Lecture # 2

Artificial Limbs I

Clinical Assessment of Gait

Gait Analysis: -

The first attempts to analyze gait, recorded in the Rig Veda more than 3500 years ago, most likely was an attempt to enhance mobility through early orthotic or prosthetic intervention. This classic prose chronicles the story of Vispala, a fierce female warrior whose leg, lost in battle, and was replaced by an iron prosthesis that enabled her return to the front to fight again.

Gait assessment describes the patterns of movement that control the progression of the body in walking. Bipedal gait requires a combination of automatic and volitional postural components. This can result in either asymmetric reciprocal movements of the lower limbs (seen in walking or running) or symmetric, simultaneous two-legged hopping. Kangaroos are bipeds that are successful two-legged hoppers. Homo sapiens have reached the zenith of movement efficiency in bipedal walking and running by using reciprocal patterns of motion.

Walking requires numerous physiological systems to work congruently. Normal walking requires stability to provide body weight support against gravity during stance, mobility of body segments, and motor control to sequence multiple segments while transferring body weight from one limb to the other. The primary goal in gait is energy efficiency in forward progression by using a stable kinetic chain of joints and limb segments working congruently to transport its passenger unit, consisting of the head, arms, and trunk (HAT) in a continuously changing environment and task demands.

Understanding the process of walking is essential to critically evaluate examination findings and suggest effective intervention plans to help patients improve their walking ability. Clinical gait assessment identifies primary or pathological gait problems and helps differentiate them from compensatory strategies. It is necessary for selection of appropriate orthotic or prosthetic components, alignment parameters, and identification of other variants that might enhance an individual's ability to walk. Clinical gait assessment also contributes to the development of a comprehensive treatment plan, with the ultimate goal of optimal energy efficiency and appropriate pathomechanical control, balancing cosmesis (it usually refers to the surgical correction of a disfiguring defect, or the cosmetic improvements made by a surgeon following incisions) and overall function.

KINEMATIC DESCRIPTORS OF HUMAN WALKING

Step length, stride length, cadence, and velocity are important quantitative, interrelated kinematic measures of gait. Step length and stride length are not synonymous. Step length is the distance from the floor-contact point of one foot in early stance to the floor-contact point of the opposite (contralateral) foot: in normal individuals, the distance from right heel contact to left heel contact. Stride length is the distance from floor contact on one side to the next floor contact on that same side: the distance from right heel contact to the next right heel contact. A reduction in functional joint motion or the presence of pain or muscle weakness can result in decreased stride or step length, or both. Pathological gait commonly produces asymmetries in step length between the two lower limbs.

Cadence is the number of steps taken in a given unit of time, most often expressed in steps per minute. **Velocit**y is the distance traveled in a given unit of time (the rate of forward progression) and is usually expressed in centimeters per second or meters per minute. Velocity is the best single index of walking ability. Decreased joint motion, pain and/ or muscle weakness can reduce cadence, velocity, or both. Velocity can also be qualitatively categorized as free, slow, or fast. **Free walking** (self-selected) speed is an individual's normal self-selected (comfortable) walking velocity. **Fast walking** speed describes the maximum velocity possible for a given individual while being safe. **Slow walking** speed describes a velocity below the normal self-selected walking speed. For healthy individuals, a fast walk velocity may be as much as 44% faster than free or self-selected walking speed. In people with musculoskeletal and neuromuscular impairments that affect gait, often much less difference is found between free and fast gait velocity.

Double limb support is the period of time when both feet are in contact with the ground. It occurs twice during the gait cycle, at the beginning and the end of each stance phase. As velocity increases, double limb support time decreases. When running, the individual has rapid forward movement with little or no period of double limb support. Individuals with slow walking speeds spend more of the gait cycle in double support.

Step width, or width of the walking base, typically measures between 5 and 10 cm from the heel center of one foot to the heel center of the other foot. A wide walking base may increase stability but also reduces energy efficiency of gait.

