Korean Academy of Rehabilitation Medicine

2021년 대한재활의학회 추계학술대회

일 자 2021년 10월 29일(금) ~ 30일(토) 장 소 서울드래곤시티, 온라인

나를 움직이는 힘 재활의학

2021.10.30 Parallel Symposium 8 (O&P)

Consensus and Recommendations on the Lower Limb Orthotic Management of Stroke Patients

Biomechanics of Lower Limb Function and Gait in Stroke Patients

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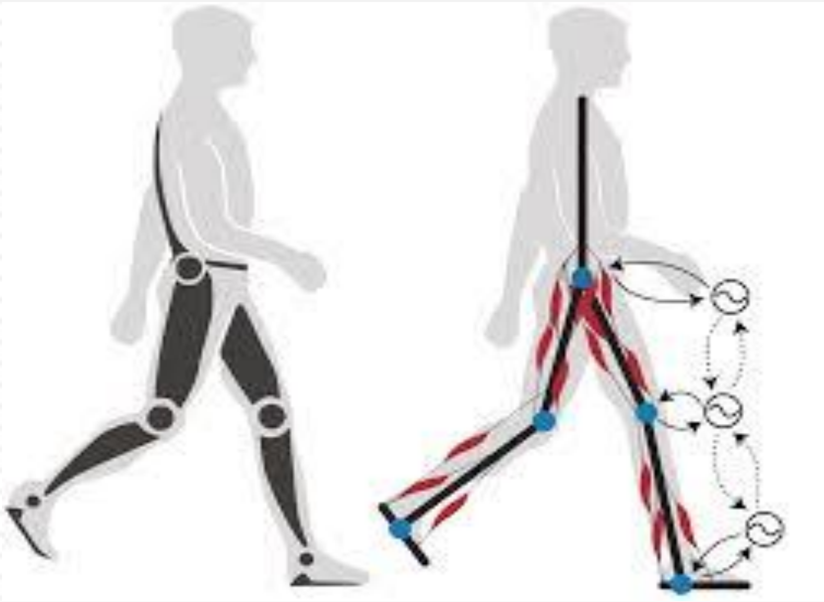
Daejeon St. Mary's Hospital

The Catholic University of Korea

CONTENTS

- Biomechanics of Normal Gait
- Normal Gait Analysis
- Pathologic Gait after Stroke



Human Gait

- **Gait** is accomplished through a **complex** and **coordinated** pattern by nerve signals

Central pattern generator

(networks of neurons of brain & spinal cord)

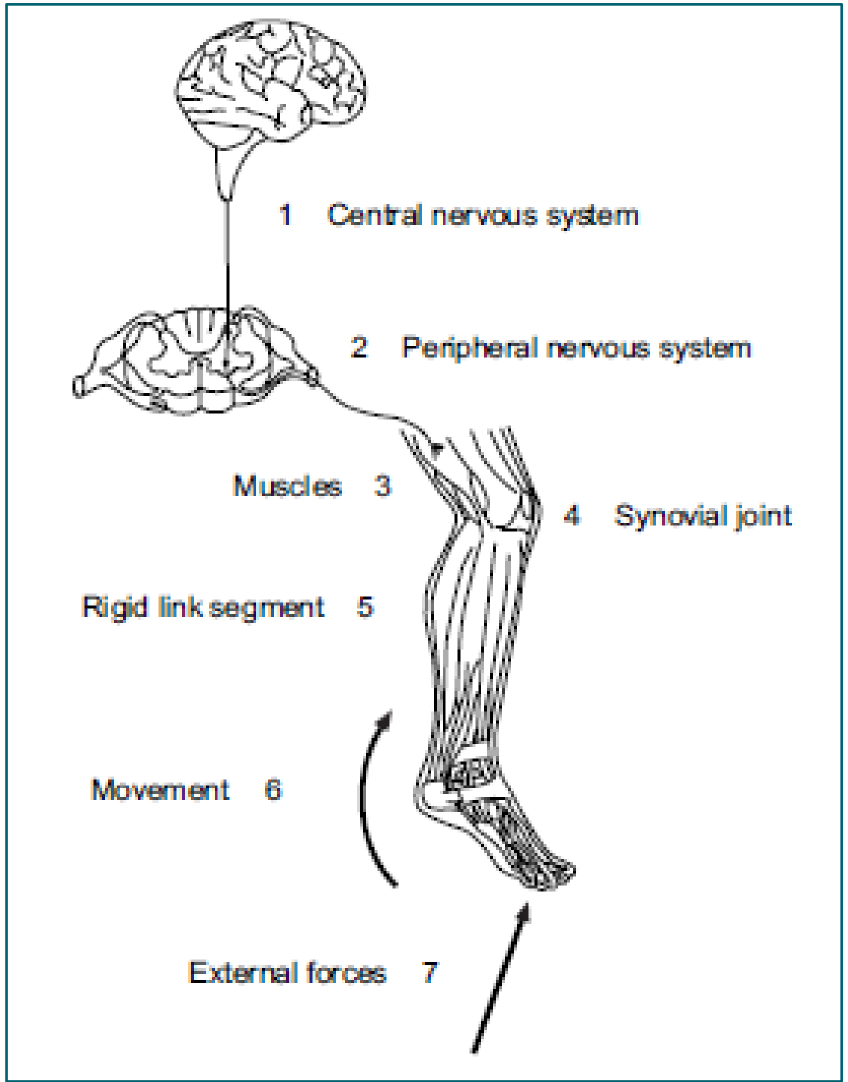
↓

Muscles

↓

Joints, Limbs, the reminder of the body

Human Gait – Top-Down Analysis of Gait



Sequence of Gait-Related Process

1. **CNS:** Registration and activation of gait command
2. Transmission of gait signal to **PNS**
3. Contraction of **muscle** -> develop tension
4. Generation of **forces, moments**
5. Regulation of the **jt. forces and moments** by the rigid **skeletal** segments
6. **Functional gait** (movement of the segment)
7. Generation of **ground reaction force** (GFR)

Functional Task of Normal Gait

Support

Maintain stance stability

Propulsion

Move the body forward

- Weight Acceptance
- Single limb support

- Limb Advancement
- Move body forward

Biomechanical considerations

- **Force**
  - Heel strike, push off…
  - Center of gravity
  - Ground reaction force
- **Moment of force**
- **Power**
- **Kinematics**
- **Kinetics**

Gait !!!!!

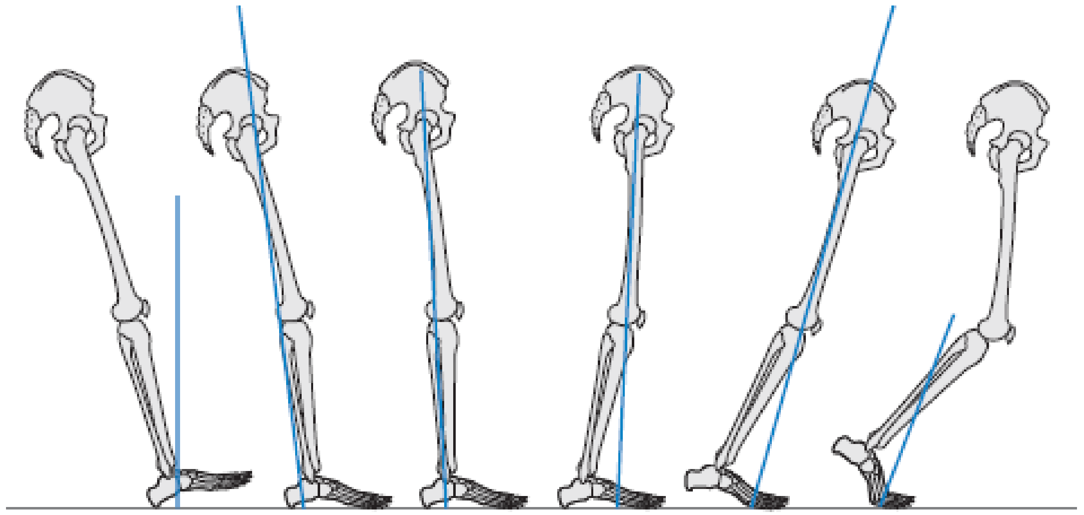
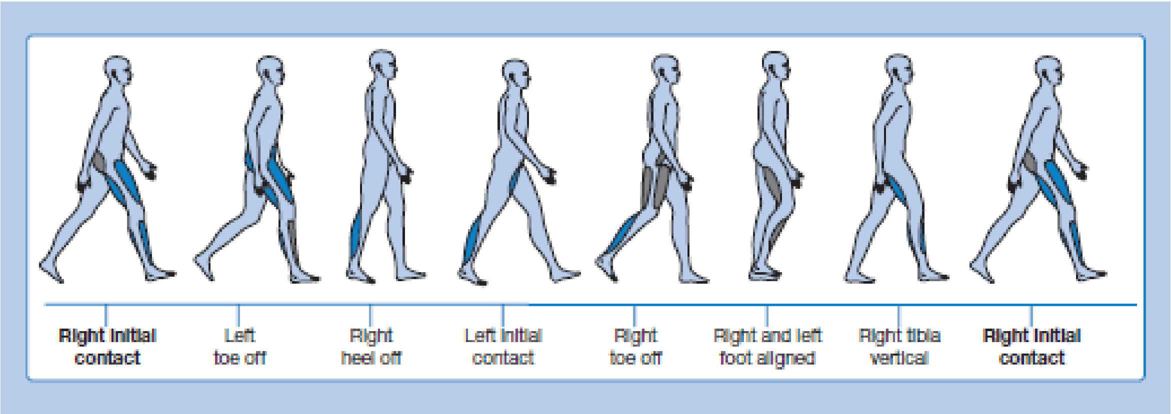
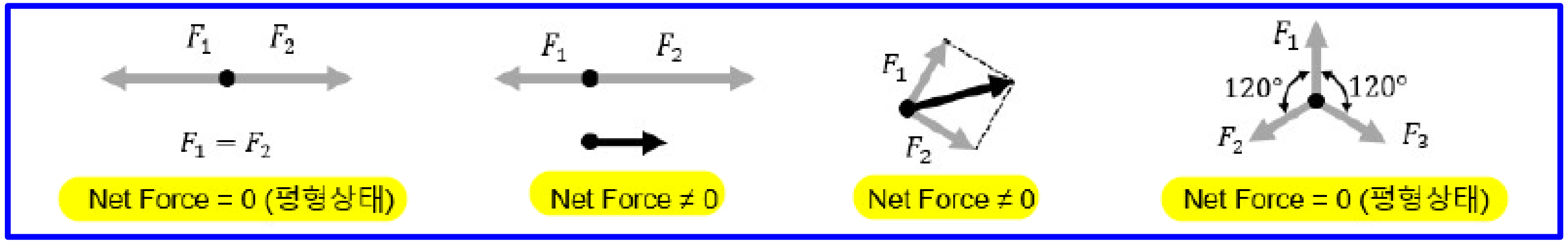


FIGURE 10-20 Location and relative magnitude of the ground reaction force vector (GRFV) in relation to the lower limb during stance phase of gait.

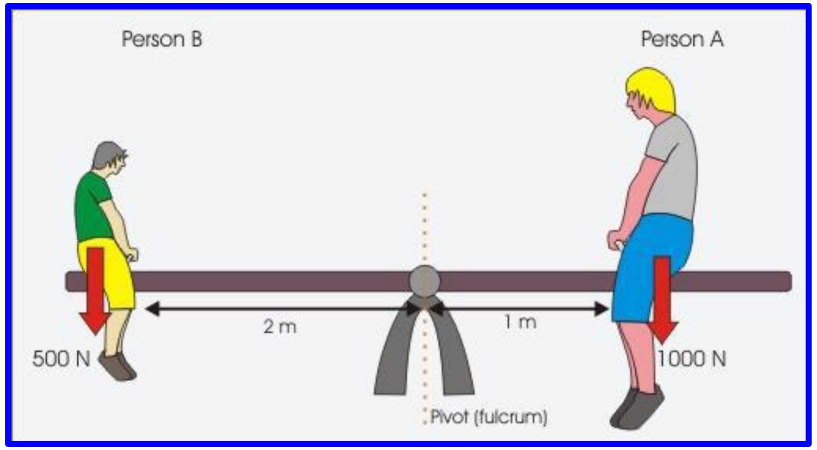


Force & Moment

- **Force**, **F = m· a (N)**
  - 정지하고 있는 물체를 움직이고, 움직이고 있는 물체의 속도나 운동방향을 바꾸거나 물체의 형태를 변형시키는 원인이 되는 물리량
  - Vector quantity.

