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Evidence-Based Treatment of Hip and Pelvic Injuries in Runners

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All too often, the runner who presents with pain or dysfunction in the hip or pelvis is approached from a one-joint or soft tissue injury concept. Because most injuries in this region are related to overuse, and, in particular, microtraumatic overload injury, a functional biomechanical approach is necessary to identify significant muscle imbalances and joint dysfunctions. A thorough understanding of the relationship between the lumbar spine, pelvis, hip, and thigh, and their relationship to the functional kinetic chain (including areas well-above and below the hip and pelvis) is key to evaluation and treatment. Using this concept, the long-term results of our treatment and the prevention of reinjury in runners will be more successful.

Approximately 5% to 21% of all athletic injuries involve the hip and pelvis [1,2]. In one study, overuse accounted for 82.4% of the injuries to the hip and pelvis that presented to a general sports medicine clinic [1]. Another investigator cited that 25% to 70% of runners sustain overuse injuries during any 1-year period [3]. Regardless of the level of athletic competition—recreational, high school, college, or professional—overuse injuries to the hip and pelvis region are equally common.

The exact causes of overuse running injuries have yet to be determined. The etiology of these injuries seems to be multifactorial and diverse in nature [4–6]. As an example, one of the most common and overlooked injuries in runners is gluteus medius tendinosis. Often, this is associated with a rigid supinated foot and a tight gastroc-soleus that does not allow

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calcaneal eversion and subsequent subtalar joint pronation. The functional kinetic chain is inhibited in internal rotation at the tibia and femur, which results in reduced stimuli to the gluteus medius muscle. The runner makes compensations in his running pattern until it is no longer possible, and finally, seeks medical attention. This emphasizes the importance of the functional kinetic chain, particularly the foot and ankle, to hip function [7].

This article does not focus on isolated stretching at the hip and pelvis as a means of prevention of injuries in runners. In fact, the focus is on exercises that simultaneously stretch and strengthen, to provide three-dimensional strengthening and flexibility. Isolated syndromes also are not addressed because the authors do not believe that these describe adequately the complex functional kinetic chain relationships that lead to pain in the hip and pelvis. Instead, the focus is on identifying the functional biomechanical deficits that lead to running-related hip and pelvis pain.

Functional anatomy and biomechanics

Although the functional anatomy and biomechanics of running have been discussed previously, a brief review of the hip and pelvis area is provided here. The important link between the pelvis, trunk, and lower extremities is emphasized. The bone architecture of the hip joint shows primary compression and tension trabeculae of the femur that carry on through the pelvis, iliac crest, and lumbar spine. This trabecular pattern allows the hip to handle peak focal pressures of approximately 3000 pounds per square inch, which occur from sitting to standing. The multiaxial ball and socket joint of the hip has three degrees of freedom, whereas stability is provided through the acetabular triangular fibrocartilage which adds more congruency to the articular surfaces. The attachments of muscles, fascia, and ligaments in this region help one to appreciate the relationship between the lumbar spine, pelvis, hip, and thigh. The intrinsic ligaments of the hip (the iliofemoral, ischiofemoral, and pubofemoral) reinforce its strong joint capsule. The femoral, obturator, and sciatic nerves contribute to the vast innervation of the hip region.

The biomechanics of the neck-shaft angle of 120° to 130° along with an average of 14° of anteversion allow for angular movements of the thigh to be converted to rotatory (transverse plane) hip motion. At 30° of flexion and abduction, the hip joint is considered to be in the resting position. Hip joint pathology causes a capsular pattern of loss with hip flexion and internal rotation lost more than hip abduction. In general, the capsular pattern of any joint is a loss of motion in a characteristic pattern that indicates a tight joint capsule or intra-articular pathology, such as osteoarthritis. In the hip, full extension with internal rotation and abduction of the hip joint is considered the close-packed position. The close-packed position in any joint represents a position where the least amount of motion occurs as a result of ligamentous, capsular, and muscle tightness.

