum (rod designating the axis of motion), the tibia (and whole limb) rolls forward in response to momentum (arrow). The rate of tibial progression is decelerated by the soleus muscle.

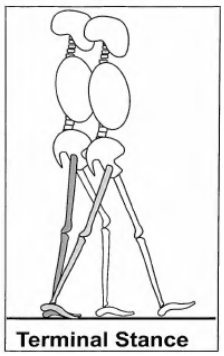



Figure 2-5. terminal stance. During the second half of SLS, the heel rises and the limb(Shaded) advances over the forefoot rocker. The knee completes its extension and then begins a new arc of flexion. Increased hip extension and heel rise put the limb in a more trailing position. The other limb(clear) is completing terminal swing

- Terminal stance
  - This phase completes the period of single support. It begins with heel rise and continues until the other foot strikes the ground. In this phase the body weight moves ahead of the forefoot
  - Interval = 30 – 50% of GC

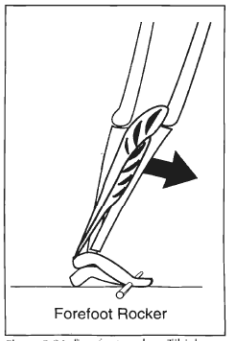



**Figure 3-24.** Forefoot rocker. Tibial progression (arrow) is continued over the forefoot rocker (rod as the axis). The gastrocnemius and soleus are active to stabilize the ankle.

- **3. FOREFOOT ROCKER.**
  - Lasts from heel rise until the end of stance.
  - It functions to extend the period of ground contact via the gastrocnemius to exploit the GRF vector's helpful influence on swing initiation.

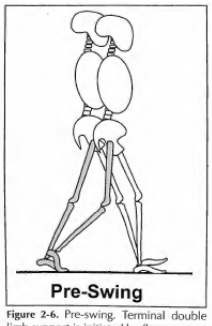



Figure 2-6. Pre-swing. Terminal double limb support is initiated by floor contact of the other limb (clear). The reference limb (shaded) responds to the initial weight transfer with increased ankle PF, knee flexion, and a reduction of hip extension. The opposite (clear) limb is in loading response.

- Preswing
  - The final phase of stance
  - the second period of double stance.
  - Begins with initial contact of the opposite limb
  - ends with ipsilateral toe-off.
  - weight is transferred to the contralateral limb.
  - Objective
    - To position the limb for swing
  - Interval = 50-60% of gait cycle

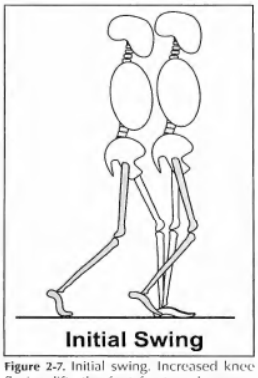



Figure 2-7. Initial swing. Increased knee flexion lifts the foot for toe clearance, and hip flexion advances the limb. Ankle DF is incomplete. The other limb (clear) is in early mid stance.

- Initial swing
  - The first third of the swing period.
  - Begins with lift of the foot from the floor
  - ends when the swinging foot is opposite the stance foot.
  - Objectives
    - advancement of the limb from its trailing position and
    - foot clearance of the foot
  - Interval = 60-73% of GC

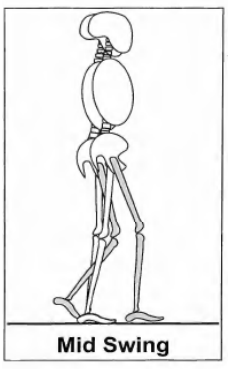



Figure 2-8 Mid swing, Advancement of the limb(shaded) anterior to the body weight line is gained by further hip flexion. The knee is allowed to extend in response to gravity while the ankle continues dorsiflexion to neutral. The other limb(clear) is in late mid stance

- Mid swing
  - The middle third of the swing period.
  - Begins when the swinging foot is opposite the stance foot
  - ends when the swinging limb is forward and tibia vertical( hip and knee flexion postures are equal)
  - Objectives
    - limb advancement
    - foot clearance.
      - Like mid stance though, this is a phase of relative control
  - Interval = 73 – 87% of gait cycle