Ground reaction force (GRF) vector is the mean load-bearing line, which takes into account the forces acting in all three planes. It has magnitude as well as directional qualities. The spatial relation between this line and a given joint center influences the direction of its rotation. The rotational potential of the forces that act on a joint is called a torque or moment.

GAIT CYCLE

A variety of conceptual approaches describe the walking process. Saunders and colleagues and Inman and colleagues define the functional task of walking as translation of the center of gravity through space in a manner that requires the least energy expenditure. They identify six determinants, or variables, that affect energy expenditure in sustained walking: pelvic rotation, pelvic tilt, knee flexion in stance phase, foot interaction with the knee, ankle interaction with the knee, and lateral pelvic displacement. Individually and collectively, these determinants have an impact on energy expenditure and the mechanics of walking. Although they help us understand the process of walking, the determinants do not themselves offer a practical clinical solution to address the problems of gait assessment.

A comprehensive system to describe normal and abnormal gait has been developed by the Pathokinesiology and Physical Therapy Departments at Rancho Los Amigos Medical Center over the past several decades. The

Rancho Los Amigos system serves as the descriptive medium for this chapter (Figure 1). Because velocity affects many parameters of walking, the description of normal gait assumes a comfortable self-selected velocity. At free walking velocity, the individual naturally recruits strategies and assumes the speed that provides maximum energy efficiency for their physiological system.

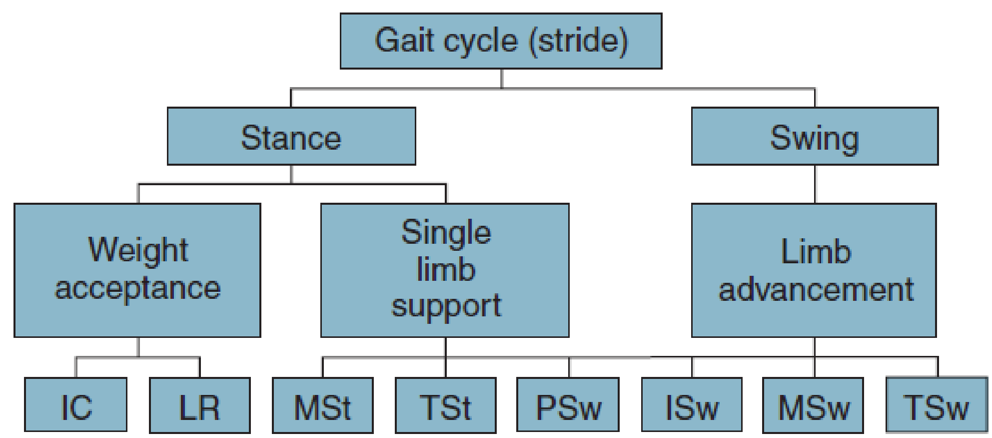

Figure 1: A complete gait cycle divided into three functional tasks of weight acceptance, single limb support, and limb advancement. The gait cycle can also be described in phasic terms of initial contact (IC), loading response (LR), mid-stance (MSt), terminal stance (TSt), pre-swing (PSw), initial swing (ISw), mid-swing (MSw), and terminal swing (TSw). The PSw phase is a transitional phase between single limb support and limb advancement.

The gait cycle is the period between any two identical events in the walking cycle. Initial contact is traditionally selected as the starting and completing event of a single cycle of gait. Each cycle is divided into two periods: stance phase and swing phase. Stance is the time when the foot is in contact with the ground; it constitutes approximately 60% of the gait cycle. Swing denotes the time when the foot is in the air; it constitutes the remaining 40% of the gait cycle. There are five sub-phases within the stance period: initial contact (IC), loading response (LR), mid-stance (MSt), terminal stance (TSt), and pre-swing (PSw). Swing phase is divided into three sub-phases: initial swing (ISw), mid-swing (MSw), and terminal swing (TSw). Because PSw prepares the limb for swing advancement, many consider PSw to be a preparatory component of swing phase.

