21. Lower back pain as a gait-related repetitive motion injury

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INTRODUCTION

It has been known for some time that patients who injure their lower backs are often an 'accident waiting to happen'. Some types of repetitious stress act on the lumbosacral spine over a significant time, which results in an inherent fragility of one or more of its structural components. Once substantial change has occurred, an apparently inconsequential movement can then trigger an incapacitating event.

Walking is an activity of daily living. Assuming only 80 min per day of weight-bearing performance, an average adult will repeat 2500 stance/swing cycles per limb. That equates to almost 1 000 000 steps per limb per year. By the age of 30, this number approaches 30 000 000 cycles. If the subject has a walking or standing job and/or participates in an exercise program, this number can easily double or triple. Should this gait practice be only slightly askew, the day-to-day cumulative effect is disguised by its subtle nature yet can be a hidden source that creates and/or perpetuates a pattern of chronic lumbosacral pain.

In the course of any particular step, many significant actions are interdependent, since the anatomy of the lumbosacral spine, upper torso, and lower extremity are all woven together. Muscle, tendon, ligament, and capsular components directly connect the medial column of the foot to the sacrum and lumbar spine (Vleeming et al 1995). While proper use creates a remarkable intrinsic stability, restrictions of motion at the foot level can adversely affect lumbosacral self-bracing and locking. Since this type of restriction is most often asymptomatic at the foot, there is rarely an association made between it and more proximal postural complaints. These mechanically inefficient motions, however, gradually create an environment for neurogenic hypersensitivity, myogenic overuse, and degenerative joint disease as the rotations necessary for secure support reverse themselves. For example, nutation of the sacrum, which is required for self-bracing of the sacroiliac joint (SIJ) during gait, demands that the biceps femoris, via its connection with the sacrotuberous ligament, relaxes during the midstance portion of the step as the pelvis rotates anteriorly. This is permitted by the ability of the weight-bearing limb adequately to extend out from under the hip joint during this point in the gait cycle. A previously described pathomechanical foot dysfunction known as functional hallux limitus has been shown to block this action (Dananberg 1986). Cyclic failure of adequate hip extension, coupled with concurrent flexion of the torso, causes a response of biceps femoris tightness, which restricts nutation and causes in its place counternutation. Self-locking, and therefore stability of the lumbosacral spine, fails to develop. Once intrinsically unstable at midstance, the ensuing motions required for walking add additional stress to this system.

In an average 70 kg adult, each lower extremity weighs approximately 15% of body weight, or 10.5 kg. At toe-off, the large iliopsoas muscles, which originate directly from the lower back, must fire to assist in the development of the swing phase of motion. Considering that this event is repeated at least 2500 times per day, the weight to be lifted equates to 26 250 kg per limb per day. Should the origin of these muscles fail to provide an adequately stable base from which to lift these limbs, cumulative stress must develop at

this site of origin. This is felt directly as lower back pain. Should the muscle group responsible for this action become hypertonic, mechanoreceptors sense this information and relay it to the CNS. The resultant spinal cord reflex gain directly lowers the pain sensor (nociceptor) threshold and can eventually cause secretion of inflammatory neuropeptides. Less and less motion creates greater perception of pain (Zimmermann 1989). Other compensatory motions then occur which assist in the limb lift process. These motions are visible as lateral trunk bends, which are created by the combination of actions of the contralateral quadratus lumborum and gluteus maximus/iliotibial band complex. These further add to the lower back pain syndrome (Dananberg 1993b).

Improper walking, as described above, causes a subtle but ever-present repetitive strain injury to the lumbosacral spine. Failure to lift each limb properly for the swing phase can essentially be seen as 'dragging the lower limbs' and is therefore a source of constant stress to the chronic lower back pain patient. Removing this deceptive origin can have a significant effect. In a previously published retrospective analysis of chronic postural pain patients considered at or near medical endpoint for long-term symptoms, 77% reported a 50–100% improvement when asymptomatic foot function was objectively addressed (Dananberg et al 1990). In a holistic approach to the back pain patient, the *application of this stress* would appear to be at least of equal consequence as the condition of the site to which it is applied. Objective gait analysis and treatment, as an addition to the physical examination and treatment of the lumbosacral spine, become an important adjunct of the therapeutic process.