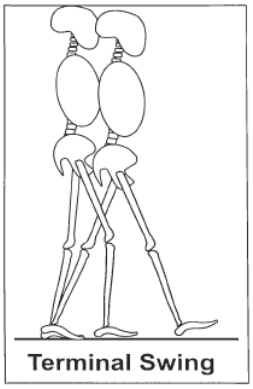



Figure 2-9 Terminal swing, Limb advancement is completed by knee extension. The hip drops slightly (to 20 flexion), and the ankle remains dorsiflexed to neutral. The other limb(clear) is in terminal stance

- Terminal swing
  - The final third of the swing period.
  - Begins with a vertical tibia
  - ends when the foot strikes the floor.
  - Limb advancement is completed as the leg(tibia) moves ahead of the thigh. The knee maximally extents.
  - Objective
    - completion of limb advancement (deceleration of the swing limb)
    - preparation for stance
  - Interval = 87 – 100% of gait cycle

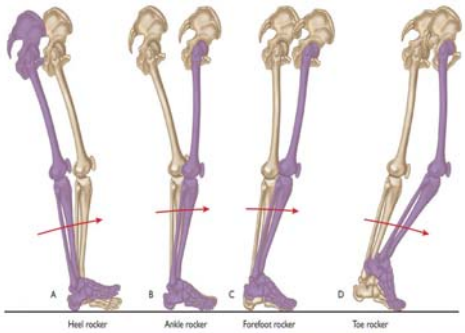



Figure 2.16. The four stages that lead to the push-off for forward propulsion. The initial heel strike (A) and receiving of body weight cause the foot to brake, come into plantarflexion, and have full contact with the ground. This process causes the metatarsal joints to open and allows the foot to adapt with a slightly lowered arch, which also spreads the force of the impact to deeper tissues beyond the plantar fascia. The swing of the opposite leg (B) and progress of the pelvis and trunk, will cause the tibia and fibula to dorsiflex over the foot and then the heel to lift, creating a rocking motion on the ball of the foot (C), leading to the push-off from the ends of the metatarsals and the toes (D).

< Deterninants of gaits >

- govern the vertical and horizontal displacement of the center of mass
- influence efficiency.

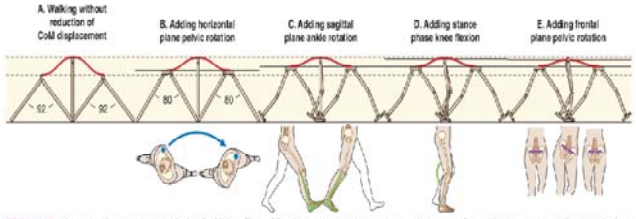
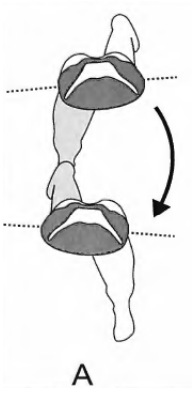
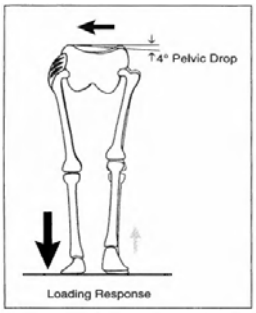



FIGURE 15-27. This series illustrates the individual and additive effects of four kinematic strategies to reduce vertical center of mass (CoM) excursion. **A** illustrates the large vertical excursion of the CoM while a person walks *without* the strategies. **B** illustrates that rotation of the pelvis in the horizontal plane functionally lengthens the lower extremities and reduces the magnitude of the hip flexion-extension angle required for a given step length, thereby reducing the downward displacement of the CoM. **C** illustrates that further reduction of the downward displacement of the CoM is achieved by rotation of the ankle in the sagittal plane. **D** illustrates that the small amount of knee flexion present during stance reduces the functional length of the lower extremity and therefore the upward displacement of the CoM. **E** shows that the contralateral pelvic drop during stance also reduces the net overall elevation of the CoM. The angle values in **A** and **B** are for illustrative purposes only and do not represent the actual hip angles during walking.




- **PELVIC ROTATION IN THE TRANSVERSE PLANE.**
  - During stance for the right limb, the pelvis rotates to the right.
  - This action extends the stride length
    -> effective limb length
    -> limit the drop of the COM.
  - as the right limb swings forward, the right side of the pelvis also moves forward so that the pelvis rotates to the left.