Three functional tasks are achieved during these eight gait phases: weight acceptance in early stance, single limb support in mid-to terminal stance, and limb advancement during swing.

Functional Task 1: Weight Acceptance

IC and LR are the sub-phases of stance where weight acceptance is accomplished. Effective transfer of body weight onto the limb as soon as it makes contact with the ground requires initial limb stability, shock absorption, and the preservation of forward momentum.

Initial Contact

IC is the instant that the foot of the leading lower limb touches the ground. Most motor function during IC is preparation for LR. At IC, the ankle is in neutral position, the knee is close to full extension, and the hip is flexed 30 degrees. The sagittal plane GRF vector lies posterior to the ankle joint, creating a plantar flexion moment (Figure 2). Eccentric contraction (force the muscle can resist increases with increasing velocity of lengthening) of the pretibial muscles holds the ankle and subtalar joint in neutral position. At the knee, the GRF vector is anterior to the joint axis, which creates a passive extensor torque. Muscle contraction activity of the three vasti (are the three separate skeletal muscles located in the thigh) of the quadriceps and hamstring muscle groups continues from the previous TSw to preserve the neutral position of the knee joint. A flexion moment is present around the hip joint because the GRF vector falls anterior to the joint axis. Gluteus maximus and hamstring muscles are activated to restrain the resultant flexion torque.

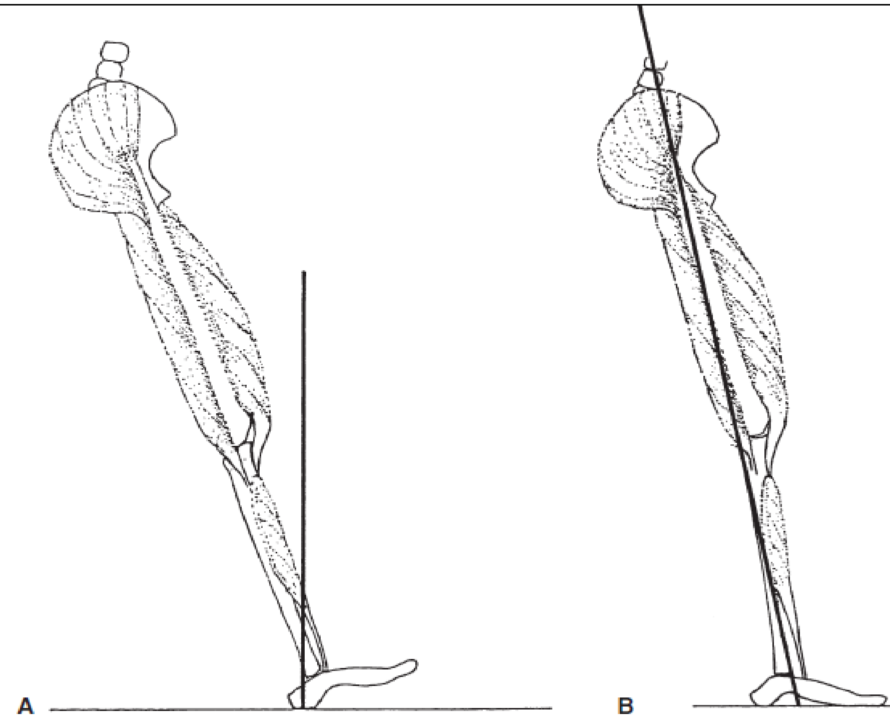

Figure 2: The two sub-phases of gait involved with the functional task of weight acceptance are initial contact (IC) and loading response (LR). A, At IC, the ground reaction force (GRF) line is posterior to the ankle and anterior to the knee and hip with activation of pretibial, quadriceps, hamstring, and gluteal muscles. Note that the length of the GRF line represents its magnitude. B, The LR phase results in an increased magnitude of the vertical force, which ultimately exceeds body weight. Activity of the same muscle groups elicited at IC increases steadily with the vertical force.