This chapter will first provide a review of the process of taking a normal step. This will include a description of the generation of the power for movement as well as the actual biomechanical response to this power input. Following this, an approach to understanding the pathomechanical process is outlined. Specific pathologic movement that may lead to an overall postural decay over time along with lumbosacral stress are detailed. Markers for gait observation are also given, so that individual patients can be examined and proper treatment prescribed.

OVERVIEW OF GAIT MECHANICS

When the ancestors of our human species became bipedal millions of years ago, they needed an ambulation system that would function in a highly efficient fashion over long distances. Upright human walking is that efficient system. In order to appreciate its mechanics, some prior misconceptions must first be addressed.

It has been theorized that walking is the process in which muscles fire, creating force moments across joints, which in turn drive the weight-bearing limb to push the body forward (Inman 1981). This view cannot be supported by either logic or currently available information on muscle function. Muscles in the weight-bearing limb predominantly function eccentrically (Winter & Scott 1991). Eccentric contraction represents the resistance to motion. While this is highly efficient (1.5–6.0 times that of concentric contraction or muscle shortening) (Abbott 1952), it cannot create a pushing force. When concentric contraction finally occurs in the gastrocnemius, for example, both the knee and hip have already begun to flex forward. This would equate to the concept of pushing rope! Flexible systems cannot be effectively driven in this manner. Therefore, another model must be used to understand the mechanics of human walking.

Efficiency of the walking process

The human body can be viewed as a perpetual motion gait machine. The pendular actions of arms and legs act reciprocally, storing potential energy and returning kinetic energy in the process. These actions are visible as counter-rotations between the pelvic and shoulder girdles. Storage occurs in the ligamentous, muscular, and tendinous structures of the lower back (Dorman 1995). The cross-connections between the ipsilateral latissimus dorsi and contralateral gluteus maximus via the fascia thoracolumbocalis are ideally suited to this storage capacity. Each step prepares for the next one; the effect is to create a forward-directed rotation on the pelvic hemisphere as it coordinates with the limb that is about to begin the swing phase motion (Gracovetsky 1987).

During walking, there are periods of both single and double limb support (Fig. 21.1).

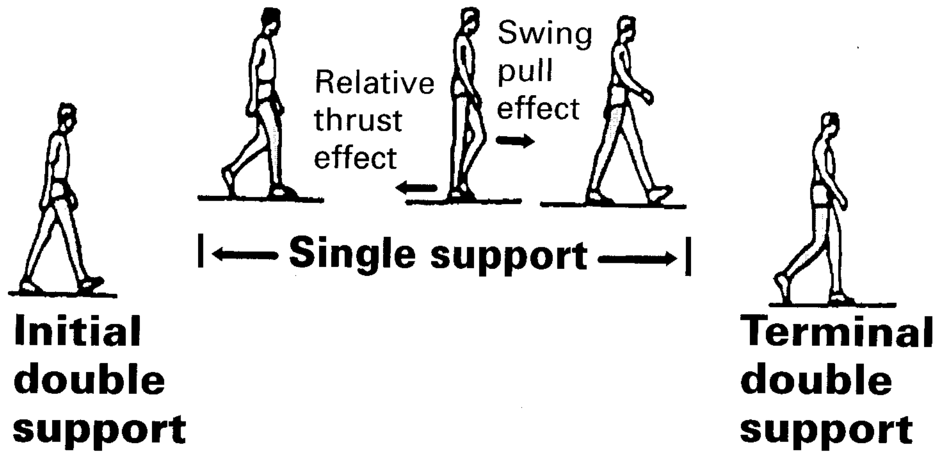


Fig. 21.1 Single and double support phases of gait.

Substantial forward motion can only occur in the approximately 400 ms of single support phase. As the weight-bearing limb supports the body, the contralateral limb acts to *pull* the center of mass forward (Claeys 1983). In essence, the free-swinging limb acts on the body and 'yanks' it over the weight-bearing side. As an analogy, imagine tying a 3 m rope between a rock and your waist. If the rock were picked up and thrown forward, a period would exist when the rope would lose its slack. Once sufficiently tightened, your body would suddenly be drawn forward towards the rock just as the rock would suddenly be halted in its forward progression. In walking, this is the action of the swing limb. It is 'thrown out' ahead of the body. As the swing limb is 'slowed' as it reaches its end range of forward motion, the center of mass is simultaneously pulled towards the forward position that the limb has attained. Gravity, continuing to act with momentum, pulls the center of mass towards the ground. Body weight, therefore, becomes the efficient prime mover (Dananberg 1993).