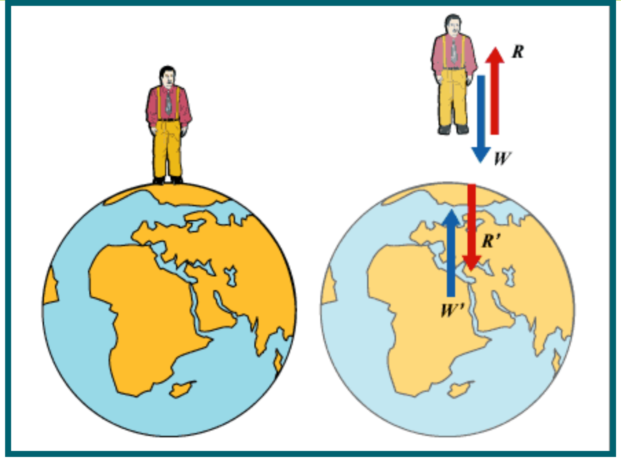


- **Moment**, **Moment = F X d (Nm)**
  - 물체에 작용하는 힘의 효력을 나타내는 물리량
  - Torque = turning moment = moment of force
  - **Person A's moment = Person B's moment**
  - **1000 x 1 = 1000Nm = 500 x 2 = 1000Nm**
  - **Seesaw is in equilibrium**

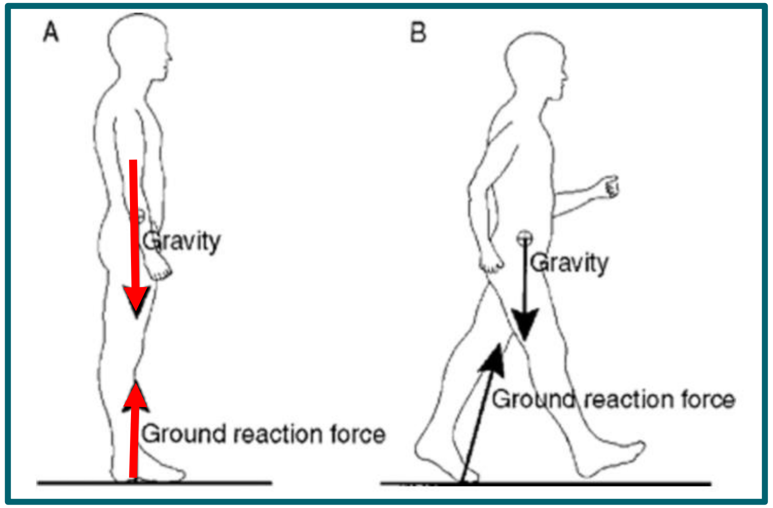


Force

- **Newton's law**
  - 1^{st} law: State of rest
  - 2^{nd} law: $F = m \cdot a$ (N)
  - **3^{rd} law: Action – Reaction**
  - Single force acting in one direction
  - –> balance out by an equal force acting in the opposite direction.



- **Center of Gravity (COG)**
- **Ground Reaction force (GRF)**

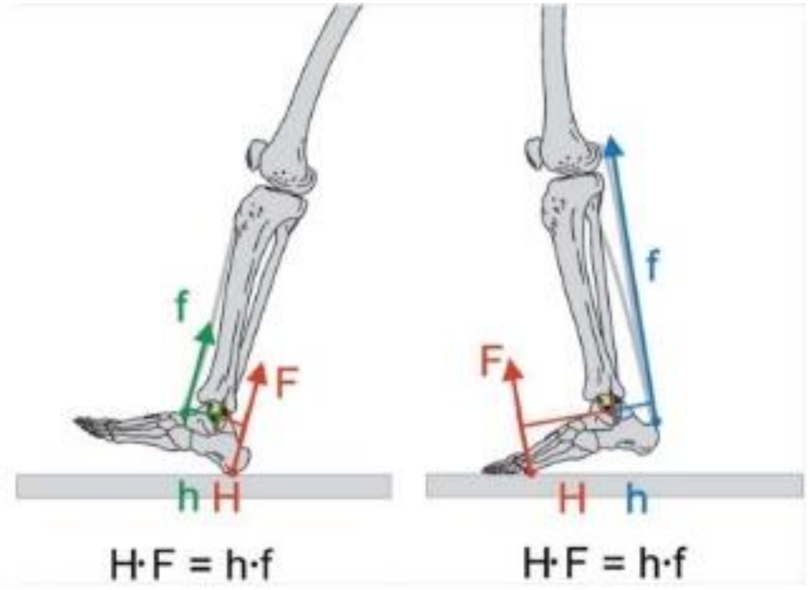


Moment of Force

Internal moment ⟷ **External Moment**

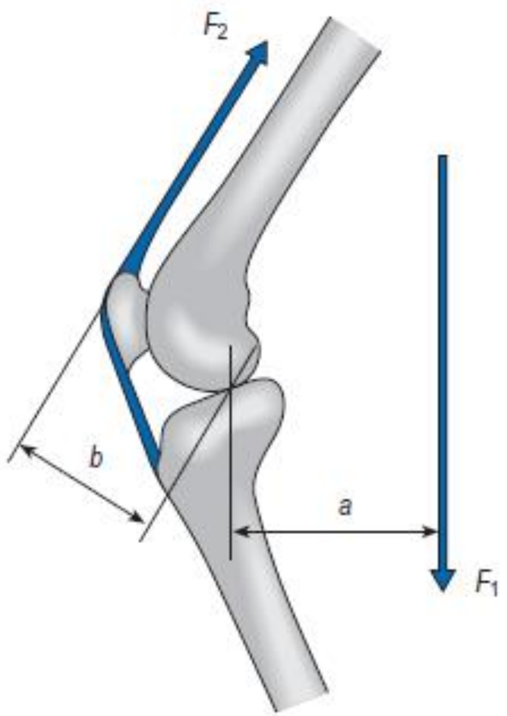
Internal moment
- **Active – muscular contraction** (concentric, isometric or eccentric)
- **Passive – bone-on-bone** forces, tension in the soft tissues, ligament

External Moment
- **Reaction moment**
- **Gravitational forces**

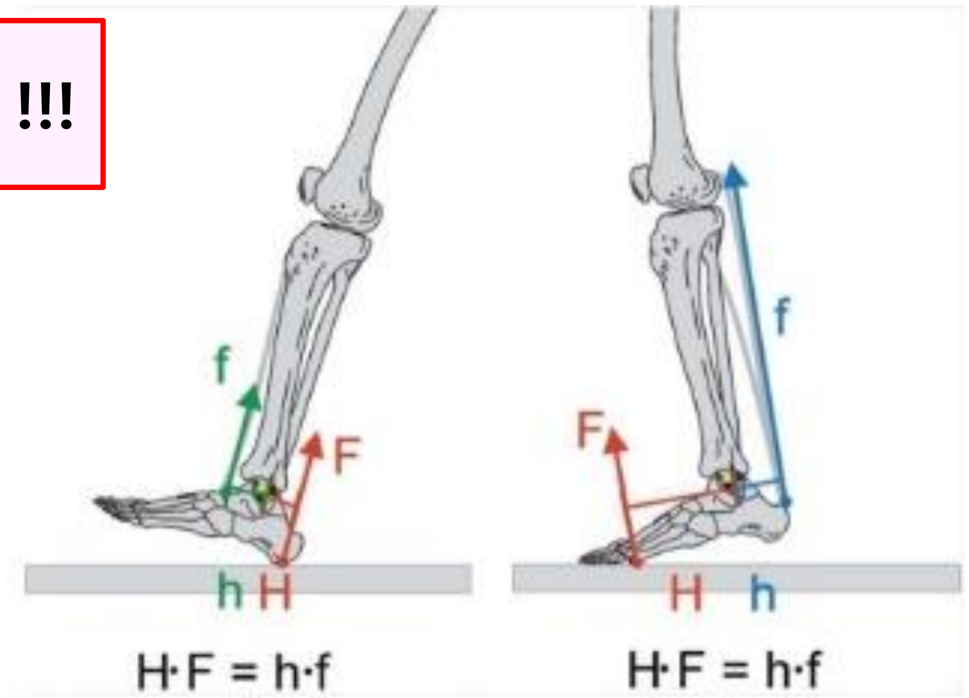


- **External forces** generates a moment at a particular joint,
- **Corresponding internal moment,** generated within the joint, to **opposite direction.**

Moment of Force



Equilibrium !!!



Moment of force about knee joint

- Gravity = Q-ceps tension
- F1 x a = F2 x b

Moment of force about ankle joint

- Heel strike (GRF) H·F =h·f (ADF)
- Toe off (GRF) H·F =h·f (APF)

Kinetics and Kinematics

Kinetics 동역학 (動力學)

- *그리스어 dynamis (힘)*
- The study of **forces, moments**, masses and accelerations
- Without any detailed knowledge of limb position or joint angle
  - 에너지를 일으킨 힘이나 그 힘을 이용하는 방법을 연구하는 학문
  - F=m·a, Nm, kg·m²/s²

Kinematics 운동학 (運動學)

- 그리스어 *kinesis*(움직임)
- Describes **motion**
- Joint angle. Velocity
- But without reference to the force
  - 힘과 운동의 관계는 생각하지 않고, 물체의 운동에 나타나는 기하학적 성질만 연구

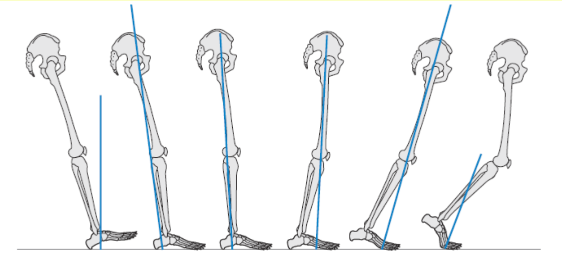
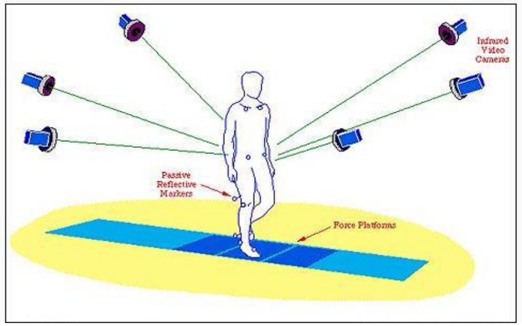
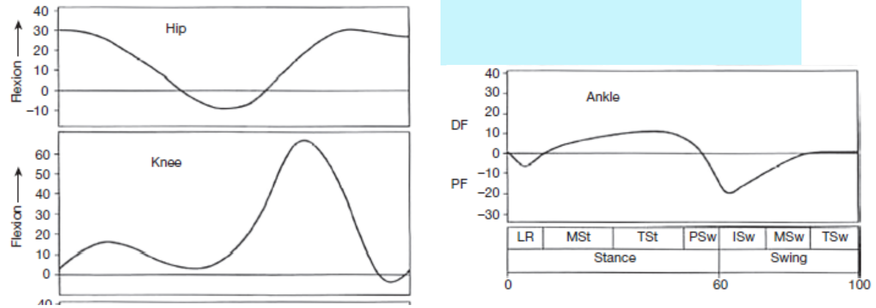


FIGURE 10-20 Location and relative magnitude of the ground reaction force vector (GRFV) in relation to the lower limb during stance phase of gait.