Loading Response

LR occupies approximately 10% of the gait cycle and constitutes the period of initial double limb support (see Figure 2-B). Two functional tasks occur during LR: controlled descent of the foot toward the ground and shock absorption as weight is transferred onto the stance limb. The momentum generated by the fall of body weight onto the stance limb is preserved by the heel rocker (first rocker) of stance phase. Normal IC at the calcaneal tuberosity creates a fulcrum about which the foot and tibia move. The bony segment between this fulcrum and the center of the ankle rolls toward the ground as body weight is loaded onto the stance foot, preserving the momentum necessary for forward progression. Eccentric action of the pretibial muscles regulates the rate of ankle plantar flexion, and the quadriceps vasti contract to limit knee flexion. The action of these two muscle groups provides controlled forward advancement of the lower extremity unit (foot, tibia, and femur). During the peak of LR, the magnitude of the vertical GRF exceeds body weight. To absorb the impact force of body weight and preserve forward momentum, the knee flexes 15 to 18 degrees and the ankle plantar flexes to 10 degrees. The hip maintains its position of 30 degrees of flexion. Contraction of the gluteus maximus, hamstrings, and adductor magnus prevents further flexion of the hip joint.

Functional Task 2: Single Limb Support

Two phases are associated with single limb support: MSt and TSt. During this period, the contralateral foot is in swing phase, and body weight is entirely supported on the stance limb. Forward progression of body weight over the stationary foot while maintaining stability must be accomplished during these two sub-phases of stance.

Mid-stance

MSt begins when the contralateral foot leaves the ground and continues as body weight travels along the length of the stance foot until it is aligned over the forefoot at approximately 20% of the gait cycle (Figure 5-3). This pivotal action of the ankle rocker (second rocker) advances the tibia over the stationary foot. Forward movement of the tibia over the foot is controlled by the eccentric contraction of the soleus assisted by the gastrocnemius.

During this phase, the ankle moves from its LR position of 10 degrees of plantar flexion to approximately 5 degrees of dorsiflexion. The knee extends from 15 degrees of flexion to a neutral position. The hip joint moves toward extension, from 30 to 10 degrees of flexion. With continued forward progression, the body weight vector moves anterior to the ankle, creating a dorsiflexion moment. Eccentric action of the plantar flexors is crucial in providing limb stability as contralateral toe-off occurs, transferring body weight onto the stance foot. By the end of MSt, the body weight vector moves anterior to the knee (creating passive extensor stability at the knee) and posterior to the hip (reducing the demand on the hip extensors). The gluteus maximus, active in early MSt, ceases its activity and now stability relies on passive structures as the hip nears vertical alignment over the femur. Vertical GRF is reduced in magnitude at MSt because of the upward momentum of the contralateral swing limb. In the coronal plane, activity of hip abductors during MSt is essential to provide lateral hip stability and almost a level pelvis.