In order for forward motion to occur, ground contact must be present. This is the ultimate purpose of the weight-bearing limb. Through an elegant series of phasic, eccentric muscular contractions, the lower extremity is stabilized to accept the force created by the body advancing above. It can use this to create a relative 'push' or 'thrust' against the ground as the body is pulled over it. The length of the weight-bearing limb provides a mechanical advantage to the pull of the swing limb. It effectively serves as 'lever-like' structure to thrust the ground beneath the foot. Since the ground does not move, the subject advances.

Sagittal plane rotation of the load-bearing joints

It is a basic requirement in human gait for the torso and head to remain erect. For this to occur, there are two specific sites at which motion is obligatory: the hip and the foot. As the body passes over the weight-bearing foot (right limb viewed from the right side), the hip joint rotates in a clockwise direction while the foot simultaneously provides the same direction of motion. This permits the torso to remain erect as the leg and thigh extend at the hip. The foot's rotation permits advancement beyond a fixed point. Should one or the other not be present, the mechanics of walking are significantly altered (Fig. 21.2).

Rotation of the hip joint is simple to visualize. It is a ball and socket joint that permits sagittal plane extension during the single support phase. The foot, however, comprises 26 joints, which rotate in a complex yet interdependent manner. It must coordinate the effect of lower extremity internal rotation with the impact at heel strike. It must then reverse the direction of rotation by midstep, and accommodate lower extremity external

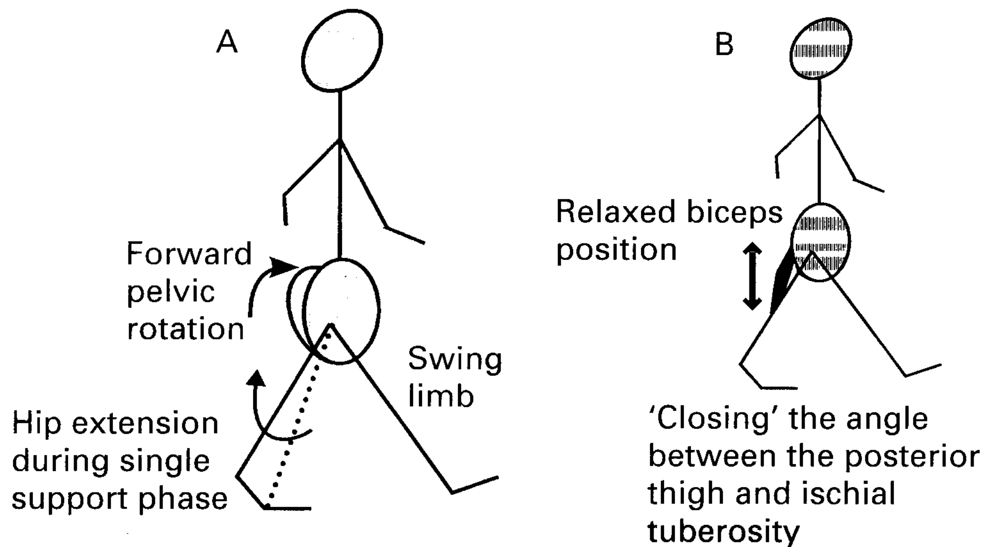


Fig. 21.2 The coordination of hip extension, forward pelvic rotation, and biceps relaxation.

rotation while simultaneously stabilizing itself to forces that can reach multiples of body weight prior to toe-off. Finally, it must maintain a portion of its structure in ground contact while permitting the entire body to pivot over it. These actions are repeated at least 2500 times per day, all within the time span of approximately 600–750 ms.

The foot as a sagittal plane pivot

The ability of the foot to permit the body to advance forward over it is a complicated action. There are three separate sites at which this pivotal response occurs (Dananberg 1995, Perry 1992). The initial location is the inferior, rounded undersurface of the calcaneus. This motion is completed following heel strike, once the forefoot touches the floor. With the heel and forefoot in contact with the ground, the ankle becomes the next site of rotation. It passively dorsiflexes as the pull of the swing limb advances the center of mass over it (Perry 1992). Dorsiflexion of the ankle is an intricate movement. The dome of the talus is shaped as a truncated pyramid, wider anteriorly than posteriorly. Therefore, as dorsiflexion occurs, the ankle joint must expand to accept the widening surface of the talar dome. This expansion is dependent on a translation motion of the fibula. It moves upward and laterally, reorienting the fibers of the syndosmosis that connect it to the tibia. Not only does this permit continued dorsiflexion, but it also appears to store energy that will be used for ankle reversal into plantar flexion later in the step. The above two actions occur in a period of less than 200 ms.