- **LATERAL PELVIC TILT IN THE FRONTAL PLANE.**
  - Ipsilateral pelvic drop of the swinging limb
  - pelvic drop is maximal at the time when the center of mass (COM) reaches its maximal vertical extent.
  - Hip abductors on the side of the stance limb contract eccentrically to allow the intended extent of controlled pelvic drop.
  - The primary function of lateral pelvic tilt
    - to control the vertical excursion of the COM.

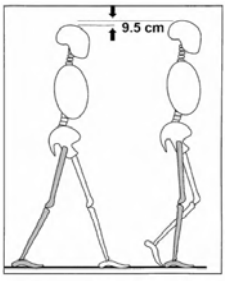



Figure 3-32. The change in body height between double and SLS would be 9.5 cm if no modifying action were performed.

- **KNEE FLEXION AT MIDSTANCE.**
  - From the time of foot-flat until midstance
    - knee joint actually flexes
  - reduce the "inverted pendulum", "vaulting" effect
  - the effective length of the limb
    - to control the vertical excursion of the COM.

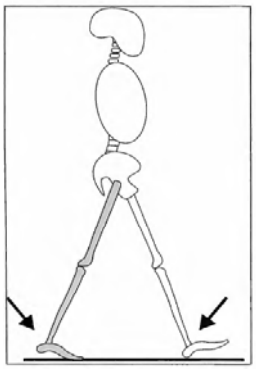
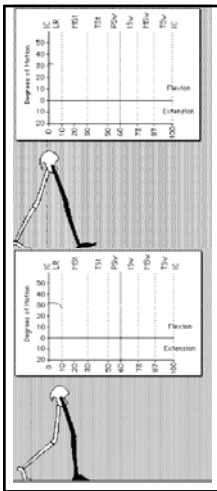


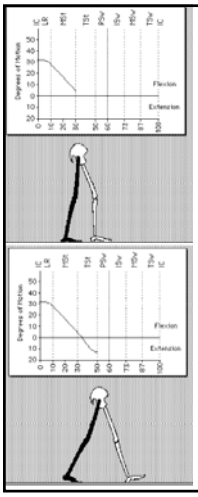
**Figure 3-35.** Ankle actions to elevate COG. Heel rise in terminal stance preserves pelvic height while ankle DF in terminal swing minimizes the need for a drop at initial contact.

- **KNEE, ANKLE, FOOT INTERACTIONS.**
  - during the loading response and preswing
    - vary the effective length of the limb.
  - They make the limbs longer
    - so that the COM does not "fall" quite so far
  - While one limb hastens the onset of heel contact with a dorsiflexed ankle
    - the opposite limb delays the time of toe off with a plantarflexed ankle.
  - These events occur concurrent with the lowest vertical position and the maximal upward acceleration of the COM as its descent ends and ascent begins during double support.

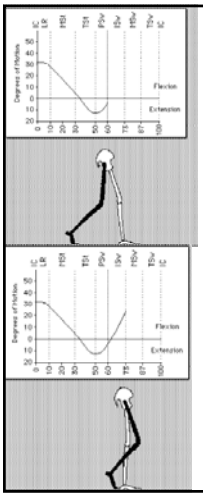
- **Gait II: JOINT KINEMATICS**
- **Lower Extremity Kinematics**
  - **Sagittal plane motions**



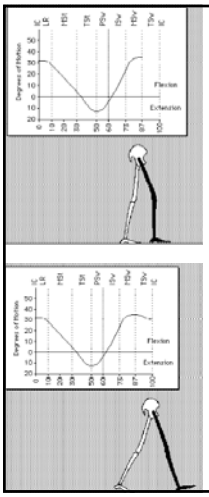

- Hip position at initial contact
  - Position is about 30 degrees of flexion
- Hip during loading response
  - the hip remains in about 30 degrees of flexion, although at the end of the phase there may be the initiation of a teensy bit of extension
    - The pelvis & trunk do move forward. However, because the knee if flexing, the overall result is little actual motion at the hip during loading response



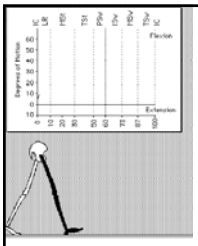
- Hip during mid stance
  - Throughout midstance the hip steadily extends toward neutral, achieving a position of about 5 degrees of flexion by the end of the phase, for a total arc of 25 degrees.
- Hip during terminal stance
  - Continued extension, through neutral to a position of 10 degrees of extension
  - Motion = 15 deg extension
    - In reality, several degrees of that apparent extension are really anterior pelvic tilting & lumbar extension, but this is very difficult to distinguish from extension at the hip