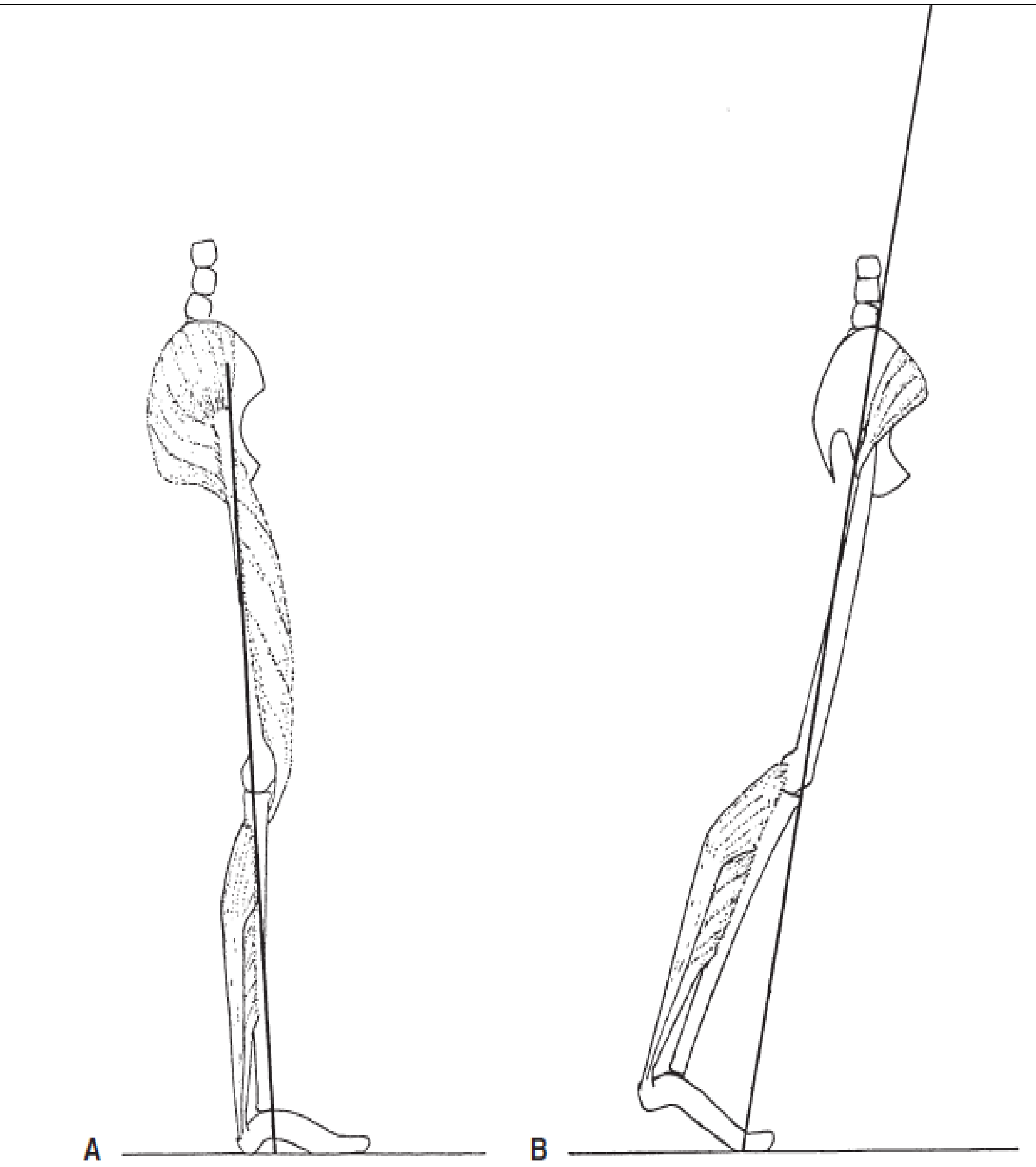

Figure 3: The subphases of gait involved in the functional task of single limb support are MSt and TSt. A, In early MSt, the vertical force begins to decrease and the triceps surae, quadriceps, and gluteus medius and maximus are active. B, During TSt, there is a second peak in vertical force, exceeding body weight, with high activity of the triceps surae, which maintain the third rocker. The tensor fascia lata restrains the increasing posterior hip vector. MSt, Midstance; TSt, terminal stance.

Terminal Stance:-

TSt, the second half of single limb support, begins with heel rise of the stance limb and ends when the contralateral foot makes contact with the ground. As the body vector approaches the metatarsophalangeal joint, the heel rises and the phalanx dorsiflexes (extends). The metatarsal heads serve as an axis of rotation for body weight advancement (see Figure 5-3B). This is referred to as the forefoot or toe rocker (third rocker). The forefoot rocker serves as an axis around which progression of the body vector advances beyond the area of foot support, creating the highest demand on calf muscles (gastrocnemius and soleus). During TSt, the ankle continues to dorsiflex to 10 degrees. The knee is fully extended, and the hip moves into slight hyperextension. Forward fall of the body moves the vector further anterior to the ankle, creating a large dorsiflexion moment. Stability of the tibia on the ankle is provided by the eccentric action of the gastrocsoleus muscles.