The pelvis is divided into three joints: the two sacroiliac joints, and symphysis pubis. The sacroiliac joint is an atypical synovial joint, and, in most cases, is patent throughout life [8]. Fusion can occur by synostosis or fibrosis. The ridges and depressions of this joint clearly are visible at the macroscopic level and are less pronounced in women [9]. The ligamentous relationship is a reminder of the connection between the lumbar spine, pelvis, hip, and thigh regions. The iliolumbar ligaments link L5 vertebral segment and, at times, L4, to the pelvis. The weaker anterior sacroiliac joint ligaments are thinner than their posterior counterparts and form an inferior sling under the sacroiliac joints. The multilevel short and stronger posterior ligaments and the long sacrotuberous and sacrospinous ligaments provide stability across the sacroiliac joint. The innervation of the sacroiliac joint is considerably vast (ie, from L2 through S2 levels); however, the main nerve supply, particularly of the posterior aspect of the joint, is received from L5, S1, and S2 dorsal rami.

Some of the important muscular relationships include the abdominals and adductors. Balance between these two muscle groups is essential, because the adductors attach from below to the pubic rami and the abdominals from above. Muscle imbalances—in which certain muscle groups become tight and others become inhibited and weak—occur frequently [10]. The tendency for the adductors to become tight and the lower abdominals to become inhibited and weak is an excellent example of a common muscle imbalance about the hip girdle.

One should consider that the pelvis and the sacroiliac joints serve as a functional link through which loads are transmitted from the lower extremities to the spine, and vice versa. The sacrotuberous ligaments are an important link in the kinetic chain between the lower extremities, pelvis, and lumbar spine [8,11–13]. The gluteus maximus attached to this ligament in all specimens studied and, in some cases, so did the piriformis and long head of the biceps [8]. In the anterior pelvis, the symphysis pubis has a superior to inferior translatory movement that may become dysfunctional secondary to imbalances of the adductors and lower abdominals. Anatomic and biomechanical research studies document sacroiliac joint motion throughout life [14,15]. The sacroiliac motion averages 2.5°, with a range of 0.8° to 3.9°. Translation averages 0.7 mm, with a range from 0.1 mm to 1.6 mm. An increase in sacroiliac joint motion by 25% is seen under relaxin influence, such as with pregnancy. Dysfunctions of the pelvis often are associated with hip, buttock, and groin pain syndromes.

Causes of overuse injuries in runners can be divided into three general categories [3]. The first category—training errors—include improper running shoes, excessive running distance or intensity, and a rapid increase in weekly running distances or intensity. The authors also include inadequate lower extremity weight training, especially in runners who are older than 30 years of age. Runners who continue to run regularly will lose approximately 30% strength (0.7% per year) if they do not properly train with weights. All too often, runners make the mistake of believing that they are strengthening their lower extremities with running, and therefore, only engage in upper body weight training. This is a grave mistake that has led many runners to frequent injuries. It is the authors' contention that the focus of a runner's cross-training routine should consist of strengthening and dynamic stretching, rather than a traditional prerun static stretching regimen.. Runners who stretch regularly before running have a higher injury rate than those who do not stretch [16].

Anatomic considerations are the second category. These include a high longitudinal arch (pes cavus), dysfunction in range of motion of ankle dorsiflexion or plantar flexion, tibia varum, rear foot varus, and leg length discrepancies. A flat foot (pes planus) also may be a risk factor.

The final category of biomechanical considerations includes kinetic variables, in particular, magnitude of impact forces, rate of impact loading, and active (push-off) forces. Rear foot kinematic variables include the magnitude and rate of foot pronation (calcaneal eversion). Although pronation is a needed physiologic factor to dampen ground reaction forces, uncontrolled pronation may be a factor that induces running injuries. Hreljac [3] looked at anatomic and biomechanical factors that are associated with running injury. These included height, weight, longitudinal arch height, footprint index, hamstring and ankle flexibility, and other biomechanical characteristics. The two most important characteristics in the group of runners that ran for 10 years injury-free were a decreased maximal vertical loading rate and a moderate rate of rear foot pronation. This is a clear indication that functional kinetic changes at the foot and ankle impact the injury rates on the whole functional kinetic chain in runners.