Net moment = Power Exchange = Gait

Power

(watts)

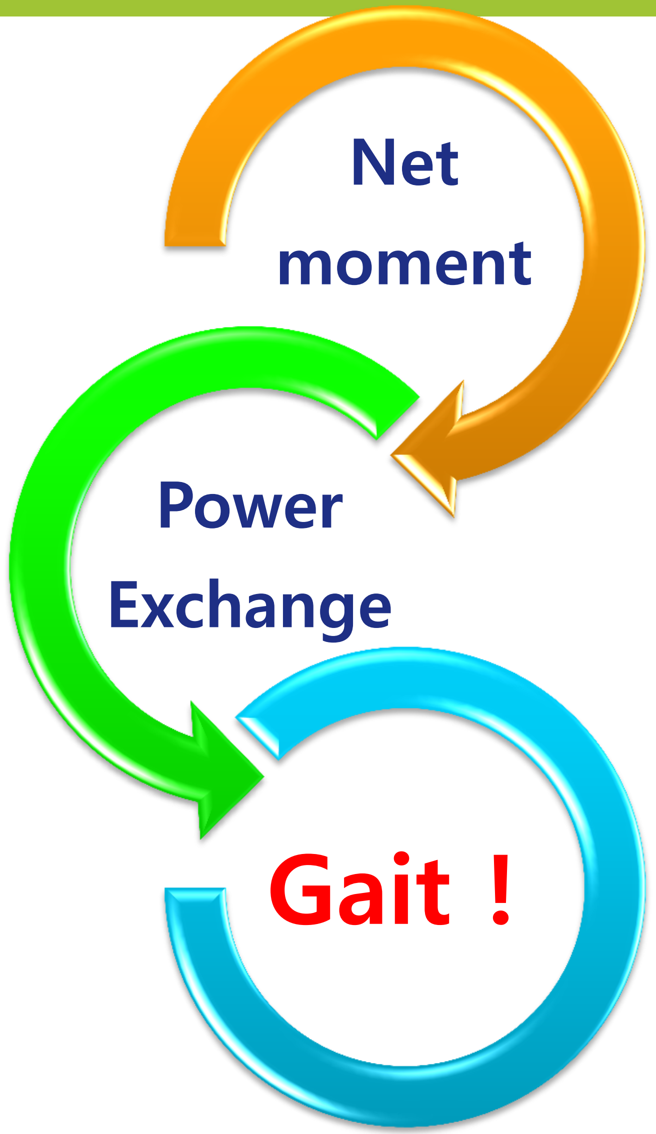
- The rate at which work is done
- **Moment of force x angular velocity**
- M (neuro-meter) x ω (radians per sec)

Power generation

Concentric contraction

Power absorption

Eccentric contraction

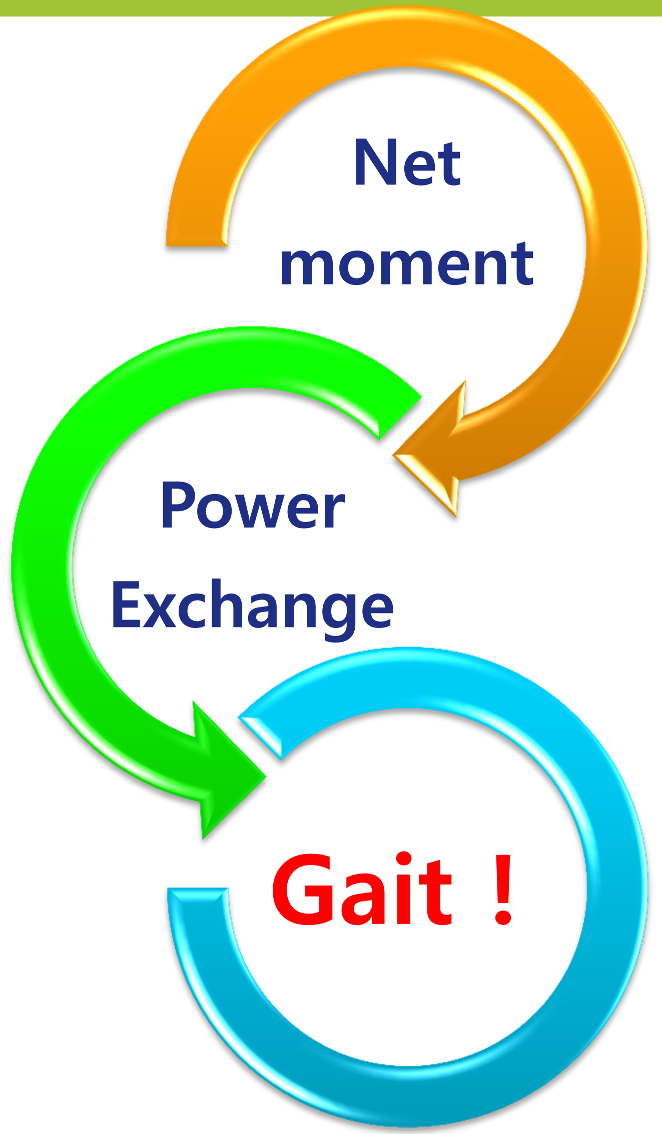


Biomechanical considerations

- **Measurement and interpretation of moments of force**
- Both **kinetic and kinematic data**

  are essential for

  understanding of normal and pathological gait !!!



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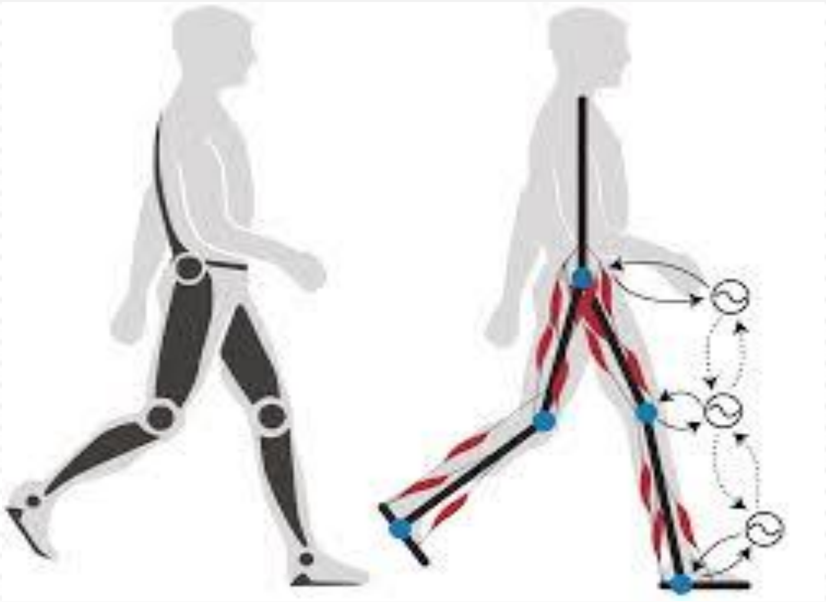
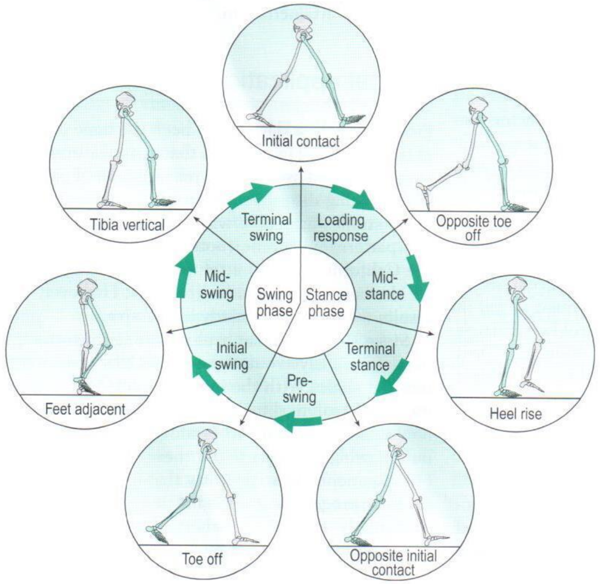


Gait Cycle

- **Traditional nomenclature**
  1. Heel strike
  2. Foot-flat
  3. Midstance
  4. Heel-off
  5. Toe-off
  6. Acceleration
  7. Midswing
  8. Deceleration

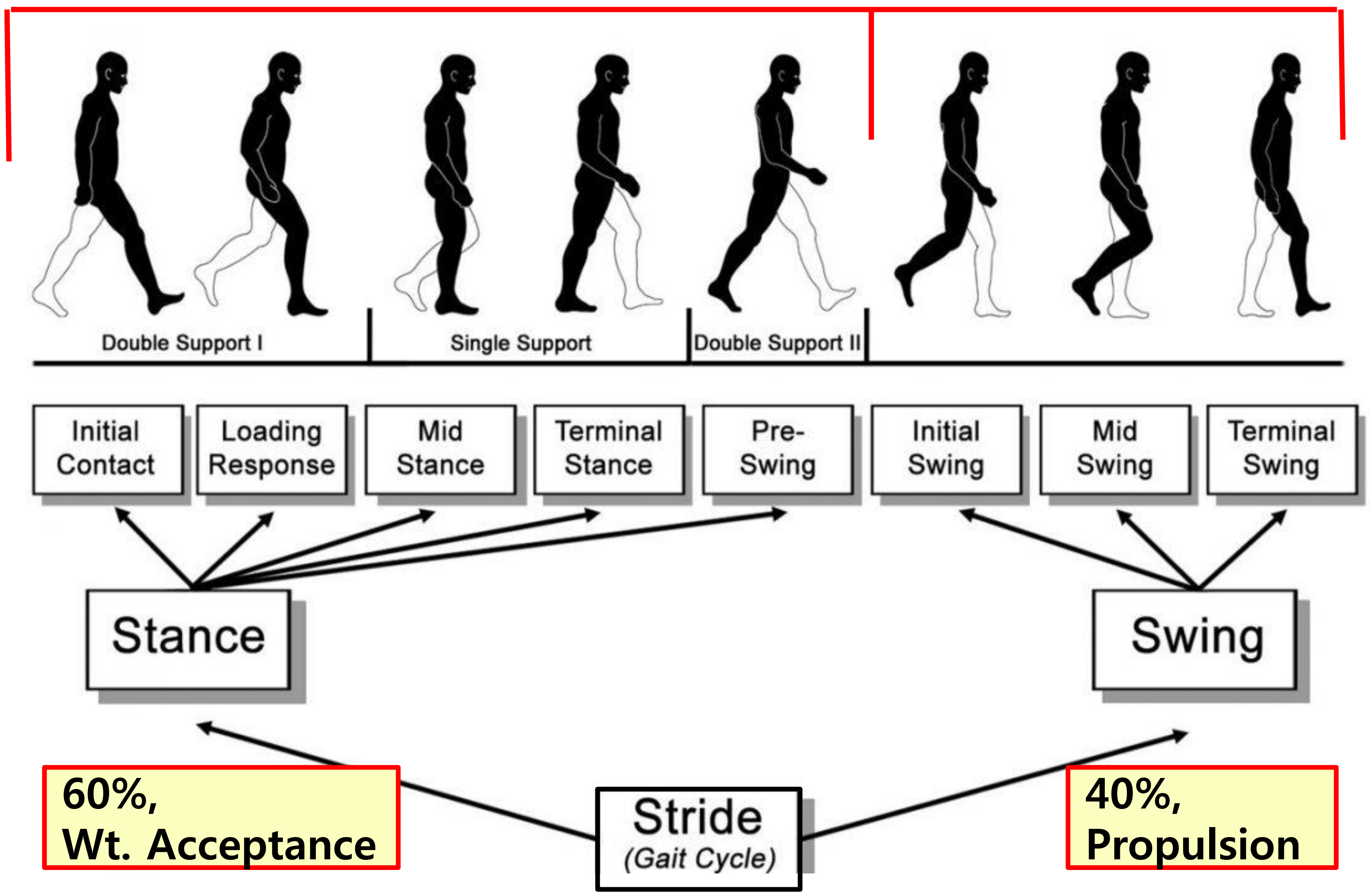
Best describes the gait of normal subjects.
But pathologic gait describe (-)

- **Rancho Los Amigos Gait**
  1. Initial contact
  2. Loading response
  3. Midstance
  4. Terminal stance
  5. Presweing
  6. Initial Swing
  7. Midswing
  8. Terminal swing

