Walking mechanism/ Gait cycle

WALKING MECHANISM

POSTURE AND GAIT

The lower limbs function primarily in standing and walking. Typically the actions of lower limb muscles are described as if the muscle were acting in isolation, which rarely occurs.

In this book, including the comments in the tables, the role of each muscle (or of the functional group of which it is a member) is described in typical activities, especially standing and walking. It is important to be familiar with lower limb movements and concentric and eccentric contractions of muscles, as described in the Introduction (p. 29), and to have a basic understanding of the processes of standing and walking.

Standing at Ease

When a person is standing at ease with the feet slightly apart and rotated laterally so the toes point outward, only a few of the back and lower limb muscles are active (Fig. 5.19). The mechanical arrangement of the joints and muscles are such that a minimum of muscular activity is required to keep from falling. In the stand-easy position, the hip and knee joints are extended and are in their most stable positions (maximal contact of articular surfaces for weight transfer, with supporting ligaments taut).

The ankle joint is less stable than the hip and knee joints, and the line of gravity falls between the two limbs, just anterior to the axis of rotation of the ankle joints. Consequently, a tendency to fall forward (*forward sway*) must be countered periodically by bilateral contraction of the calf muscles (plantarflexion). The spread or splay of the feet increases lateral stability. However, when *lateral sway* occurs, it is countered by the hip abductors (acting through the iliotibial tract). The fibular collateral ligament of the knee joint and the evertor muscles of one side act with the thigh adductors, tibial collateral ligament, and invertor muscles of the contralateral side.

Walking: The Gait Cycle

Locomotion is a complex function. The movements of the lower limbs during walking on a level surface may be divided into alternating swing and stance phases, illustrated in Figure 5.20 and described in Table 5.2. The **gait cycle** consists of one cycle of swing and stance by one limb. The **stance phase** begins with a **heel strike** (Fig. 5.20A), when the heel strikes the ground and begins to assume the body's full weight (loading response), and ends with a *push off* by the forefoot (Fig 5.20G)—a result of plantarflexion. (See the blue box "Absence of Plantarflexion," p. 607).

The **swing phase** begins after push off when the toes leave the ground and ends when the heel strikes the ground. The swing phase occupies approximately 40% of the walking cycle and the stance phase, 60%. The stance phase of walking is longer than the swing phase because

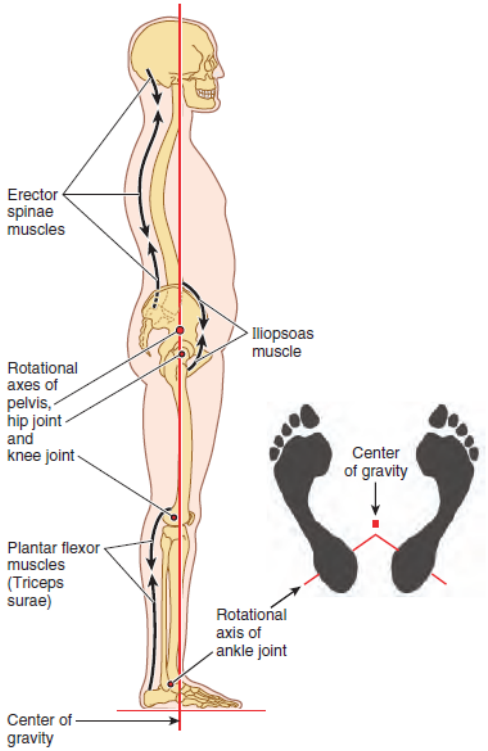

FIGURE 5.19. Relaxed standing. A. The relationship of the line of gravity to the transverse rotational axes of the pelvis and lower limb in the relaxed standing (stand-easy) position is demonstrated. Only minor postural adjustments, mainly by the extensors of the back and the plantarflexors of the ankle, are necessary to maintain this position because the ligaments of the hip and knee are being tightly stretched to provide passive support. **B.** A bipedal platform is formed by the feet during relaxed standing. The weight of the body is symmetrically distributed around the center of gravity, which falls in the posterior third of a median plane between the slightly parted and laterally rotated feet, anterior to the rotational axes of the ankle joints.

it begins and ends with relatively short periods (each 10% of the cycle) of double support (both feet are contacting the ground) as the weight is transferred from one side to the other, with a more extended period of single support (only one foot on the ground bearing all body weight) in between as the contralateral limb swings forward. In **running**, there is no period of double support; consequently, the time and percentage of the gait cycle represented by the stance phase are reduced.