Functional evaluation

Efficient running requires that momentum of the body is maintained in a sagittal direction with minimal vertical displacement of the center of mass and with minimal deflection of the body into the frontal and transverse planes. This requires a sufficient level of spinal stability to offset the powerful loads that are placed on the spine by the propulsive force that is generated by the hip and pelvic muscles [17]. Function of these core muscles is enhanced by the coordination of the joints and muscles of the lower extremity and pelvis and by concomitant linked motions that occur in the shoulder girdle. This biomechanical linkage of the leg, core, and upper quarter has been described in terms of pronation (eccentric loading) and supination (concentric contraction) by Gray [18]. Eccentric loading is crucial for activating peripheral afferents that modify the centrally generated pattern of locomotion. Eccentric loading further provides the potential energy that is required to produce efficient concentric muscle contraction [19]. The motions of supination and pronation occur in three planes at each joint (see the article elsewhere in this issue on the biomechanics of running).

Gray and Tiberio also described a second phase of pronation in stance when the foot is supinated and behind the body that eccentrically loads the muscles of the hip and calf to facilitate the swing phase of gait.

With jogging, the ability to control pronation is crucial because the hip joint incurs contact forces of up to five times body weight [20]. The muscles and joints that make up the hip and pelvis play a key role in attenuating and transmitting this tremendous force during running. To that end, the body is designed with a massive bony pelvis and large powerful hip girdle musculature to attenuate force loads. Because of their short lever arms, hip muscles must generate greater forces to maintain hip stability during impact and throughout stance. This predisposes this region to soft tissue injury and potentially injurious intra-articular loads [21].

An orthopedic examination is useful for identifying the tissues that are affected by the potential mechanical overload of running. A regional orthopedic examination is unable to identify the mechanical limitations in the kinetic chain that may have predisposed the hip to injury, however [22]. Furthermore, the regional examination is unable to predict who is at risk for a running injury before participation, nor is it able to identify specific modifications that may help to rehabilitate or enhance a runner's performance [23]. To evaluate and treat the runner, or any athlete, it is necessary to apply loads in a way that parallel the specific demands of the activity. Ideally, the examiner should be able to identify by observation and, in some cases, by measurement, the specific joints and planes of motion that place the hip in jeopardy when running. Testing should establish biomechanical deficits, such as abnormal muscle function or poor mechanics of the hip. Seven functional tests that are used by the authors' clinicians who evaluate hip function as part of a linked kinetic chain are described.

Functional examination

1. Observation:
    a. Static alignment of the lower extremity: Static alignment is suggestive but does not reveal how the pelvis, hip, knee, ankle, and foot interact in response to body weight and ground reaction force [24]. Williams and coworkers [25] noted that stiff-arched runners demonstrated increased loading rates which may predispose them to injury.
    b. Running: Whenever practical, the clinician should watch the patient run. Compensatory strategies that are a source of overload might be seen at this time. Observation should be made regarding length of stride. Impact forces and vertical displacement increase with stride length [26]. A shortened stride may be related to a proximal or distal sagittal blockade at any of the joints of the lower extremity. The amount of trunk motion in all three planes relative to the pelvis is a key observation. Insufficient or excessive motion in a specific plane

about the trunk may suggest difficulty or inability to load the abdominals eccentrically to stabilize the pelvis.

2. Unilateral squat (Fig. 1): The pronation phase of a single leg squat mimics, to some extent, the key events of the loading phase of running and walking. Special attention is paid to how the patient controls eccentric loading of the muscles of the hip and pelvis. Important events to observe by plane of motion:

   a. Sagittal plane (SP): Excessive forward bending of the trunk relative to the amount of knee flexion is suggestive of quadriceps and gluteus maximus weakness or an overreliance on the hamstrings to decelerate anterior tilting of the pelvis and forward momentum of the trunk. This may result in a forward sway of the trunk in the initial stages of propulsion.
   b. Frontal plane (FP): A Trendelenburg sign (frontal plane lurch) may be elicited with a single leg squat. This usually indicates gluteus medius and minimus weakness.
   c. Transverse plane (TP): Rotation to the same side leg, to stabilize the hip over the femur, suggests weakness in the gluteus maximus in this plane of motion.
   d. Special attention should be given to excursion (range of motion) and control of subtalar joint pronation. The rate of subtalar motion should be proportional to the rate of internal rotation/abduction at