The final pivotal 'hurdle' occurs in the second half of the single support phase. This represents the peak reactive ground thrust periods during the final 200 ms of one-leg support and further coordinates with the greatest forces concurrently being applied. Since the foot must act as both a shock absorber at heel strike and then reverse to be a rigid platform for propulsion at this time, a system must be present which regulates these events sequentially and establishes a stable structure from a flexible one. While this occurs, it must continue to permit the body to advance forward directly over it. This action has been shown to be dependent on the proper function of the first metatarsophalangeal (MTP) joint, the final pivotal site. In 1954, J. H. Hicks, a British research physician, proposed such a mechanism in the Journal of Anatomy (Hicks 1954). As recently as 1995, his concepts have been proven most accurate (Thordarson 1995).

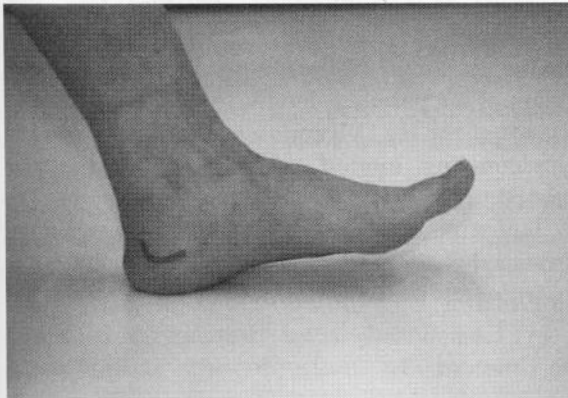
This action, known as the windlass effect, is a purely mechanical (and therefore non-muscular) response. It uses the plantar aponeurosis as a ten-

sion band, altering its tightness as required by body and foot position. The plantar aponeurosis originates from the base of the calcaneus and inserts into the base of the proximal phalanx of the great toe (as well as providing smaller fibers to the lessor digits). As the MTP joint dorsiflexes to permit heel lift, the large, drum-like shape of the first metatarsal head–sesamoid bone complex serves as a mechanically advantaged cam, tightening the aponeurosis between the heel and toes. As the aponeurosis tightens, it secondarily close-packs the calcaneal cuboid joint on the lateral column of the foot. This action precipitates a stabilization of the tarsus, midtarsus and metatarsus, because the forces that would otherwise flatten the foot are rapidly escalating as the body advances forward (Bojsen-Møller 1979). The same movement that permits the body to pivot over the planted foot simultaneously stabilizes it to the cyclically applied stresses (Fig. 21.3).

The swing phase terminates with heel strike, and the entire process reverses, the trailing limb beginning its transition to swing movement. The passage from the stance to swing represents a mechanical challenge. It requires taking the 10.5 kg limb from an 'at rest' position to a full-speed, swing motion in 100 ms. The greater the efficiency in this transformation, the less the muscular input required.

Initiating swing phase

It appears that the body uses the actual weight of the limb itself to initiate this swing motion. As the former swing limb strikes the ground, the trailing limb immediately begins the 'pre-swing' activity. 'From its *extended* position', the knee joint 'collapses' into flexion. With knee flexion, there is a concurrent flexion of the hip joint above. Below, the ankle rapidly plantar flexes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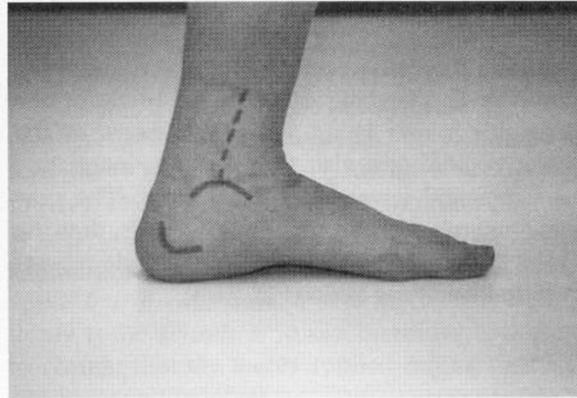
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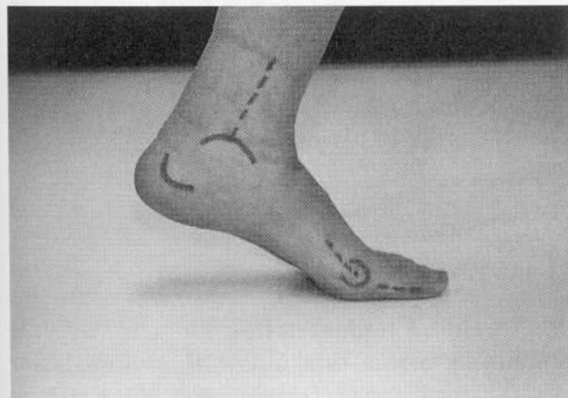
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Fig. 21.3 (A) At heel strike, the round underside of the calcaneus serves as the initial pivotal site. (B) Once foot flat is achieved, sagittal motion is now accommodated by the ankle joint via dorsiflexion. (C) At heel lift, ankle motion reverses to plantarflexion as the MTP joint provides for the balance of the required sagittal plane motion.