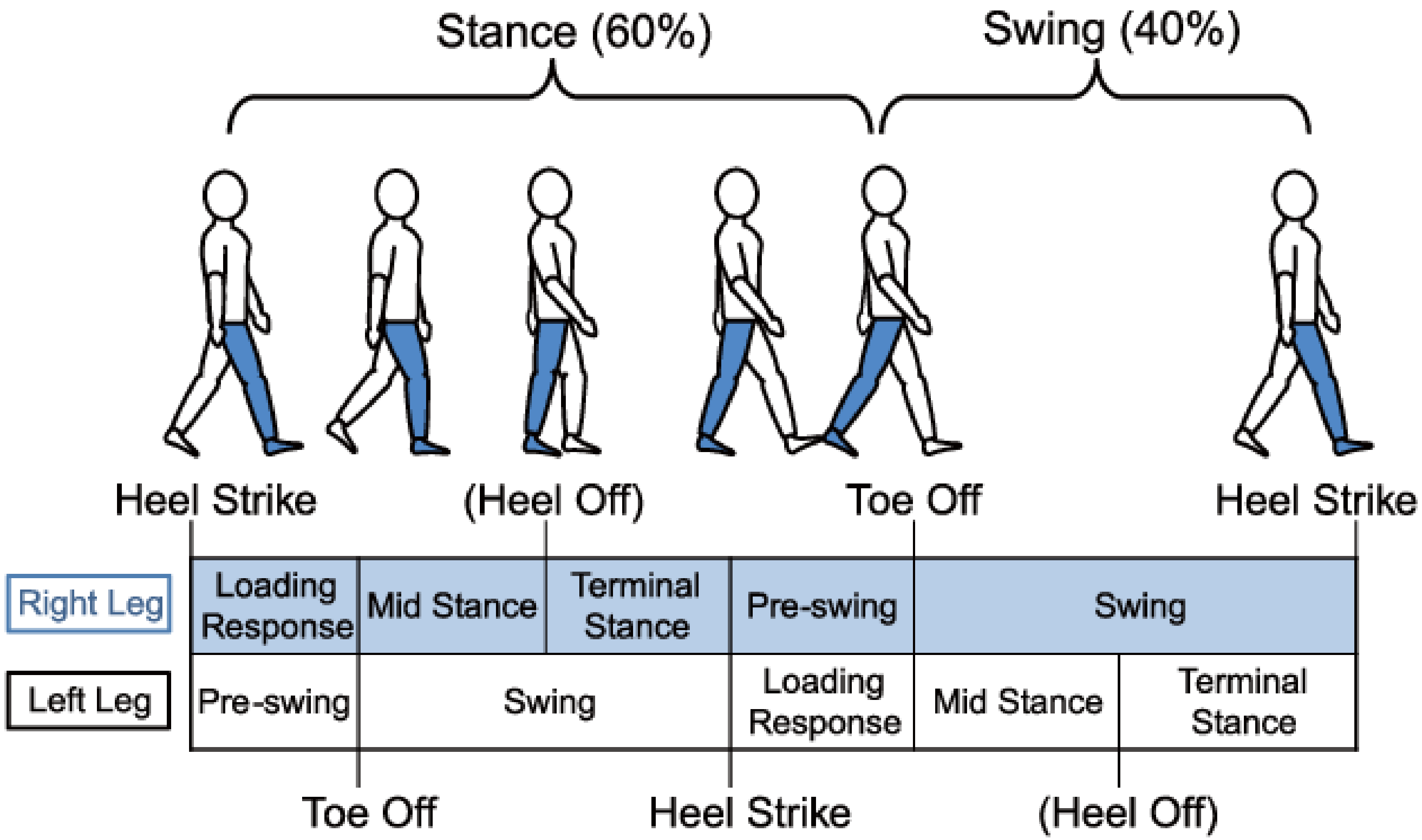


Developed by Perry and her associates (1982)
Sufficiently applied to any type of gait

Gait cycle (Rancho Los Amigo Gait)



Gait cycle (Traditional)



Initial Contact (초기 접지기)

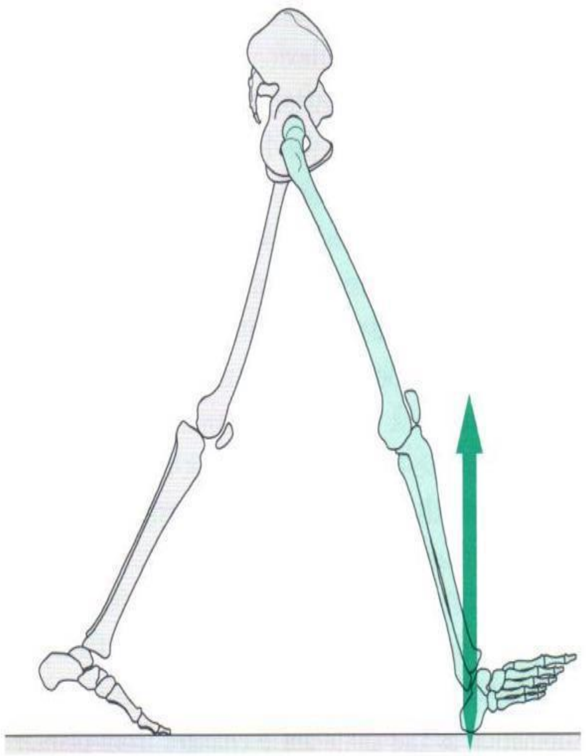
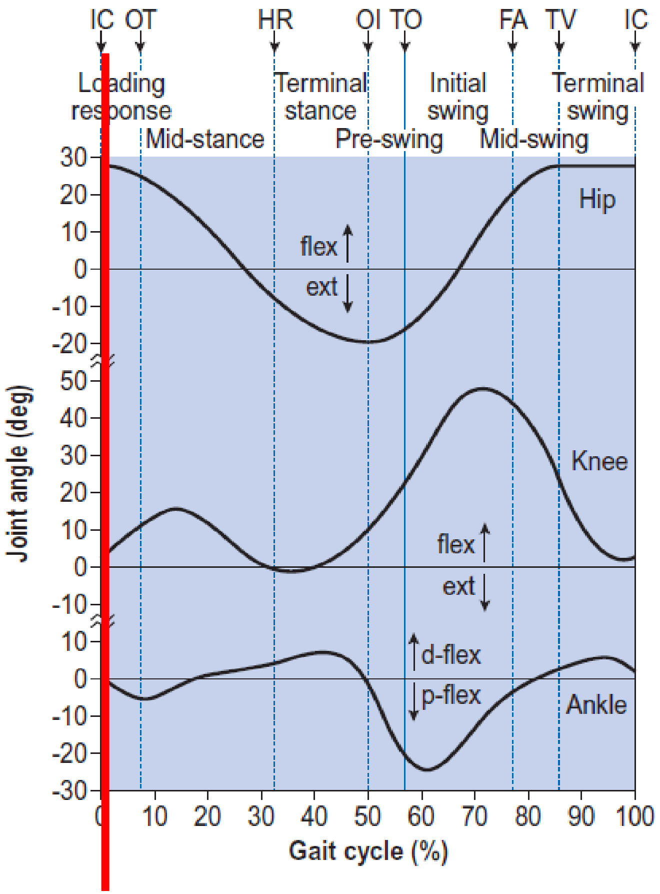
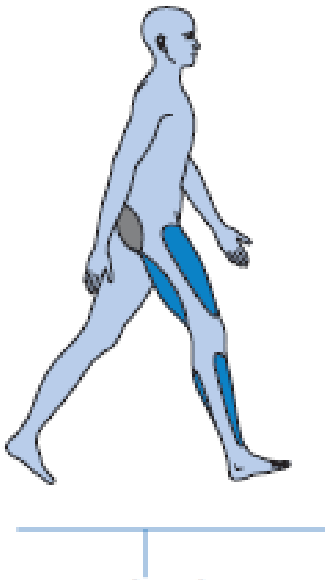


Fig. 2.11 • Initial contact: position of right leg (green), left leg (grey) and ground reaction force vector during the heelstrike transient. This illustration also applies to terminal foot contact.





- **Heel strike**
- Foot contact to the ground

- **Muscle activity**
  - Hip extensor: prepare Wt. bearing
  - Knee extensor: Eccentric contraction to control knee flexion and prevent knee buckling
  - Ankle dorsiflexor: Eccentric contr. to control APF

Loading response (부하 반응기)

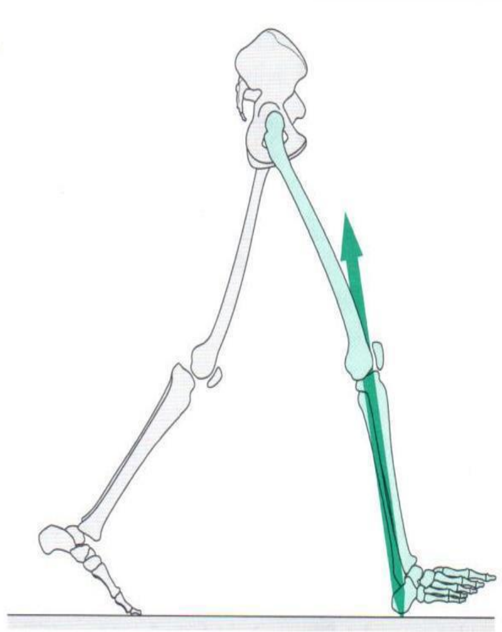
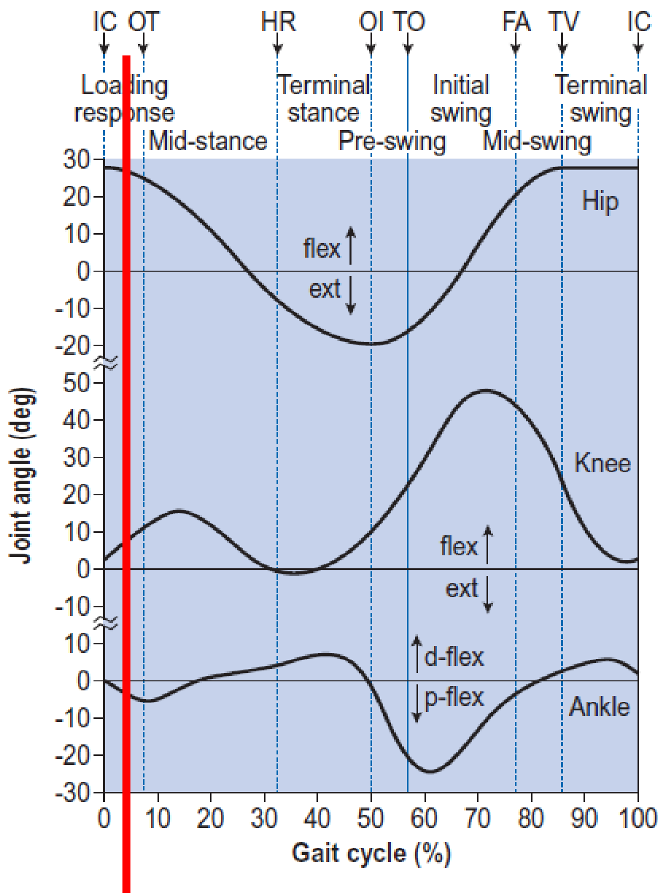
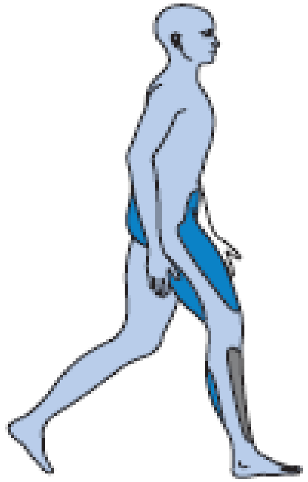


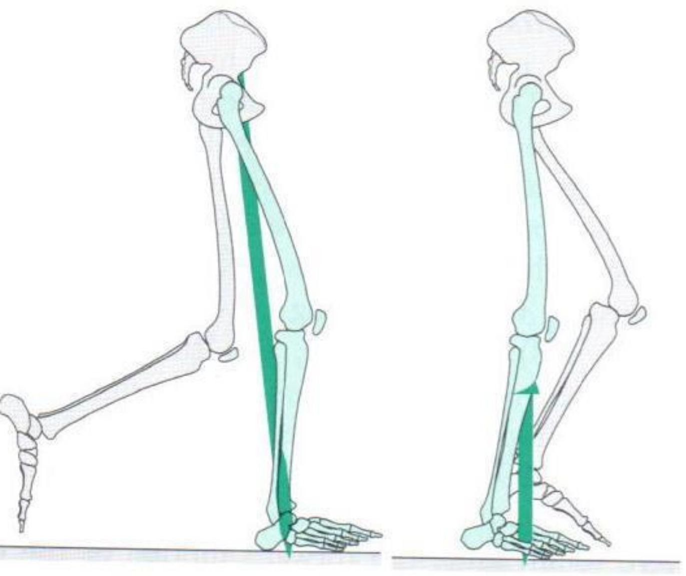
Fig. 2.12 • Loading response: position of right leg (green), left leg (grey) and ground reaction force vector 20 ms after initial contact.