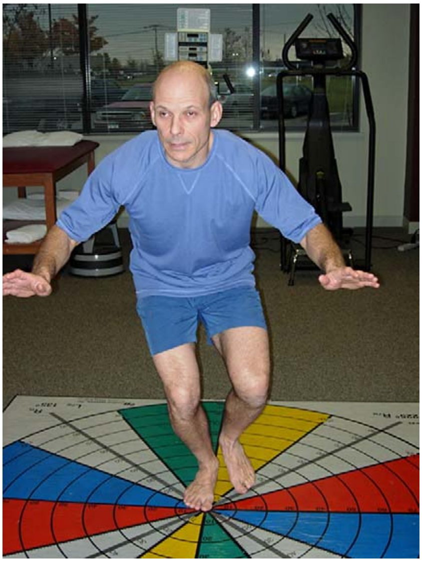

Fig. 1. Single leg squat. Controlled knee abduction and hip adduction should be noted in the frontal plane.

the tibia and femur. An immediate flattening of the longitudinal arch of the foot may be related to compromised control of pronation at the hip. Pronation that occurs too rapidly often is noted in the FP at the knee by excessive knee valgus as a result of poorly controlled femoral abduction. This is correlated with a weakened gluteus medius. It was noted that female recreational runners exhibited greater TP and FP motion at the hip and knee. The ability to control this excursion range may play a key role in avoiding overload of the lower extremities, and ultimately, injury [27].

3. Core mobility testing: The relationship of mobility of the lumbopelvic region and distal joints is examined in each plane of motion.

    a. Sagittal core (Fig. 2): The test is performed in a bilateral stance posture. The clinician demonstrates the test with minimal verbal coaching. Restriction of posterior to anterior translation during extension of the spine and extremities suggests tightness in the anterior hip capsule or psoas. Hyperextension of the lumbar spine and knee flexion are common compensatory patterns to achieve anterior translation of the trunk. During the flexion phase of this examination, an early heel rise is noted if there is inadequate ankle dorsiflexion, which often is associated with gastrocnemius tightness. Excessive hip flexion often is seen as a compensatory motion for restricted ankle dorsiflexion.
    b. Frontal core (Fig. 3): The starting position and instruction procedure is the same as with sagittal core testing. The primary observation is the ability to translate the pelvis in the frontal plane during truncal side-bending. Lateral translation of the pelvis to one side requires ipsilateral adduction and contralateral abduction of the hips. A restriction in abduction reflects tightness in the inferior or medial hip joint capsule, hip adductors, or medial hamstrings.
    c. Transverse core (Fig. 4): This test provides a wealth of information for functional diagnosis and treatment. It is performed in symmetric stance posture with feet shoulder width apart. The following points are kept in mind when observing the runner:

        (1) When compared with running and walking, the joint mechanics on the leg to the side of pelvic rotation are similar to those of the late stance phase of the propelling leg. The mechanics on the leg opposite the direction of pelvic rotation is similar to the loading portion of early stance. With supination, the pelvis, tibia, and femur are rotating externally (from top down), which results in subtalar joint inversion and locking of the foot. With supination, the pelvis goes through greater excursion (range) than the femur and tibia. This rotation of the pelvis relative to the femur maintains an ideal length tension for the gluteals, which are active in the later stages of propulsion [28].

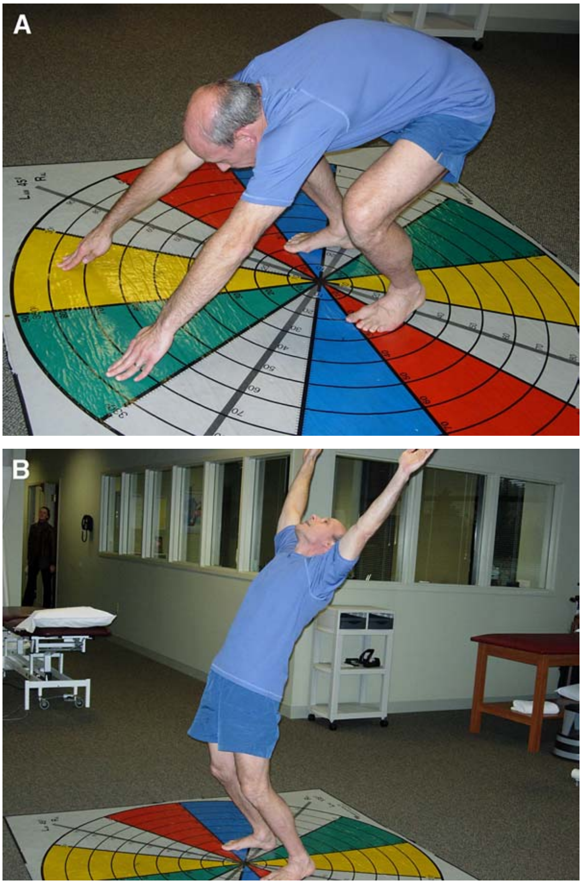

Fig. 2. Core testing in the sagittal plane. (*A*) Flexion phase. Tightness in the posterior hip capsule may restrict anterior to posterior pelvic translation. (*B*) Extension phase. Tightness in the anterior hip capsule may restrict posterior to anterior translation of the pelvis.