while the MTP joint dorsiflexes at the same rate. The thigh therefore, based on the collapsing of the support joints, begins to accelerate rapidly forward until toe-off occurs. Just prior to toe-off, the gastrocnemius provides a brief burst of concentric contraction, propelling the limb into the swing phase (Dananberg, 1993a). (Since the knee and hip are flexing at this time, it would be impossible for this gastrocnemius activity to push the center of mass directly. It would, as described above, be analogous to 'pushing rope'. Instead, it provides the final thrust from below to initiate the swing phase.)

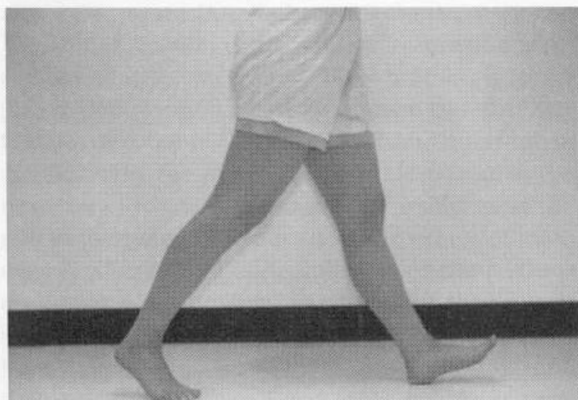
At the moment of toe-off, the now swing limb's motion is perpetuated by the hip flexors, the iliacus and psoas groups, which fire at this time. The iliacus originates from the crest of the ilium, whereas the psoas takes its origin from the lumbar spine, discs, and intervertebral septa. They insert via a common tendon to the lessor trochanter of the femur. Their action is complete by 50% of the swing phase cycle. The advancement of the swing limb coordinates with the energy return of the pelvis and shoulder girdle system (Dorman & Vleeming 1995). The pelvis of the swing side is now being propelled forward by the 'spinal engine' (see also Chapter 20), integrating the upper and lower body interactions. The now swinging limb pulls on the center of mass, drawing it over the weight-bearing limb as the cycle repeats itself time and time again (Fig. 21.4).

Changing from stance to swing: the pelvis–SIJ interaction

In order for the lower extremity and pelvic girdle to act in a synchronous fashion as rotations change directions rapidly, the SIJ acts as an intermediary, or 'clutch', permitting the transference of forces from the stance to the swing limb (Dorman & Vleeming 1995). For the clutch to close and create 'self-locking', the sacrum must undergo a forward rotation known as nutation. It is this motion which permits both a form and force closure of the SIJ and is critical in proper function.

The sacrum is interconnected to the lower extremity through a series of anatomic structures. The sacrotuberous ligament, originating from the coccygeal vertebrae, the SIJ capsule, and the posterior iliac spines, runs distally to the attachment of the biceps femoris on the ischial tuberosity. It has been shown that the biceps/sacrotuberous ligament is a continuous structure (see also Chapter 3). The distal connection of the biceps is to the proximal tibia, fibula, and fibers of the origin of the peroneus longus muscle on the lateral aspect of the leg (Vleeming et al 1995). Through this coupling, motion of the sacrum is integrally related to the function of the lower extremity.