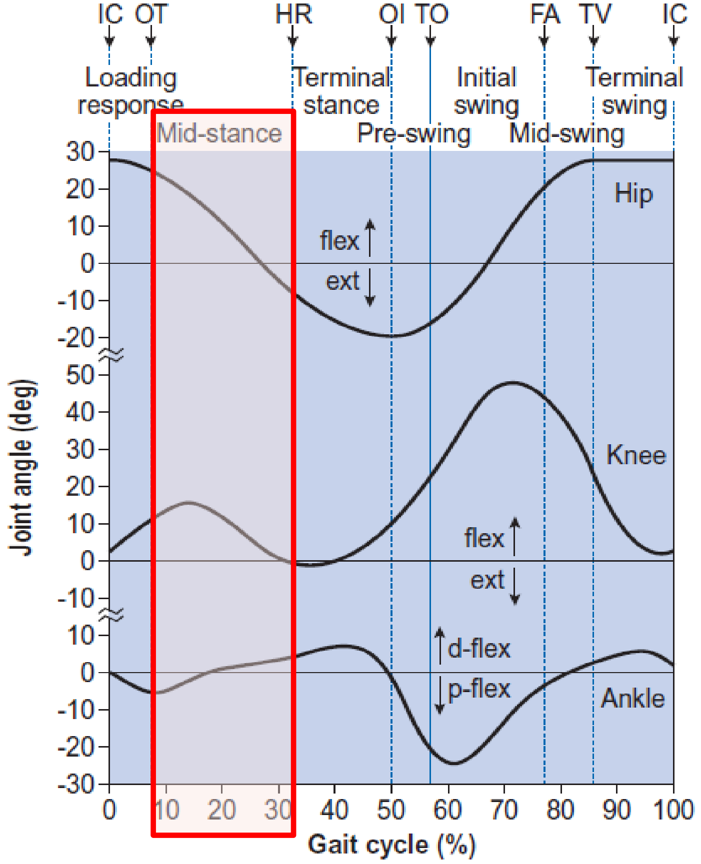




- Foot flat (Plantar flexion activity)
- From ipsilateral flat foot position
- Until the opposite foot is off the ground for swing
- Muscle activity
  - Hip extensor: Concentric or isometric contraction to control hip & knee flexion. prepare Wt. bearing
  - Knee extensor: Eccentric contraction to control knee flexion and prevent knee buckling
  - Ankle dorsiflexor: Eccentric contr. to control APF in loading response

Mid stance (중간 입각기)





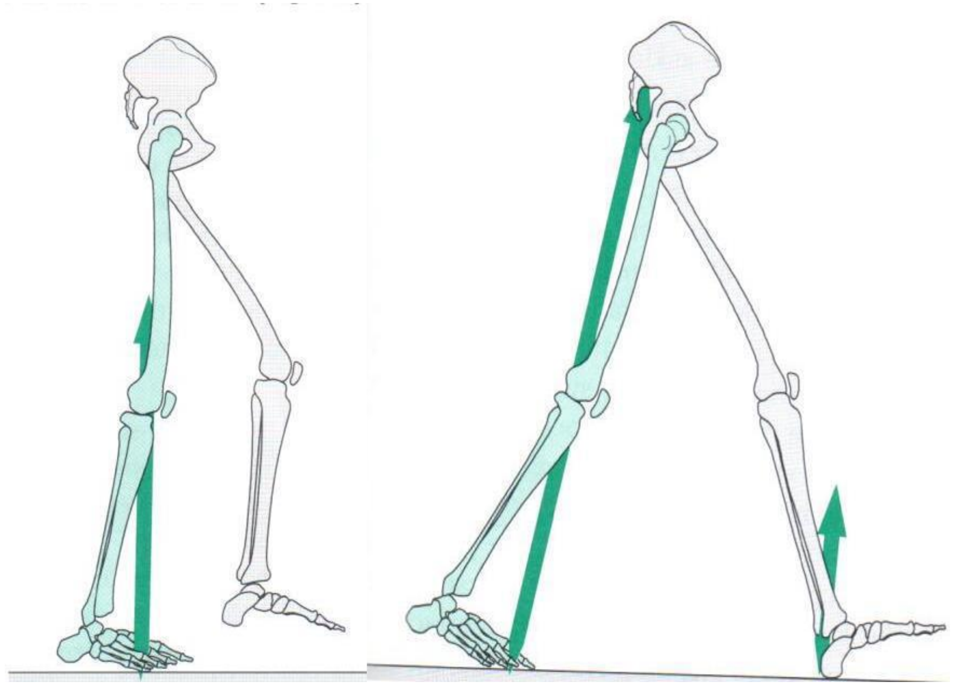
- From contralateral foot leaves ground

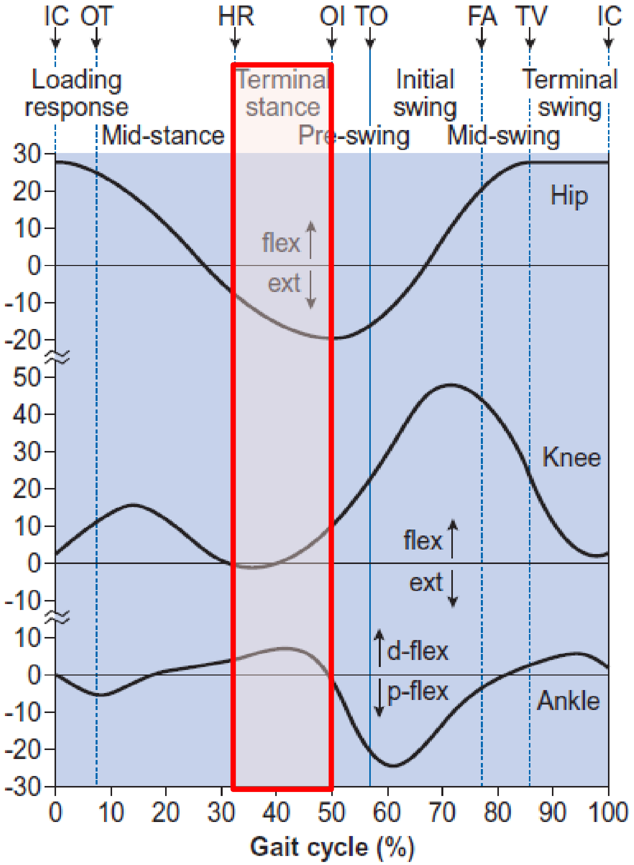
-> to ipsilateral heel leaves ground

- **COG 이동: 뒤 -> 앞**
- **Muscle activity**
  - Ankle P. flexor: eccentric contraction to control the ADF moment and prevent excessive forward tibia rotation.

발이 지면에 닿아 하퇴부가 전방으로 이동하는 시기 (키가 가장 크다)

Terminal stance (말기 입각기)





- **Ipsilateral Heel-off**
- **-> Contralateral initial contact**

- **Muscle activity**
  - Hip flexors: eccentric contraction to slow and control of the thigh post, rotation.
  - Knee extensors: eccentric contraction to control knee collapse and early heel rise
  - Ankle P. flexors: concentric contraction for push-off

Pre-swing (전 유각기)

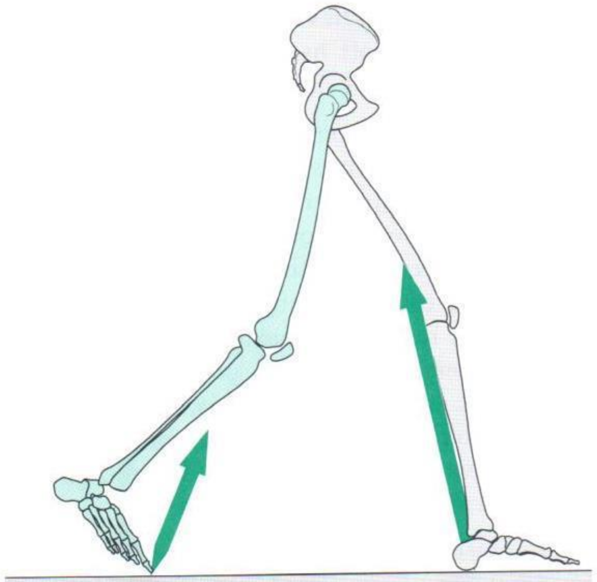
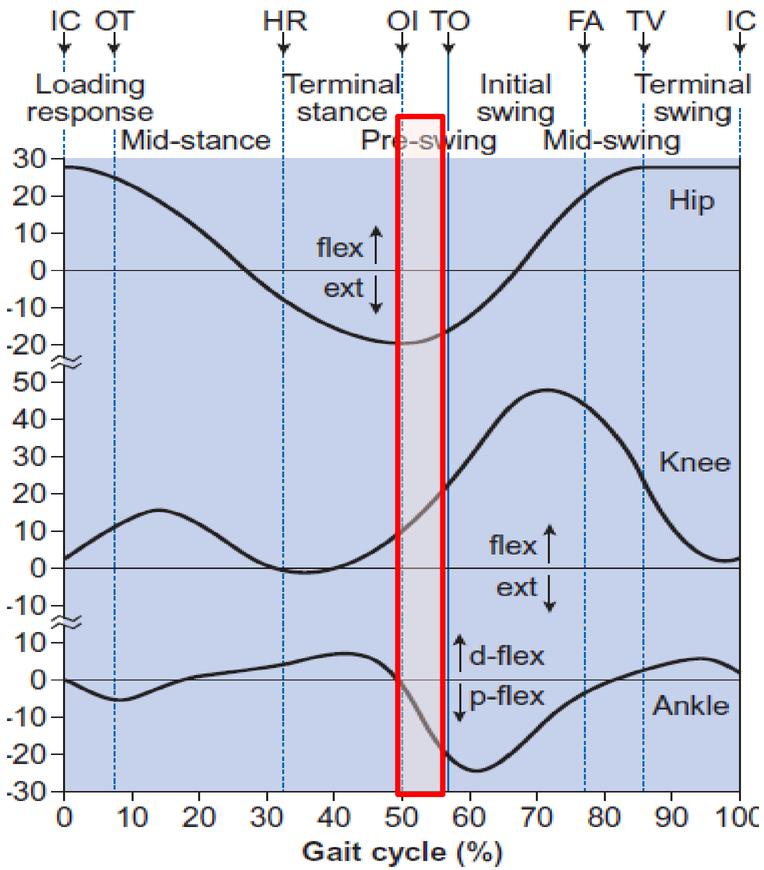
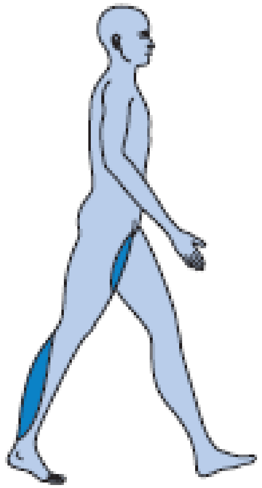


Fig. 2.17 • Toe off: position of right leg (green), left leg (grey) and ground reaction force vector.





- **Ipsilateral Toe-off**
- Contralateral initial contact
- **Stance phase end**

- **Muscle activity**
  - Ankle P. flexors: concentric contraction for acceleration of the swing limb.

Initial swing (초기 유각기)

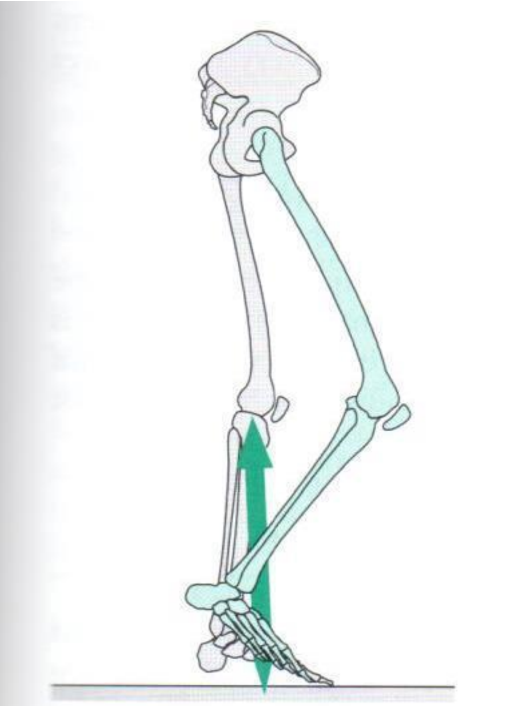
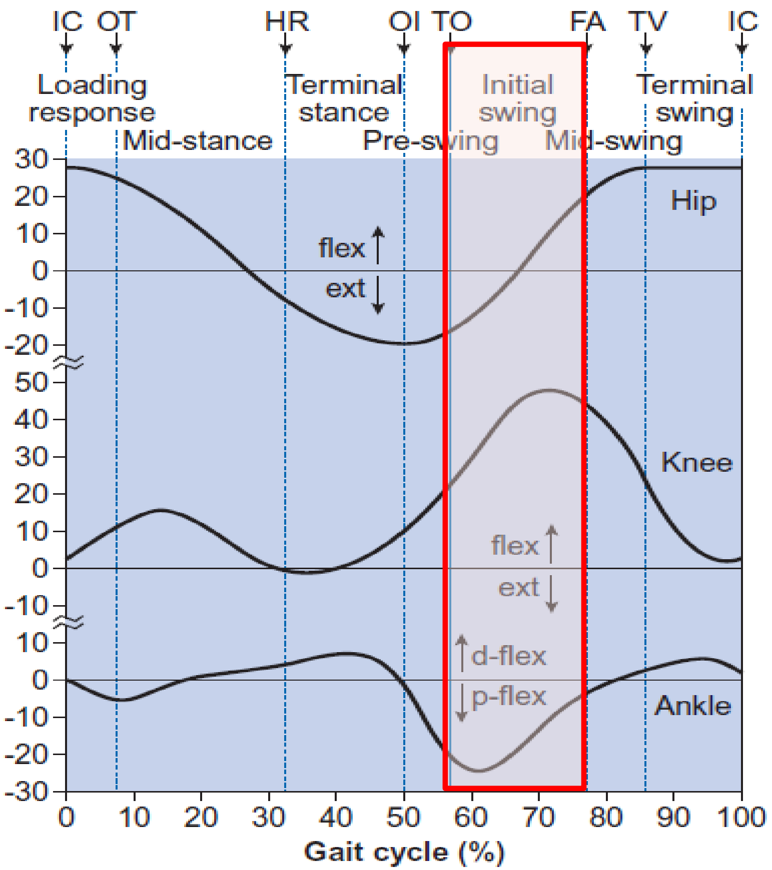
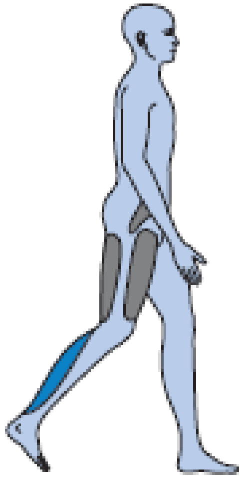