(2) In the transverse core test, the subtalar joint on the side of pelvic rotation should be able to invert the calcaneus and lock up the midtarsal joint, as it does in the last phases of stance, without a notable change in the anterior to posterior orientation of the foot. Attention should be paid to the feet and midtarsal joints to see if they remain stable or twist or roll to the side of rotation. Excessive lateral movement of the foot in this test may be associated with tightness of any of the muscles and joint structures that could restrict hip internal rotation—primarily the psoas, short external rotators of the hip, and posterior hip capsule. As decelerators of pelvic rotation to the rear leg, the adductor longus and medial hamstrings are potential contributors to this deficit in hip internal rotation. At the ankle, a tight medial

Fig. 3. Core mobility in the frontal plane.

gastrocnemius is a limiting factor in the ability to rotate the tibia externally.

(3) At the leg opposite the side of pelvic rotation, the biomechanical events of pronation occur. The relationship of the foot to the hip

Fig. 4. Core mobility in the transverse plane. Right rotation supinates the right lower extremity and pronates the left lower extremity.

on this side is demonstrated by the ability of the subtalar joint to convert the internal rotation of the femur and tibia into calcaneal eversion [29]. Because the knee tends to flex on this side, the influence of the gastrocnemius on the subtalar joint is lessened. As a result, a restriction in calcaneal eversion and ankle dorsiflexion tends to be more articular than soft tissue related. If a lack of calcaneal eversion is seen, then manual joint techniques of the subtalar joint may be useful to improve the ability of the entire chain to absorb shock. An excessively pronated foot, where the calcaneus is everted fully to end range in weight bearing, also can be a problem.

4. Eccentric-Concentric Control of the Core (ECC): These tests look at the ability of the core muscle groups, primarily the abdominals, spinal extensors, psoas, iliacus, quadratus lumborum, latissimus dorsi, and hip girdle muscles to control the body's center of mass.
    a. Sagittal ECC (Fig. 5): This test assesses the ability of the psoas, rectus femoris, short hip adductors, and rectus abdominis to control eccentrically extension of the spine and anterior translation of the pelvis. Each side is tested. Common compensatory patterns include restricted anterior translation of the pelvis with overextension by the lumbar or thoracic spine, excessive flexion of the knee, "clawing" of the toes, or hyperactivity of the toe extensors to stabilize distally.
    b. Frontal ECC (Fig. 6): This test challenges pelvic stability in the frontal plane, which makes it an excellent test of gluteus medius function. Loss of balance or a Trendelenburg sign mark the onset of fatigue in this muscle and lateral stabilizers of the pelvis. This is a common finding, even in well-conditioned runners who train primarily in the SP, and derive minimal challenge to the FP activity of hip and thigh muscles.
    c. Transverse (Fig. 7): On the stance leg, the external abdominal oblique, contralateral internal abdominal oblique, and psoas will rotate the spine contralaterally. The gluteus maximus and deep hip rotators will rotate the pelvis contralaterally. The pelvis and spine should rotate synchronously—ipsilaterally as these muscles lengthen and contralaterally as they shorten. Motion in the spine that markedly exceeds pelvic motion in relationship to the femur of the stance leg indicates tightness in the short hip external rotators and posterior hip capsule. It also suggests an inability of the hip to load the gluteals eccentrically in the transverse plane during the propulsion stage of stance.
    d. All of these tests can be made more or less challenging to meet the functional capabilities of the runner by modifying the amount of support, speed, number of repetitions, and the range of the

Fig. 5. Sagittal eccentric/concentric control of the core.

excursion. A successful base test requires 10 controlled repetition on each side.

5. Hip-scapula reaction (HSR): The pelvic girdle, which is connected to the scapula by the axial skeleton and associated thoracolumbar soft tissues,

Fig. 6. Frontal eccentric/concentric control of the core.