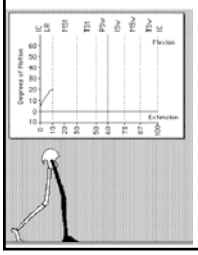


- Hip during preswing
  - Reveral of direction, so that flexion to nearly neutral occurs.
  - Moton = 10 deg flexion
- Hip during initial swing
  - Rapid flexion to about 25 degrees (of flexion )
  - Motion = 25 deg flexion

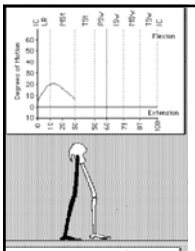


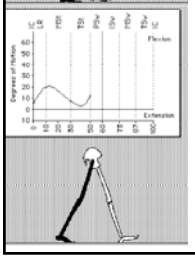
- Hip during mid swing
  - Flexion slows, then stops at the end of the phase, at a position of about 35 degrees ( of flexion )
  - Motion = 10 deg flexion
- Hip during terminal swing
  - The hip at first holds steady, then extends slightly to a position of about 30 degrees ( of flexion ).
  - Motion = 5 deg flexion
  - This is primarily due to hip extensor activity (decelerating the swinging limb )



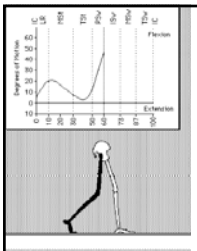


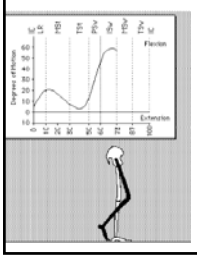
- Knee at initial contact
  - At initial contact the knee is in about 5 degrees of flexion, and knee flexion is already underway
  - This is ideal for absorbing the "shock" of loading response
- Knee during loading response
  - The knee continues to flex, reaching a position of close to 20 degrees of flexion, nearly its peak flexion
  - Motion = 15 deg flexion



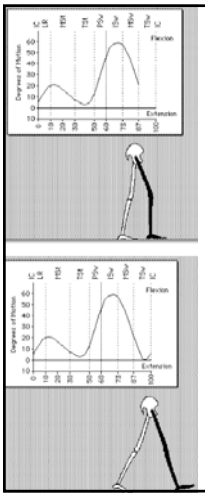


- Knee, mid stance
  - Very early in midstance flexion ceases and the knee begins extending.
  - Thus during midstance the knee is mostly extending, reaching a position of about 8 degrees of flexion, for a total excursion of about 12 degrees.
  - Motion = 12 deg extension
- Knee, terminal stance
  - At first the knee continues extentending, reaching about 5 degrees of flexion, then the motion is reversed and the knee begins flexing to about 12 of flexion
  - Motion = 3 deg extension
  - 7 deg flexion
  - Primarily because of heel rise/plantarflexion

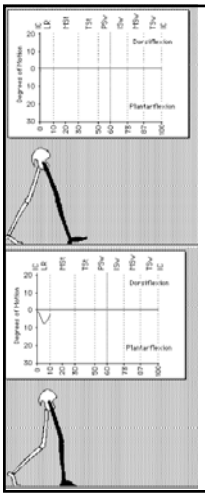




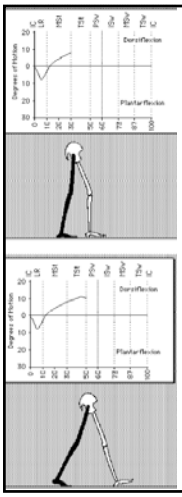
- Knee, preswing
  - Rapid flexion to about 40 degrees of flexion
  - Motion = 28 deg flexion
- Knee, initial swing
  - During most of this phase the knee continues flexing, reaching a peak of about 60 degrees. Then the motion is reversed and the knee begins extending, so that at the end of initial swing a position of 55 degrees of flexion has been achieved.
  - Motion = 20 deg flexion
    5 deg exetension