The trailing posture of the limb and the presence of the vector anterior to the knee and posterior to the hip provide passive stability at hip and knee joints. The tensor fascia lata serves to restrain the posterior vector at the hip. At the end of TSt, the vertical GRF reaches a second peak greater than body weight, similar to that which occurred at the end of LR.

Functional Task 3: Limb Advancement

Four phases contribute to limb advancement: PSw, ISw, MSw, and TSw. During these phases the stance limb leaves the ground, advances forward, and prepares for the next IC.

Pre-swing

PSw, the second period of double limb support in gait, comprises the last 10% of the stance phase. It begins when the contralateral foot makes contact with the ground and ends with ipsilateral toe-off. During this period, the stance limb is unloaded and body weight is transferred onto the contralateral limb (Figure 5-4). The ankle moves rapidly from its TSt dorsiflexion into 20 degrees of plantar flexion. During this subphase, plantar flexor muscle activity decreases as the limb is unloaded. Toward the end of PSw, the vertical force is diminished such that plantar flexors rapidly decrease their activity to complete quiescence. There is no active muscle contraction for “push off ” in normal reciprocal free walk bipedal gait.6 The knee also flexes rapidly to achieve 35 to 40 degrees of flexion by the end of PSw. The GRF vector is at the metatarsophalangeal joints and posterior to the knee, creating passive knee flexion with toe clearance. Knee flexion during this phase prepares the limb for toe clearance in the swing phase. PSw hip flexion is initiated by the rectus femoris and the adductor longus, which also decelerates the passive abduction created by contralateral body weight transfer. The sagittal vector extends through the hip as the hip returns to a neutral position.