Fig. 7. Transverse eccentric/concentric control of the core.

induces a pattern of scapula motion in all three planes as a response to its movement (Table 1). Although this ‘‘scapula reaction’’ is not a mandatory movement, joint mechanics of the upper quarter are optimized by linked movements with the trunk and pelvis. Similarly, the mobility of the pelvis and function of the muscles of the torso and hips are influenced by the ability of the scapula and thoracic cage to move freely in all three planes (Figs. 8–10). In respect to running, HSR underscores the role of the abdominals in controlling the triplanar

Table 1
Hip–shoulder relationships with hip–scapular reaction maneuvers

Position of eccentric hip loading	Concentric hip activity	Shoulder motion	Scapula motion
I/L hip flexion	I/L hip extension	Flexion	Anterior tilt
C/L hip flexion	C/L hip extension	Extension	Posterior tilt
C/L hip internal rotation	C/L hip external rotation	External rotation	Retraction
I/L hip internal rotation	I/L hip external rotation	Internal rotation	Protraction
C/L hip adduction	C/L hip abduction	Abduction	Upward rotation
I/L hip adduction	I/L hip abduction	Adduction	Downward rotation

Abbreviations: C/L, contralateral; I/L, ipsilateral.

movement of the spine, pelvis, and even the shoulder/arm. This controlled motion during running allows for energy-efficient movement to maintain forward momentum [30].

6. Lower extremity balance and reach: Balance and reach activities are used to accentuate the stability and mobility deficits that are noted on the squat, core, and stability tests. They also allow quantification of function by measuring the distance reached or the number of reaches that is performed in a set period of time. The direction of the reach is named by referencing the stance or balancing leg. A running-specific

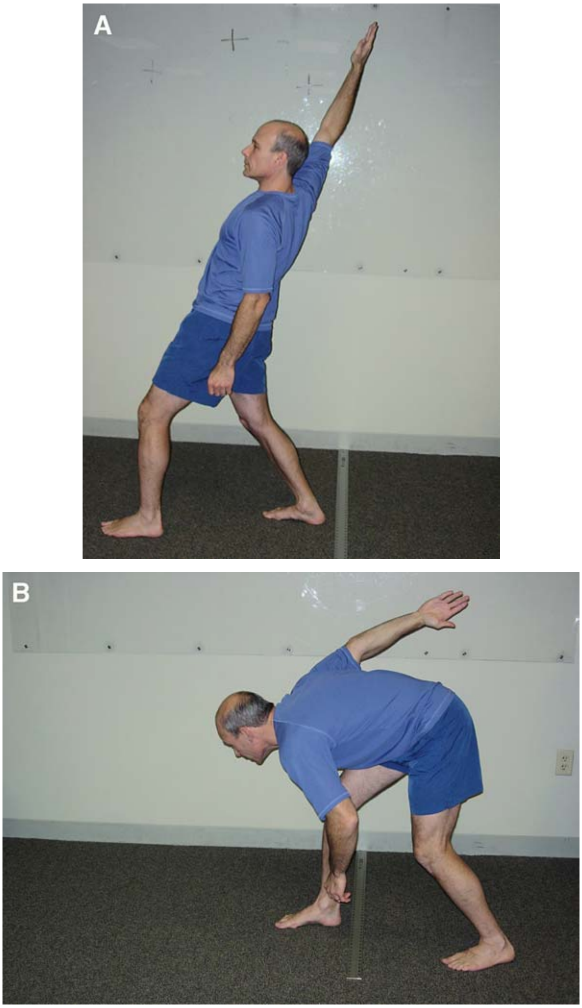

Fig. 8. Sagittal hip scapular reaction. (*A*) Shoulder flexion with ipsilateral hip extension. (*B*) Contralateral hip and shoulder extension.