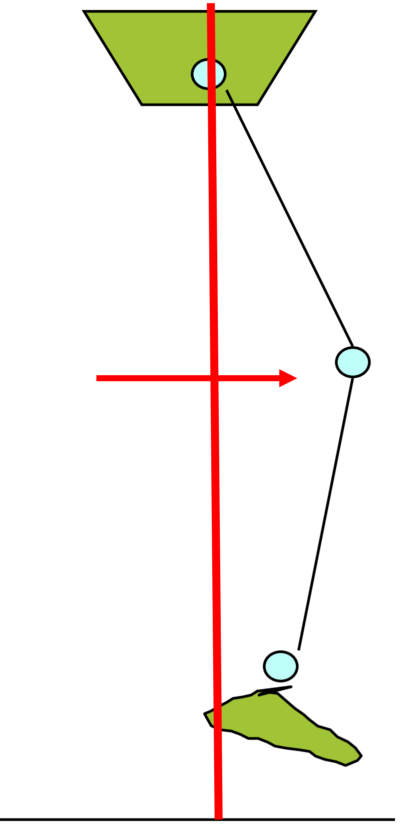
Fig. 2.18 • Feet adjacent: position and left leg (grey).





- **lift-off of the foot from floor**
- Ends when the foot is aligned with the opposite foot
- **Acceleration**
- **Muscle activity**
  - Hip flexors: concentric contraction to accelerate the swing limb forward.
  - Knee flexors: concentric contraction to produce knee flexion and foot clearance
  - Ankle D. flexors: concentric contraction to facilitate foot clearance

Mid swing (중간 유각기)



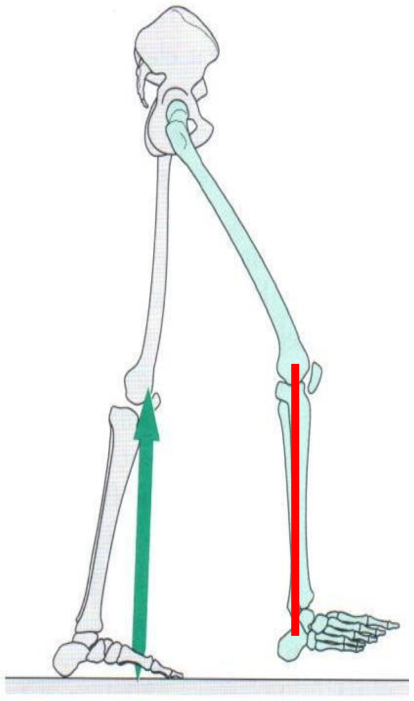
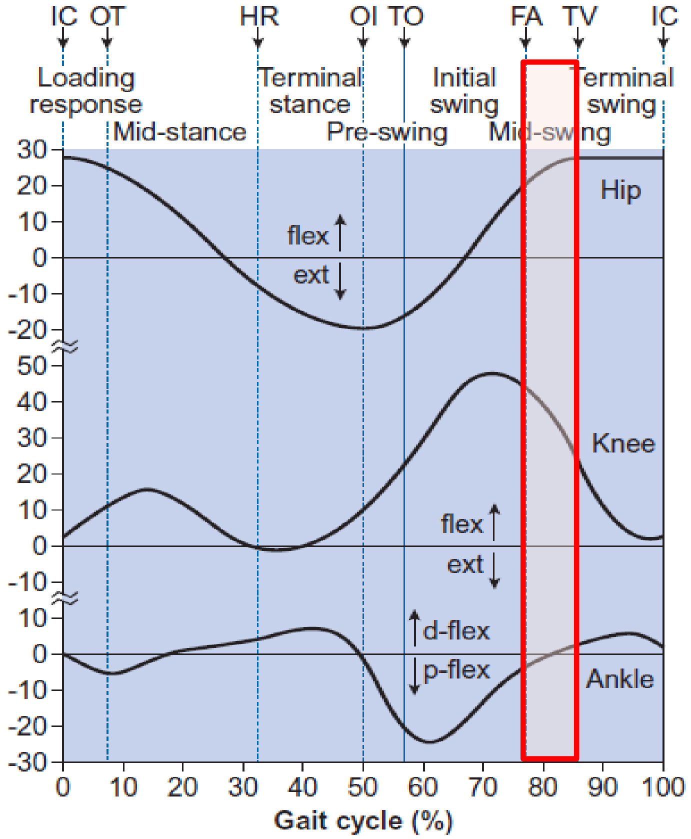


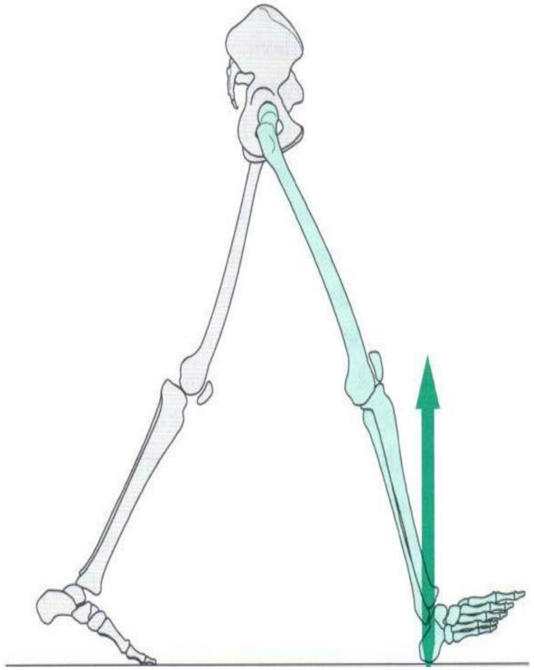
Fig. 2.19 • Tibia vertical: position of right and left leg (grey).

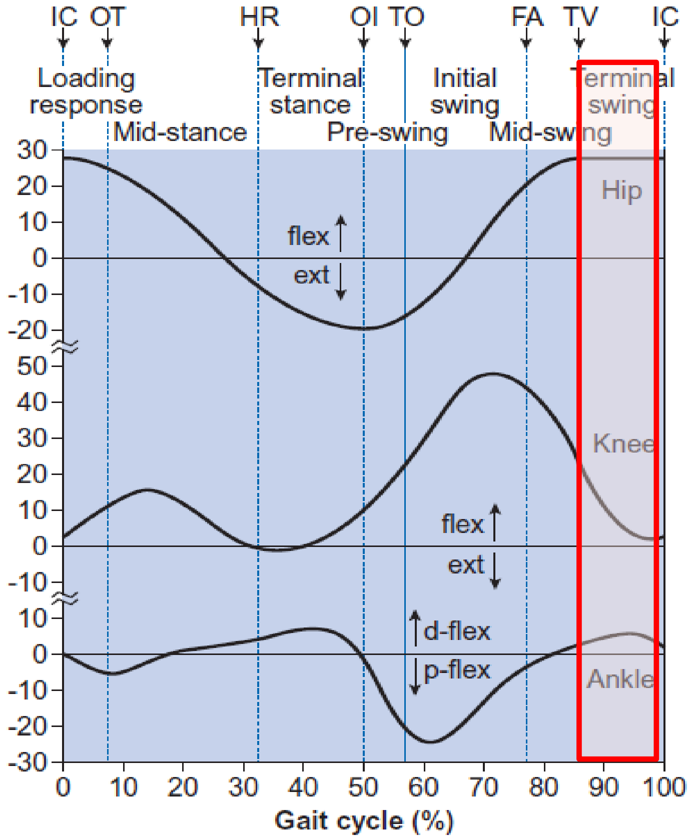


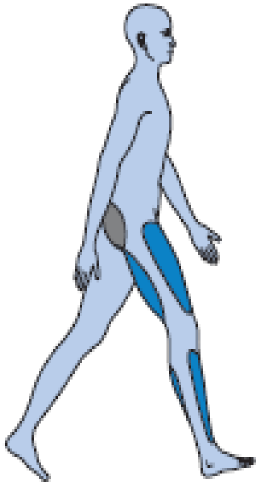
- Ipsilateral foot: maximal knee flex.
- Ends when the tibia is vertical
- Contralateral foot: Wt. acceptance

- **Muscle activity**
  - Knee flexors: concentric contraction to produce knee flexion and foot clearance
  - Ankle D. flexors: concentric contraction to facilitate foot clearance

Terminal swing (말기 유각기)







- Deceleration, Gait cycle ends
- Heel strike를 준비하기 위해 knee extension 되는 시기
- Begins when the tibia is vertical
- Ends the foot contacts the ground
- **Muscle activity**
  - Hip extensor: concentric cont. thigh posteriorly rotate and stabilize the limb
  - Knee flexors: eccentric & isometric contraction to control knee extension

Efficient gait through minimizing the movement of the COG

- **Energy Conservation (에너지 보존의 법칙)**
  - 보행주기 동안 반복적인 운동에너지, 위치에너지 총합 일정
  - Center of Gravity (COG: S2 vertebral body 1in 앞)
    - Double limb support 때 가장 낮고,
    - Single limb support 시기 mid-stance & contralateral mid-swing tibia vertical 가장 높음.

- **Stance phase**
  - Synergic action 에 의해 abrupt loading 을 없애고,
  - Stability 유지 forward progression 유지

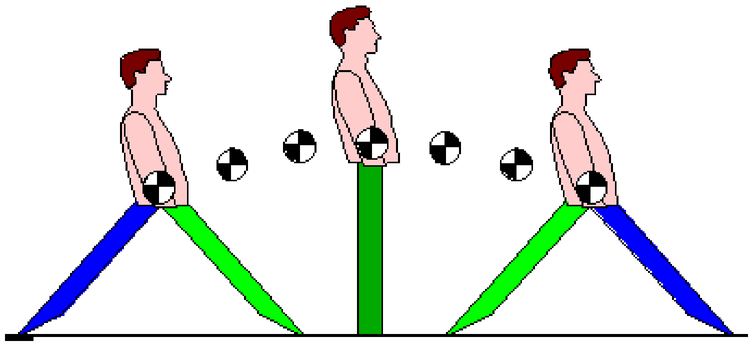
- **Swing phase**
  - Maximizing progression
  - Foot clearance

신체를 전방으로 추진 시킬 수 있는 충분한 에너지 공급 !!!