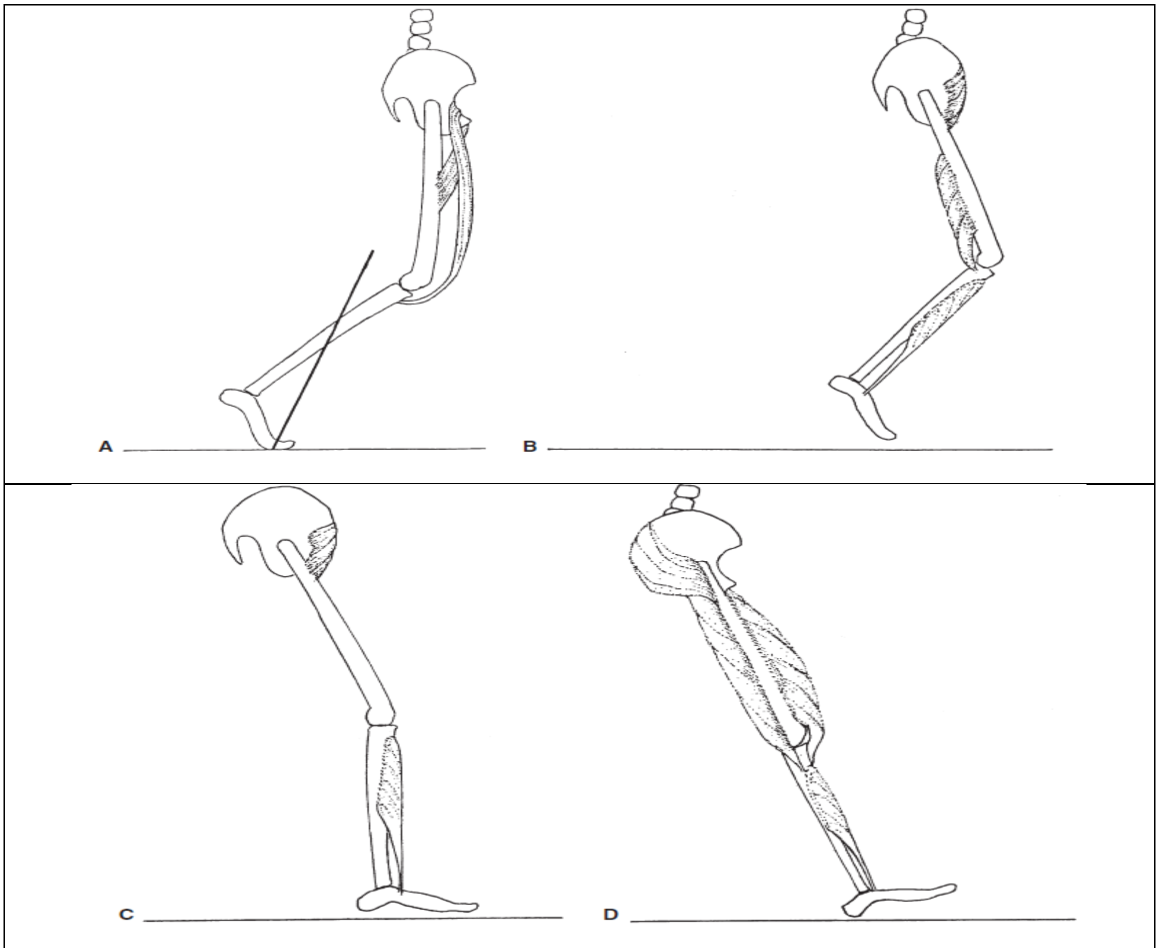

Figure 5: The subphases of gait involved in the functional task of swing limb advancement include preswing (PSw), initial swing (ISw), midswing (MSw), and terminal swing (TSw). A, During PSw, contralateral loading results in limited muscle activity in the limb transitioning from stance to swing. The rectus femoris and adductor longus initiate hip flexion. Knee flexion is passive, resulting from the planted forefoot and mobile proximal segments. B, During ISw, the pretibial muscles, short head of the biceps femoris, and iliacus are active in initiating limb advancement and providing swing clearance. C, A vertical tibia signals the end of the period of MSw. Here contraction of the iliacus preserves hip flexion while pretibial muscle activity maintains foot clearance. D, At TSw, the gluteus maximus, hamstrings, quadriceps, and pretibial muscles are active to prepare for limb placement and the ensuing loading response.

Initial Swing

Approximately one third of the swing period is spent in ISw. It begins the moment the foot leaves the ground and continues until maximal knee flexion (60 degrees) occurs, when the swinging extremity is directly under the body (see Figure 4 B). Concentric contraction of pretibial muscles initiates foot dorsiflexion from its initial 20 degrees to 5 degrees of plantar flexion. This is necessary for toe and foot clearance as swing phase begins. Knee flexion, resulting from action of the short head of the biceps femoris, also assists in toe clearance. The knee continues to flex until it reaches a position of 60 degrees of flexion. Contraction of the iliacus advances the hip to 20 degrees of flexion. Contraction of the gracilis and sartorius muscles during this phase assists hip and knee flexion.

Mid-swing

During MSw, limb advancement and foot clearance continue. MSw begins at maximum knee flexion and ends when the tibia is vertical. Knee extension, coupled with ankle dorsiflexion, contributes to foot clearance while advancing the tibia (see Figure 4C). Continued concentric activity of pretibial muscles ensures foot clearance and moves the foot toward the neutral position. Momentum creates an extension moment, advancing the lower leg toward extension from 60 degrees to 30 degrees of flexion, with the quadriceps quiescent. Mild contraction of hip flexors continues to preserve the hip flexion position.

Terminal Swing

In the final phase, TSw, the knee extends fully in preparation for heel contact (see Figure 4 D). Eccentric contraction of the hamstrings and gluteus maximus decelerates the thigh and restrains further hip flexion. Activity of the pretibial muscles maintains the ankle at neutral to prepare for heel contact. In the second half of TSw, the rectus femoris is quiescent but the rest of the quadriceps vasti become active to facilitate full knee extension. Hip flexion remains at 30 degrees.