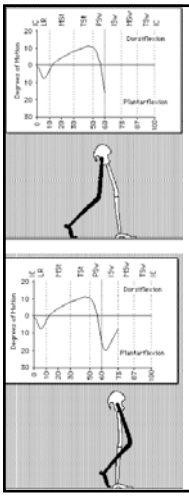
- Knee, mid swing
  - Rapid extension to a position of about 20 degrees of flexion
  - Motion = 35 deg extension
- Knee, terminal swing
  - During most of this phase the knee continues extending, reaching or almost reaching the neutral(0 deg) position. Ten the mition is reversed and the knee begins flexing, so tha at the end of terminal swing a position of about 5 degrees of flexion has been achieved.
  - Motion = 20 deg extension
    5 deg flexion



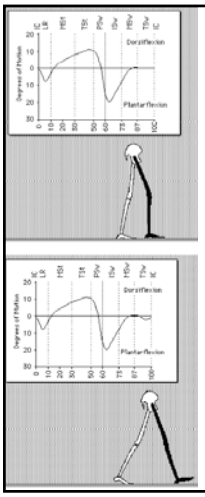
- Ankle, initial contact
  - Ideally the ankle is in neutral(0 degrees) at initial contact. This helps initiate a heel rocker. It also places the ground reaction force vector behind the ankle, creating a plantarflexion moment.
- Ankle, loading response
  - The ankle begins this phase in neutral(0 deg), plantarflexes rapidly to about 8 deg (achieving footflat) then reverses this motion and dorsiflexes so that at the end of loading response the ankle has returned to neutral.
  - Motion = 8 deg plantarflexion
    8 deg dorsiflexion



- Ankle, mid stance
  - Throughout midstance the ankle steadily dorsiflexes to about 10 degrees. This is the "ankle rocker" which allows progressing over the weightbearing limb.
  - Motion = 10 deg dorsiflexion
- Ankle, terminal stance
  - The heel begins to rise, but initial the ankle continues dorsiflexing, reaching a peak of about 12 degrees. Eventually (because of enough gastroc-soleus activity) this motion ceases, and then anke begins plantarflexing, reaching about 10 deg(of DF) by the end of terminal stance
  - Motion = 2 deg DF
    2 deg PF



- Ankle, preswing
  - Rapid PF from 10 deg of DF to about 20 deg of PF, as GCM & soleus continue contracting ( at least initially ) and as weight is shifted onto the other limb.
  - Motion = 30 deg PF
- Ankle, initial swing
  - Initially there may be a smidgen of additional PF, but amost immediately the ankle begins Dfing, in order to clearing the toes during swing, to about 10 degrees of PF.
  - Motion = 0-3 deg DF
    10-12 deg PF



- Ankle, mid swing
  - DF is completed as the ankle reaches neutral
  - Motion = 10 deg DF
- Ankle, terminal swing
  - Ankle remains in neutral

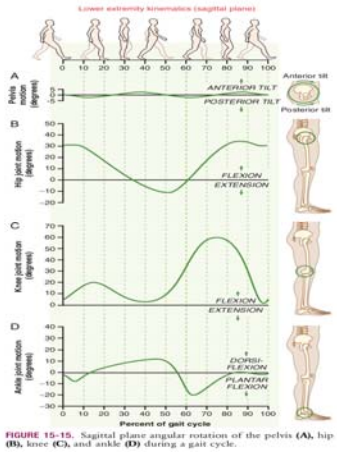
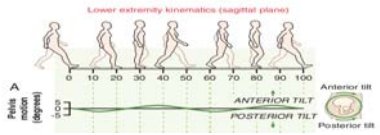


FIGURE 15-15. Sagittal plane angular rotations of the pelvis **(A)**, hip **(B)**, knee **(C)**, and ankle **(D)** during a gait cycle.