Walking is a remarkably efficient activity, taking advantage of gravity and momentum so that a minimum

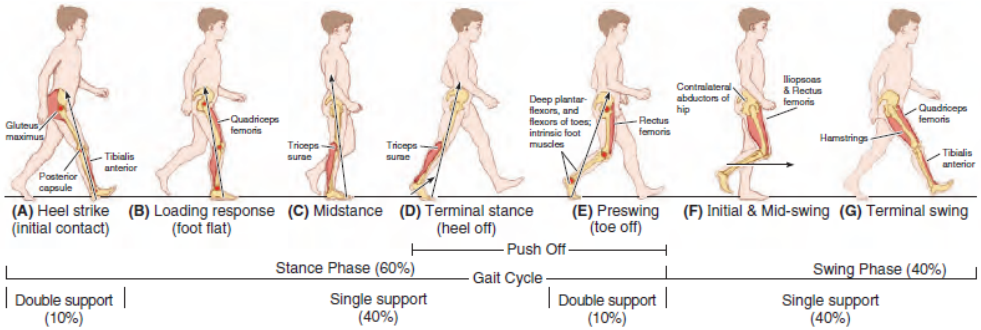

FIGURE 5.20. Gait cycle. The activity of one limb between two repeated events of walking. Eight phases are typically described, two of which have been combined in (**F**) for simplification.

TABLE 5.2. MUSCLE ACTION DURING GAIT CYCLE

	Phase of Gait	Mechanical Goals	Active Muscle Groups	Examples
STANCE PHASE	**Heel strike** (initial contact)	**Lower forefoot to ground**	Ankle dorsiflexors (eccentric contraction)	**Tibialis anterior**
		Continue deceleration (reverse forward swing)	Hip extensors	Gluteus maximus
		Preserve longitudinal arch of foot	Intrinsic muscles of foot	Flexor digitorum brevis
			Long tendons of foot	Tibialis anterior
	Loading response (flat foot)	**Accept weight**	Knee extensors	**Quadriceps**
		Decelerate mass (slow dorsiflexion)	Ankle plantarflexors	Triceps surae (soleus and gastrocnemius)
		Stabilize pelvis	Hip abductors	**Gluteus medius and minimus; tensor fasciae latae**
		Preserve longitudinal arch of foot	Intrinsic muscles of foot	Flexor digitorum brevis
			Long tendons of foot	Tibialis posterior; long flexors of digits
	Midstance	Stabilize knee	Knee extensors	Quadriceps
		Control dorsiflexion (preserve momentum)	Ankle plantarflexors (eccentric contraction)	Triceps surae (soleus and gastrocnemius)
		Stabilize pelvis	Hip abductors	**Gluteus medius and minimus; tensor fasciae latae**
		Preserve longitudinal arch of foot	Intrinsic muscles of foot	Flexor digitorum brevis
			Long tendons of foot	Tibialis posterior; long flexors of digits
	Terminal stance (heel off)	**Accelerate mass**	Ankle plantarflexors (concentric contraction)	**Triceps surae (soleus and gastrocnemius)**
		Stabilize pelvis	Hip abductors	**Gluteus medius and minimus; tensor fasciae latae**
		Preserve arches of foot; fix forefoot	Intrinsic muscles of foot	Adductor hallucis
			Long tendons of foot	Tibialis posterior; long flexors of digits

TABLE 5.2. MUSCLE ACTION DURING GAIT CYCLE (Continued)