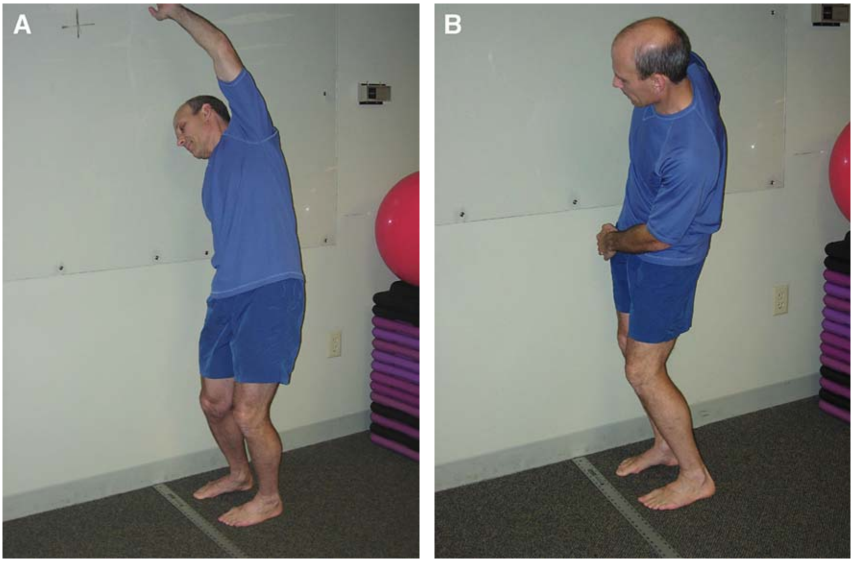

Fig. 9. Frontal hip scapular reaction. (*A*) Contralateral hip and shoulder abduction. (*B*) Shoulder adduction with ipsilateral hip abduction.

balance and reach is a bilateral upper extremity posterior overhead reach with a posterior lower limb reach. The torso should not flex to counterbalance hip extension to offset the spinal extension that is introduced by bilateral shoulder flexion (Fig. 11). This test challenges

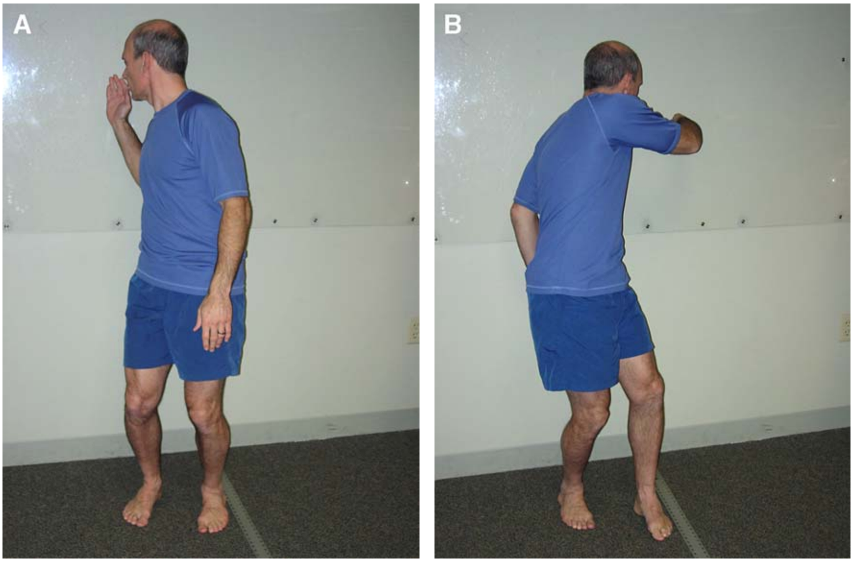

Fig. 10. Transverse hip scapular reaction. (*A*) Shoulder external rotation and ipsilateral hip internal rotation. (*B*) Shoulder internal rotation and contralateral hip internal rotation.

the runner to extend the hip without compensatory forward bending and is a functional test of the psoas' ability to lengthen eccentrically in the sagittal plane without loss of lumbar extension. This test is particularly useful when examining the runner who has hip or lumbosacral pain.

7. Open kinetic chain assessment of the foot and ankle: The examination allows assessment of the foot and ankle without the influence of soft tissues. The examiner should correlate these findings with those in the closed chain, particularly foot and ankle motion that is assessed with the single leg squat test. The following is assessed with the open kinetic chain maneuvers:

   a. Hallux dorsiflexion (first metatarsophalangeal [MTP] extension): Hallux extension of 65° to 70°, in late stance, is ideal to achieve sufficient tension in the plantar aponeurosis to lock up the foot [31] and adequate hip extension. Both are needed to perform forceful propulsion.
   b. Subtalar joint motion: With the runner seated, subtalar motion is assessed through passively inverting and everting the calcaneus. Flexion of the knee removes the influence of the gastrocnemius. An end feel assessment is made to determine if limited motion is due to a capsular/ligamentous restriction or a bony block. Because pronation is a triplanar activity of many joints and bones of the foot/ankle complex, restricted calcaneal eversion causes a cascade of