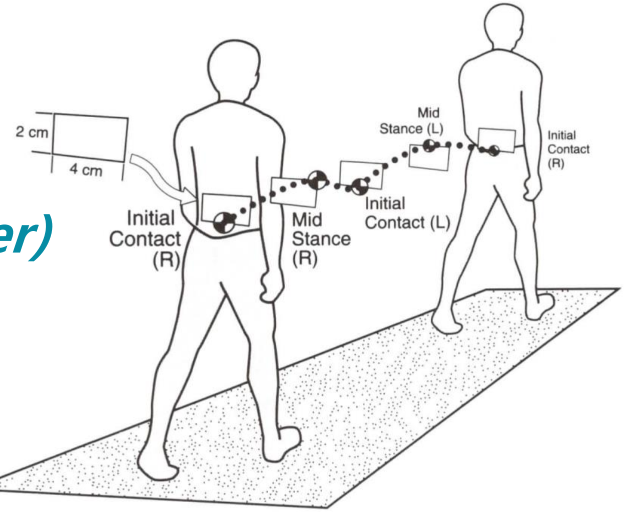
신체를 전방으로 추진 시킬 수 있는 충분한 에너지 공급

6 Determinants of Gait – 이거 발표 내용

- **Most efficient gait** through **minimizing the movement of the COG**
- Described by ***Saunders et al*** in 1953, and ***Inman*** in 1981



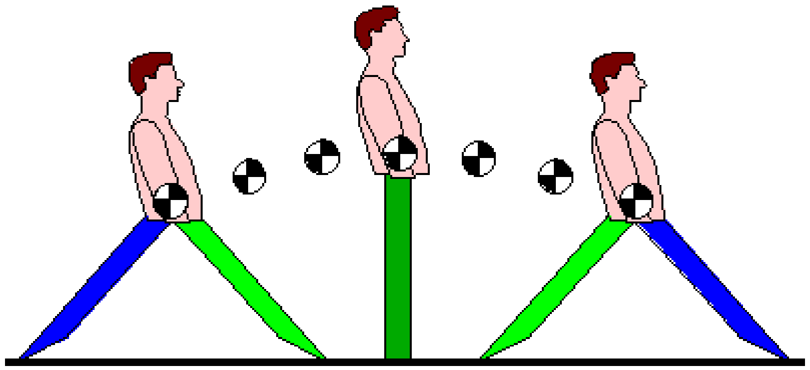
- **3 pelvic levels**
  - Pelvic rotation in the horizontal plane
  - Lateral displacement of pelvis
  - Contralateral pelvic drop
- **3 knee, ankle & foot motion (rocker action)**
  - Knee flexion in the stance phase *(loading response, ankle rocker)*
  - Heel strike initial contact phase *(heel rocker)*
  - Heel rise terminal stance phase *(forefoot rocker)*



- COG follows a **smooth, sinusoidal path** in the frontal, transverse, and sagittal planes.

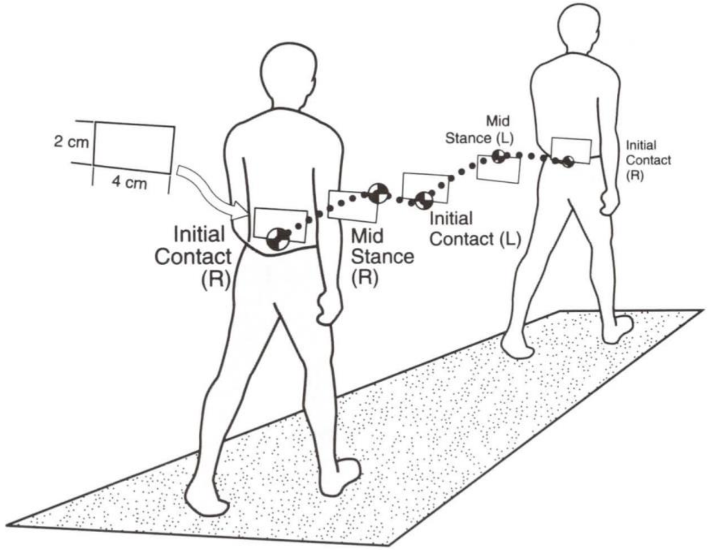
6 Determinants of Gait – 슬라이드 제출

- **Most efficient gait** through **minimizing the movement of the COG**
- Described by ***Saunders et al*** in 1953, and ***Inman*** in 1981

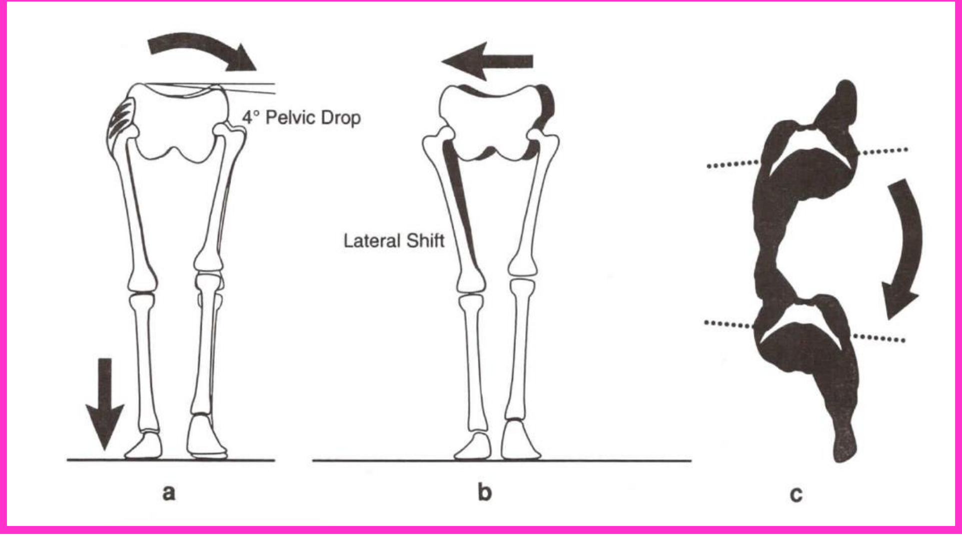


6 determinants of Gait

- **3 pelvic levels**
  - Pelvic rotation in the horizontal plane
  - Lateral displacement of pelvis
  - Contralateral pelvic drop
- **3 knee, ankle & foot motion**
  - Knee flexion in the stance phase (loading response)
  - Heel strike initial contact phase
  - Heel rise terminal stance phase



Determinants of gait – Pelvic



- **Contralateral pelvic drop**
  - Loading response loading limb 의 abrupt loading of Wt.

  -> contralateral limb 을 unloading 시켜 contralateral pelvic drop

  -> Loading limb의 abductor muscle action 에 의해 pelvic drop 정도가 4′ 정도 감소함.
  - Contralateral pelvic drop이 덜 생기게 함.

- **Lateral displacement of pelvis**
  - Transfer of body Wt. onto the stance limb
  - During LR & early mid stance, both vertical and lateral re-alignment of the COG occur.

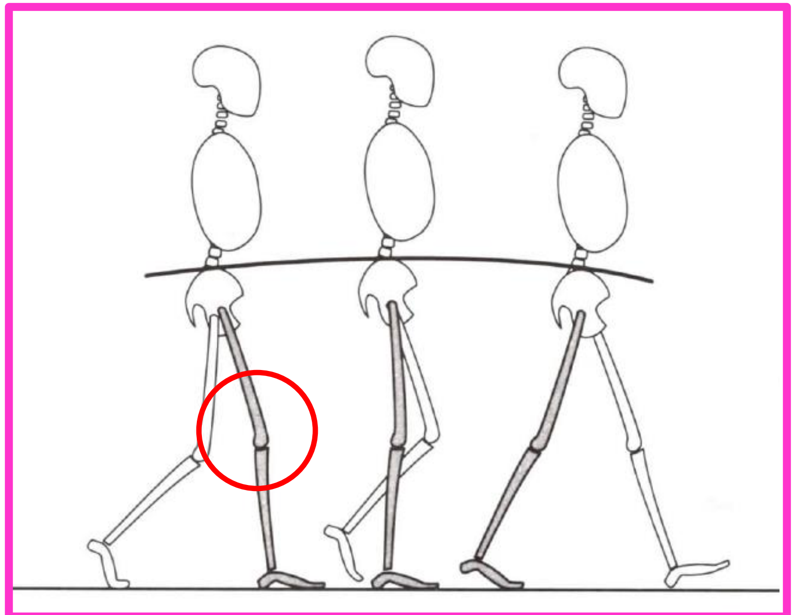
- **Pelvic rotation in the horizontal plane**
  - Horizontal rotation – functionally lengthens the limb, moves hip joints closer to midline,

  -> reduce amount of limb obliquity needed to accomplish the desired step length.

Determinants of gait – Knee, Ankle & Foot

Knee flexion in loading response

- Shock absorption
- Minimize displacement of COG
- Reduce the height of hip joint in midstance
- Decrease energy expenditure

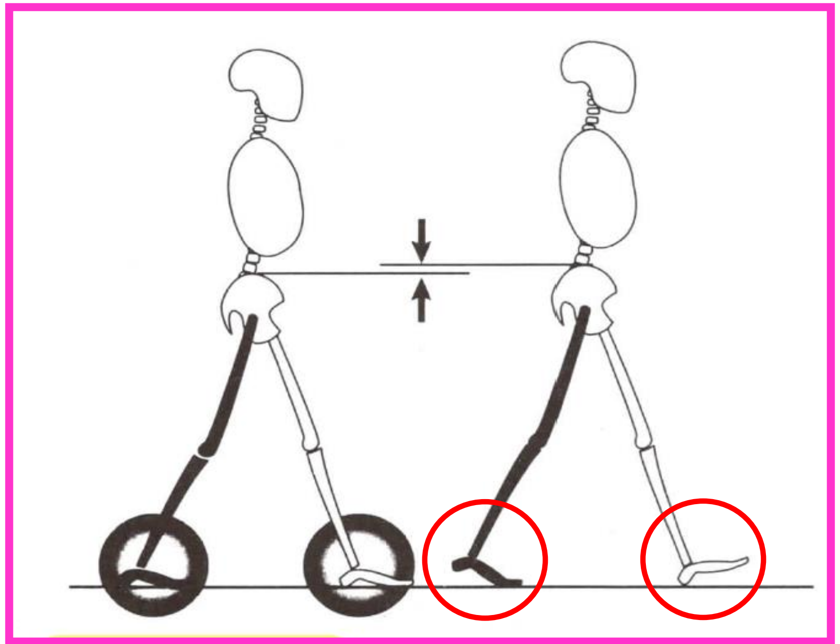


Heel strike initial contact phase

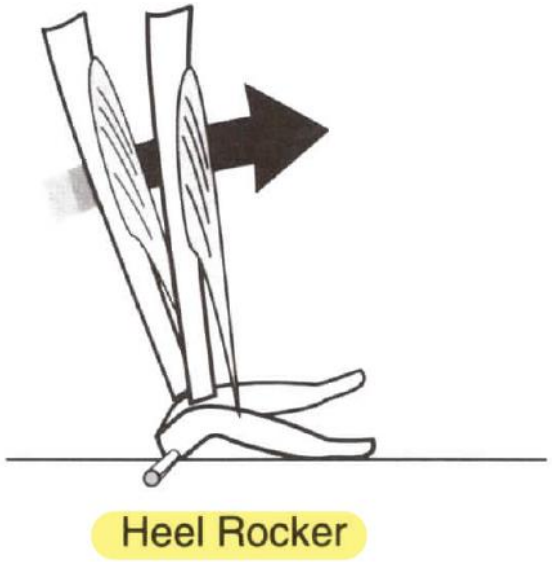
- Adds length to the forward limb

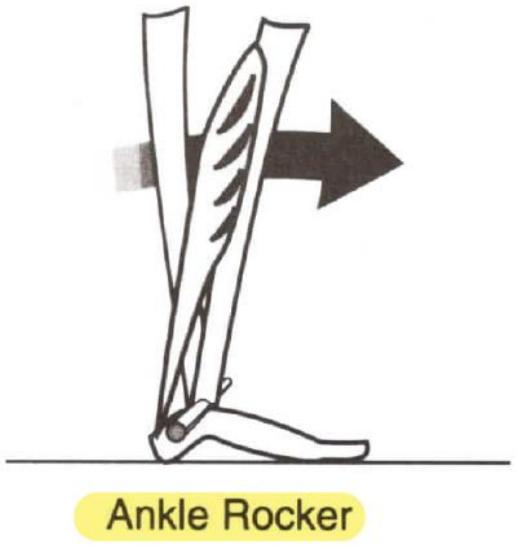
Heel rise terminal stance phase

- Trailing limb을 lengthens



Foot rockers





Heel rocker – IC, LR

- APF torque, knee flexion torque
- TA eccenteric contraction
- **Power absorption**

Ankle rocker –Mid stance

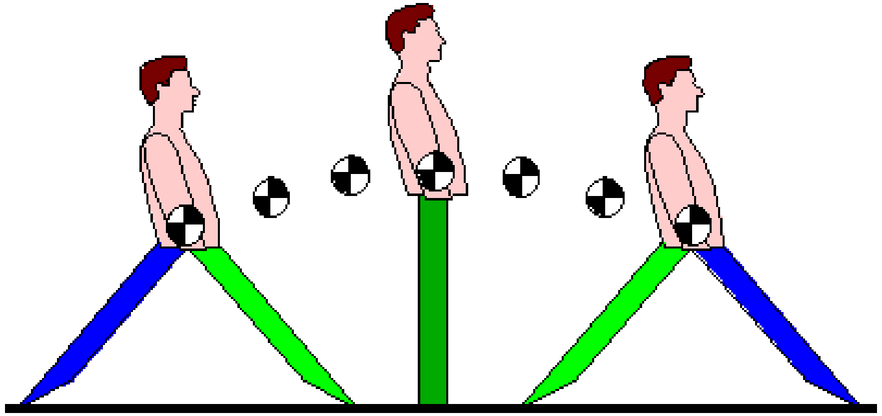
- Ankle smooth rolling
- Tibia progression
- M. contraction- soleus