- **PELVIC TILT**
  - **Two full cycles**
  - **At right heel contact, the pelvic is in a near neutral position**
  - **Loading response, posterior pelvic tilt occur**
  - **Until just after mid stance(30% of GC)**
  - **In the second half of the stance phase, the pelvis tilts posteriorly until just after toe off.**
  - **During initial and mid swing(60~87 of GC), the pelvis again tilts anteriorly before starting to tilt in the posterior direction in terminal swing**




- **non-sagittal plane motions**
- **PELVIC ROTATION**
  - The pattern of pelvic rotation is fairly symmetrical.
  - rotates externally from initial contact until the onset of preswing
  - internally during preswing and swing, the second 50%

- **HIP INTERNAL AND EXTERNAL ROTATION**
  - The hip rotates ± 8° from neutral in a monotonic fashion (*i.e., like a sine-wave, with one maximum and one* minimum).
  - Peak internal rotation occurs during Pre-Swing
  - Peak external rotation occurs toward the end of Loading Response.
  - That is, rotation at the hip trails pelvic rotation slightly so at the end of Loading Response the hip begins internally rotating and continues to do so until well into Pre-Swing when it begins externally rotating (and does so until well into Loading Response).

*Figure 2.13. As we progress up the leg, all of the bones are moving in the same direction (osteokinematics) and the relationship at the joints (arthrokinematics) is a medial rotation: the bones are all moving medially, but, because of the different speeds and degrees of movement, the inferior bone at each joint is medially rotated when compared to its superior neighbor.*

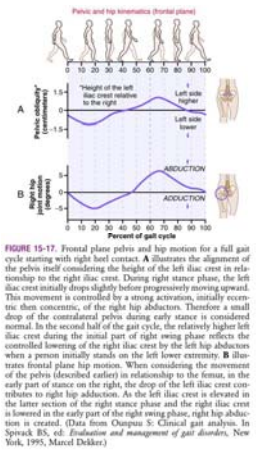


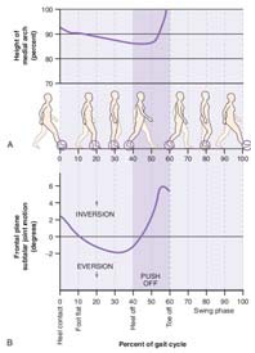

FIGURE 15-17. Frontal plane pelvis and hip motion for a full gait cycle starting with right heel contact. **A** illustrates the alignment of the pelvis itself considering the height of the left iliac crest in relationship to the right iliac crest. During right stance phase, the left iliac crest initially drops slightly before progressively moving upward. This movement is controlled by a strong activation, initially eccentric then concentric, of the right hip abductors. Therefore a small drop of the contralateral pelvis during early stance is considered normal. In the second half of the gait cycle, the relatively higher left iliac crest during the initial part of right swing phase reflects the controlled lowering of the right iliac crest by the left hip abductors when a person initially stands on the left lower extremity. **B** illustrates frontal plane hip motion. When considering the movement of the pelvis (described earlier) in relationship to the femur, in the early part of stance on the right, the drop of the left iliac crest contributes to right hip adduction. As the left iliac crest is elevated in the latter section of the right stance phase and the right iliac crest is lowered in the early part of the right swing phase, right hip abduction is created. (Data from Ounpuu S: Clinical gait analysis. In Spivack BS, ed: *Evaluation and management of gait disorders*, New York, 1995, Marcel Dekker.)

## HIP AB / AD DUCTION

- The hip ab- and adducts ± 7° from neutral.
- During the loading response, the pelvis undergoes a controlled drop on the contralateral side, thus the ipsilateral hip adducts under the eccentric control of gluteus medius and minimus
- During midstance, the hip moves in the abductor direction, returning to neutral (level pelvis) by the onset of terminal stance and more or less remaining so until the onset of preswing.

## • PELVIC OBLIQUITY

- Pelvic obliquity is analogous to ab- and adduction at the hip, and indeed, the patterns are so similar that the description for hip ab-adduction can almost be substituted for pelvic obliquity.
- The basic feature of pelvic obliquity is that the pelvis is higher on the stance side than on the swing side.
- The orientation angle of the pelvis in the frontal plane varies ± 4° from neutral, with the reference side highest relative to the opposite side at the end of the loading response, and conversely, lowest at the onset of swing.




**SUBTALAR JOINT**

- The subtalar joints vary ± 5° from neutral in a roughly monotonic fashion. There is rapid eversion during the loading response, which slows greatly but continues into midstance.
- The subtalar joints begin resupinating during midstance, ideally returning to neutral during terminal stance.
- Peak inversion occurs during preswing and the subtalar joints actually begin to return towards neutral before toe off.
- The return to neutral is completed during initial swing, and the subtalar joints hover near neutral for the remainder of swing, often entering initial contact in slight inversion (thus contact on postero-lateral heel).