Thurston and Harris (1983) have demonstrated that the sagittal plane motion of the pelvis coordinates with the motion of the swing limb.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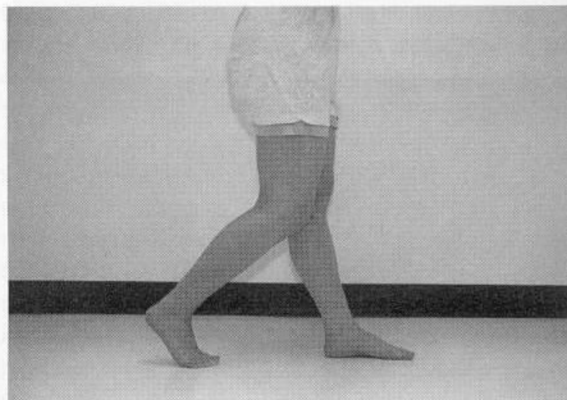
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Fig. 21.4 (A) At the end of single support phase, the trailing limb reaches the peak amount of extension at the hip joint. The knee is fully extended and the foot has lifted off the support surface via motion at the MTP joints.

The pelvis is most posteriorly tilted just prior to toe-off, and is most anteriorly tilted just prior to heel strike. Sagittal plane motion of the pelvis during swing phase is therefore from posterior to anterior, or forwardly directed. This motion would directly coordinate with sacral nutation, which is a forward tilting of the sacrum and synonymous with SIJ self-locking (see Fig. 21.2).

Synchronizing the lower extremity and the pelvis

The synchronicity of motion of the lower extremity and the lumbosacral spine are essential for normal function. As any step occurs, the weight-bearing thigh will progressively extend at the hip joint until this motion terminates with opposite limb heel strike. With this extension motion, the angle between the posterior leg and the ischial tuberosity 'closes', thus keeping the biceps femoris in a relaxed position relative to its origin and insertion. This coordination of biceps relaxation and posterior-to-anterior pelvic motion is fundamental in maintaining the appropriate relationship between the pelvis and sacrum. Should the biceps fire prematurely, the forward rotation of the pelvis would be resisted. This would result in an inability to reach the necessary position required as single support terminates with the impact of the next heel strike.

Just prior to opposite limb heel strike, the biceps femoris becomes active (Basmajian 1974), which affects the direction of motion of the pelvis. Once heel strike occurs, the pelvis rapidly reverses its motion and moves from anterior to posterior (Lee 1995). Motion at this time is critical as the impact loads from heel strike must be either attenuated and/or stored as potential energy for use later in the step. The long dorsal ligament of the SIJ comes into significance at this time. As the pelvic rotation is reversed at this time, the ligament gradually becomes taut as the sacrum counternutates with posterior pelvic rotation. Failure to reach the full forward rotated position would mean that the available range of pelvic motion at heel strike would be lost. It would also create a situation in which the long dorsal ligament would be tightened prematurely, thus preventing its gradual loading during the impact period. As double support phase completes and a new swing phase begins, the cycle of pelvic rhythm repeats again.

In summary, during normal function walking is a perpetual motion process. The active pull of the swing side provides a passive thrusting in the stance side against the ground. Pivotal motion of the hip and foot allow for the proper utilization of this power. Coordination of movement permits stabilization of the entire lower extremity/lumbosacral structure ideally suited for maximum efficiency. Cycles of stance and swing are repeated at least 2500 times per limb per day.

PATHOMECHANICAL PROCESS OF SAGITTAL PLANE BLOCKADE

Sagittal plane motion of the foot during the single support phase is critical to normal ambulation. It appears to coordinate both forward advancement with close-packing stabilization. A failure within this process would be repeated more than a million times a year. Wolfe, in the late nineteenth century proposed the axiom 'Form follows function'. This was shown to have validity by D'Arcy Thompson early in the twentieth century. It is now considered to be an absolute in understanding the reaction of the body to the stress applied to it over time. For a model of postural decay to be sound, it would therefore be logical to require that the forces applied during function would create the resultant form. It is the intent of this next section to demonstrate how failure of the sagittal plane pivotal action of the foot results in a cyclic breakdown in maintaining an erect posture and actually causes flexion deformity via a compensatory process.

The three sites of pivotal function at the foot were described earlier. The round, underside of the calcaneus, with essentially 'no moving parts', rarely fails to provide its initial pivotal action. The ankle and first MTP joints, however, are complex in their movements and, either singly or combined, can act to block normal progression.

Ankle equinus, or failure to achieve 10° of dorsiflexion while loaded, is a common pathomechanical entity. It has been shown to be an