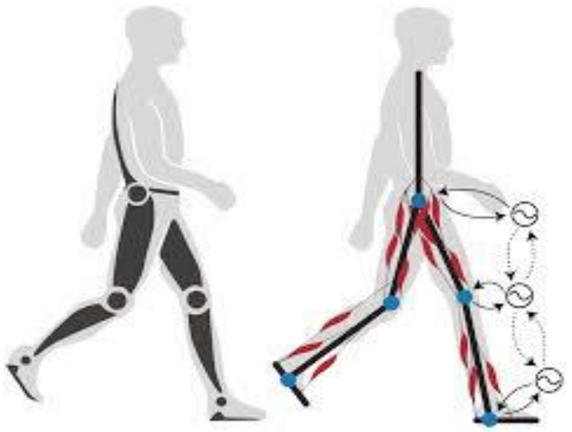
Forefoot rocker – terminal stance

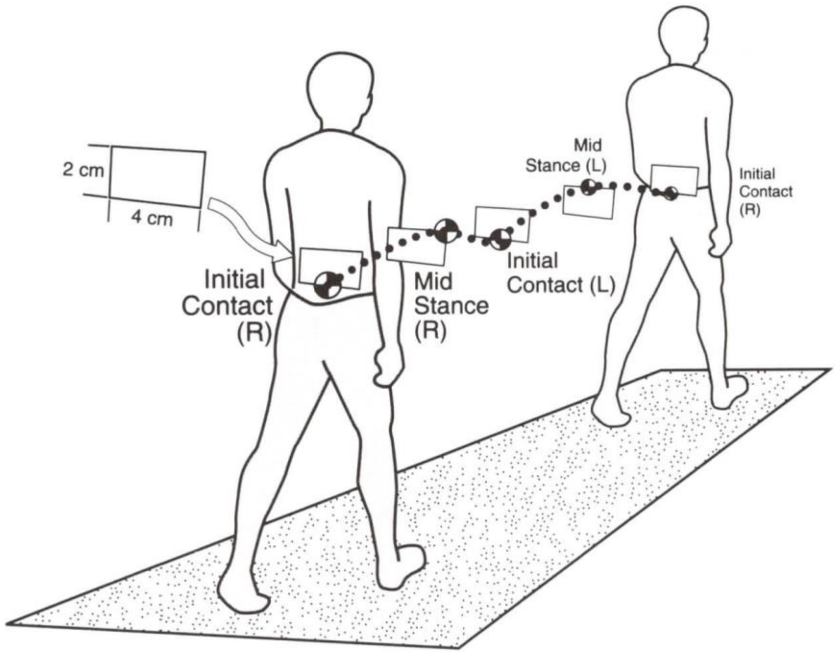
- Soleus, GCM- concentric contraction
- Push off
- **Power generation**

Determinants of Gait

- **Increase the efficiency and smoothness** of pathway of gait
- **Decrease** the vertical and lateral **displacement of center of gravity** to two inches excursion
- **Decrease the energy expenditure**
- Make gait more graceful.







Clinical Aspects of Gait Attributes in Normal Gait

Stability in Stance

Foot Clearance in Swing

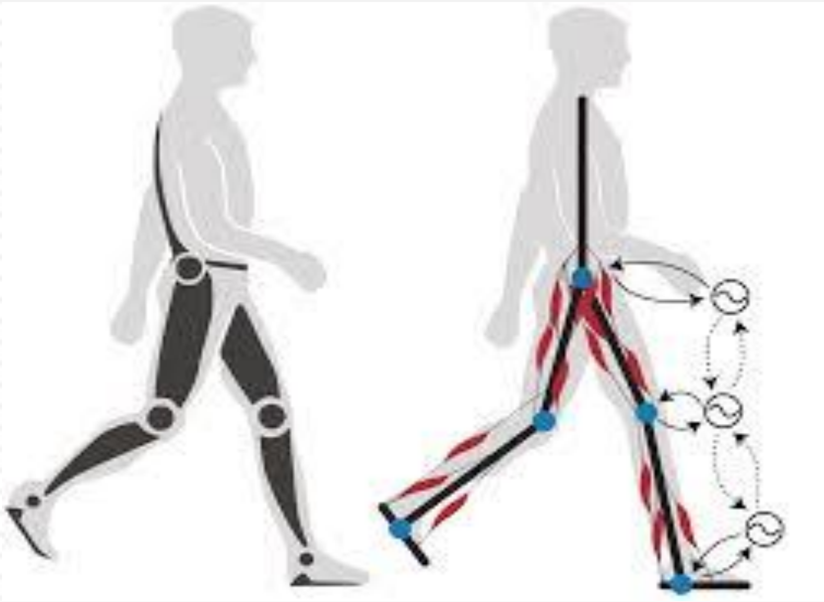
Pre-positioning for IC

Adequate Step Length

Energy Conservation

CONTENTS

- Biomechanics of Normal Gait
- Normal Gait Analysis
- Pathologic Gait after Stroke



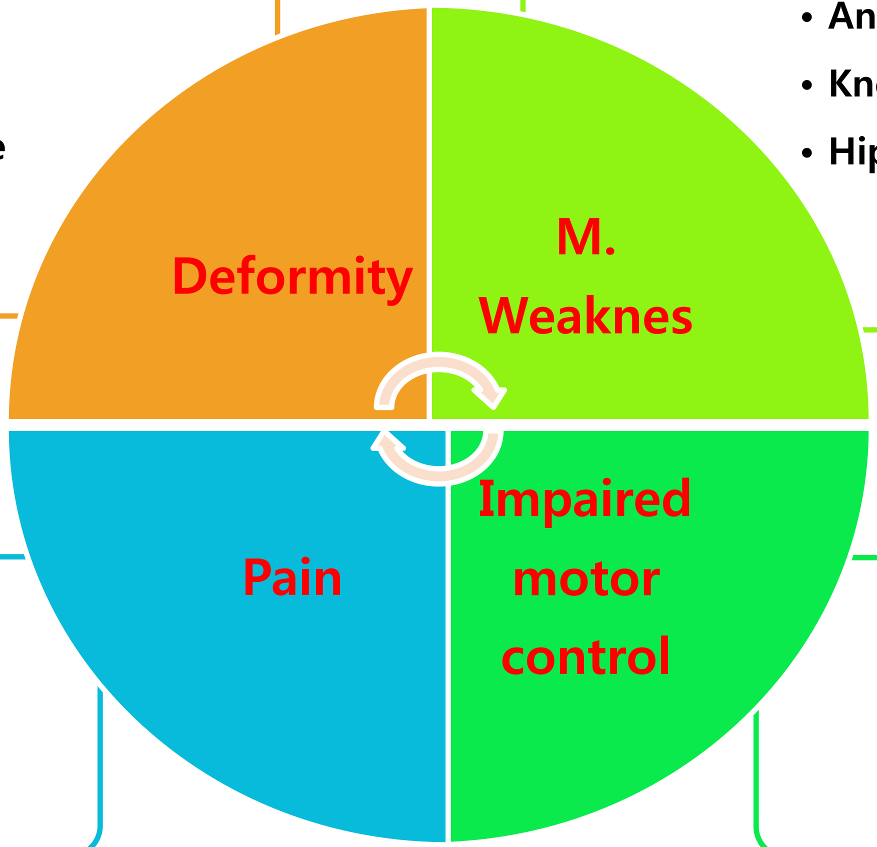
Pathologic Gait

- 4 Functional categories of pathologic gait
  - Deformity
  - Muscle weakness, Sensory loss
  - Pain
  - Impaired motor control

Post stroke Gait disturbance

- Ankle PF contracture
- Ankle inversion
- Knee flexion contracture
- Hip flexion contracture
- Hip ER contracture

- Ankle dorsiflexor weakness
- Knew extensor weakness
- Hip flexor weakness



- Poststroke central pain
- CRPS

- Spasticity
- Ataxia

Deformity

- **Ankle plantar flexion contracture**
  - Standing phase: tibial advance 방해
  - Swing phase: foot clearance 방해, hip, knee flexion 증가
- **Ankle inversion**
  - Foot clearance 방해, stance phase stability 감소
- **Knee flexion contracture**
  - Thigh advance 방해, knee stabilizing (Q-ceps) demand 증가
- **Knee extension contracture**
  - Swing phase시 foot clearance 방해
- **Hip flexion contracture**
  - Forward progression 제한, step length 저하

Post stroke Gait **Hemiplegic Gait**

- **Impaired motor control**

- **Asymmetric pattern**
  - Contralateral motor weakness
  - Sensory and/or proprioceptive loss
  - Ataxia

- **Increased energy cost of walking** d/t m weakness

Post stroke Gait **Hemiplegic Gait**

- **Synergic pattern, Spasticity, Contracture 등에 따라 보행양상 나타남.**

- **Synergic pattern**
  - Flexor synergy pattern of upper ext.
  - Extensor synergy pattern of lower ext. (Hip extension & add, knee ext. ankle PF & inver.)
- **Stance phase**
  - Affected limb initial contact – heel contact 잘 안됨. (d/t ankle PF contracture, ankle weakness)
  - **Genu recurvatum** (d/t ankle PF contracture & spasticity, knee extensor weakness & spasticity)
- **Swing phase**
  - Foot clearance 방해, compensation 위해 circumduction, vaulting
  - Hip, knee flexion 저하 (d/t muscle weakness)

Primitive Locomotor Patterns

- Upper ext. flexor synergy pattern
- **Lower ext. extensor synergy pattern**
  - Hip extension. adduction
  - knee extension
  - Ankle PF, inversion

  - lengthening of paretic limb
  - non-paretic limb – vaulting
  - Paretic limb- hike the hip, circumduction during swing
  - Insufficient toe clearance during swing

Hemiparetic Gait Kinematic change

- Non-paretic pelvic drop d/t paretic hip abductors weakness (G. me & min)
- Paretic hip flexion decrease
  - heel strike decrease
  - Pre-swing is delayed
- Paretic knee flexion weakness
  - Early stance knee flexion instability.
  - Swing phase decreased knee flexion (stiff-knee gait)
- Paretic hip, knee flexion decrease
  - decreased ability to toe clear in swing phase
- Genu recurvatum
  - Ankle Plantar flexion spasticity and/or contracture
  - Quadriceps spasticity and/or Quadriceps weakness
  - Hamstring weakness

Hemiparetic Gait Kinematic change

- Paretic knee hypertext. In midstance & GCM-sol weakness
  - Impaired Forward progression of tibia on the paretic limb
  - Inadequate plantar flexor power is generated at terminal stance
- Knee extension at terminal stance & decrease hip flexion
  - Shortened step length
- Foot drop
  - d/t Insufficient ADF strength and/or APF spasticity
  - ADF weakness -> heel strike decrease (initial contact), flat foot
- **Equinovarus deformity**
  - Excessive APF and inversion d/t Spasticity and primitive locomotor
  - Most common pathologic limb posture
  - Initial contact -

Hemiparetic Gait

Table 1
Effect of hemiparesis on spatiotemporal gait parameters

Walking velocity (m/s)	Decreased
Stride length (m)	Decreased
Step length (m)	Decreased
Cadence (steps/min)	Decreased
Paretic single-stance duration (s)	Decreased
Double-stance duration (s)	Increased
Paretic stance duration (s)	Decreased
Paretic swing duration (s)	Increased

Table 2
Effect of hemiparesis on kinematic gait parameters

Pelvis	
Tilt	Increased
Hip	
Flexion at heel strike	Decreased
Flexion at midswing	Decreased
Extension at preswing	Decreased
Knee	
Flexion at heel strike	Decreased
Flexion in swing	Decreased
Extension in stance	Increased
Ankle	
Dorsiflexion at heel strike	Decreased
Plantar flexion in swing	Increased
Inversion in swing	Increased

Clinical Assessment of Hemiplegic Gait…….

- **Understanding of normal human gait is necessary !!!**

- To assess the **complex interplay** of
- Motor, sensory, and proprioceptive loss; spasticity & ataxia on hemiparetic gait.

- Based on……
  - Neurologic exam
  - Observation of gait (Gait analysis, dynamic EMG)

- Identify how the **gait pattern differs from normal walking**
- What is the **cause of the dysfunction**

경청해 주셔서 감사합니다.