	Phase of Gait	Mechanical Goals	Active Muscle Groups	Examples
STANCE PHASE (cont'd.)	**Preswing** (toe off)	Accelerate mass	Long flexors of digits	Flexor hallucis longus; flexor digitorum longus
		Preserve arches of foot; fix forefoot	Intrinsic muscles of foot	Adductor hallucis
			Long tendons of foot	Tibialis posterior; long flexors of digits
		Decelerate thigh; prepare for swing	Flexor of hip (eccentric contraction)	Iliopsoas; rectus femoris
SWING PHASE	**Initial swing**	**Accelerate thigh; vary cadence**	**Flexor of hip (concentric contraction)**	**Iliopsoas; rectus femoris**
		Clear foot	**Ankle dorsiflexors**	**Tibialis anterior**
	Midswing	**Clear foot**	**Ankle dorsiflexors**	**Tibialis anterior**
	Terminal swing	Decelerate thigh	Hip extensors (eccentric contraction)	Gluteus maximus; hamstrings
		Decelerate leg	Knee flexors (eccentric contraction)	Hamstrings
		Position foot	**Ankle dorsiflexors**	Tibialis anterior
		Extend knee to place foot (control stride); prepare for contact	**Knee extensors**	Quadriceps

of physical exertion is required. Most energy is used (1) in the eccentric contraction of the dorsiflexors during the beginning (**loading response**) phase of stance (Fig. 5.20B) as the heel is lowered to the ground following heel strike, and (2) especially at the end of stance (**terminal stance;** Fig. 5.20D) as the plantarflexors concentrically contract, pushing the forefoot (metatarsals and phalanges) down to produce push off, thus providing most of the propulsive force.

During the last part of the stance phase (**push off** or *toe off;* Fig. 5.20E), the toes flex to grip the ground and augment the push off initiated from the ball of the foot (sole underlying the heads of the medial two metatarsals). The long flexors and intrinsic muscles of the foot stabilize the forefoot and toes so that the effect of plantarflexion at the ankle and flexion of the toes is maximized.

The swing phase also involves flexion of the hip so that the free limb accelerates faster than the forward movement of the body. During **initial swing** (Fig. 5.20F), the knee flexes almost simultaneously, owing to momentum (without expenditure of energy), followed by dorsiflexion (lifting the forefoot up) at the ankle joint. The latter two movements have the effect of shortening the free limb so that it will clear the ground as it swings forward. By **midswing,** knee extension is added to the flexion and momentum of the thigh to realize anterior swing fully.

The extensors of the hip and flexors of the knee contract eccentrically at the end of swing phase (**terminal swing;** Fig. 5.20G) to decelerate the forward movement, while extensors of the knee (quadriceps) contract as necessary to extend the leg for the desired length of stride and to position the foot (present the heel) for heel strike.

Contraction of the knee extensors is maintained through the heel strike into the loading phase to absorb shock and keep the knee from buckling until it reaches full extension. Because the unsupported side of the hip tends to drop during the swing phase (which would negate the effect of limb shortening), abductor muscles on the supported side contract strongly during the single support part of the stance phase (Fig. 5.20F & G), pulling on the fixed femur to resist the tilting and keep the pelvis level. The same muscles also rotate (advance) the contralateral side of the pelvis forward, concurrent with the swing of its free limb.

Of course, all these actions alternate from side to side with each step. The extensors of the hip normally make only minor contributions to level walking. Primarily, the hip is passively extended by momentum during stance, except when accelerating or walking fast, and becomes increasingly active with increase in slope (steepness) during walking uphill or up stairs. Concentric hip flexion and knee extension are used during the swing phase of level walking and so are not weight-bearing actions; however, they are affected by body weight when their eccentric contraction is necessary for deceleration or walking downhill or down stairs.

Stabilization and resilience are important during locomotion. The invertors and evertors of the foot are principal stabilizers of the foot during the stance phase. Their long tendons, plus those of the flexors of the digits, also help support the arches of the foot during the stance phase, assisting the intrinsic muscles of the sole.