Fig. 11. Left lower extremity posterior reach with bilateral upper extremity posterior overhead reach. Movement of the limbs is referenced to the leg in stance.

events. It prevents the talus adduction and plantar flexion that is needed for loading phase after heel strike, and thus, results in a loss of dorsiflexion during midstance. A loss of ankle dorsiflexion results in restricted knee flexion and diminished sagittal plane stimulation of the quadriceps [30].

c. Midtarsal joint motion: Midtarsal joint motion is compared in all three planes of motion with the calcaneus inverted and everted. Calcaneal eversion unlocks the midtarsal joint and makes it mobile. Conversely, calcaneal inversion restricts midtarsal motion. A midtarsal joint that does not lock with calcaneal inversion prevents shifting of body weight to the first MTP and results in an apropulsive gait or running style.

Differential diagnosis

Overuse injuries of the hip and pelvis in runners may be classified as soft tissue injuries or as primary joint and bone pathology (Box 1). By far, in the authors' experience, soft tissue injuries are the most common in runners, particularly gluteus medius tendinopathy. Pelvis and sacroiliac joint dysfunctions are underappreciated in many clinics. In our experience, runners frequently develop superior shears, anterior innominate rotations, and sacral torsions. The diagnosis of hip labral tears, previously underappreciated in runners, is increasing in frequency as a result of better imaging with magnetic resonance arthrogram. Radicular pain in the runner also may cause hip pain. A full pattern of radiculopathy or radiculitis down the lower extremity often may not be seen. Specific evaluation techniques, such as the slump test with seated straight leg raising, is helpful in picking up radicular pain (Fig. 12). Sensitizing and relieving maneuvers with the slump test can help to differentiate hamstring tightness from adverse neurodynamic tension. Similarly, the side-lying femoral nerve stretch test uses sensitizing and relieving maneuvers and can help to differentiate quadriceps tightness from adverse neurodynamic tension in the distribution of the femoral nerve (Fig. 13).

Treatment approaches for the runner

In the authors' experience, use of the closed kinetic chain approach is the most effective means of rehabilitating the injured runner and improving his performance because it attempts to train muscles and joints to absorb and dissipate properly the forces that are encountered in running. Closed kinetic chain exercises avoid isolating one structure in treatment; instead, this approach trains patterns of movements. In evaluation and treatment, biomechanical deficits are identified as are the planes, joints, and specific

Box 1. Differential diagnosis of hip and pelvis overuse injuries

- *Soft tissue injuries*
  - Muscle and tendon pain
    - Gluteus medius tendonitis
    - Hip flexor tendonitis
    - Tensor fascia lata tendinitis
  - Bursitis
    - Trochanteric bursitis
    - Ischial bursitis
  - Snapping (clicking) hip
  - Muscle imbalances
    - Pelvic crossed syndrome
    - Piriformis syndrome
  - Impingement syndromes
    - Anteromedial impingement
    - Anterolateral impingement
    - Proximal impingement
- *Primary joint and bone pathology*
  - Dysfunctions of the pelvis and sacroiliac joints
    - Symphysis pubis
    - Sacroiliac
  - Joint inflammation and bony pathology
    - Spondyloarthropathy, sacroiliitis, and osteitis pubis
    - Stress fractures
    - Avascular necrosis
    - Slipped capital femoral epiphysis
    - Avulsion fractures
    - Coccydynia
    - Osteoarthritis and hip synovitis
    - Labral tears
    - Tumors
- *Referred pain*
  - Lumbar
  - Nonmusculoskeletal disorders
- *Radicular pain*

activities where the runner experiences success. These activities are the basis for an initial exercise program. An understanding of the biomechanical responses that occur at each joint during pronation and supination allows the clinician to identify potential sources of injury.

Ideally, therapeutic exercise should simulate the biomechanical sequence of pronation and supination at each joint in the kinetic chain. Eccentric loading before concentric muscle contraction is a well-established approach

Fig. 12. Slump test. (*A*) Sensitizing maneuvers: introduction of knee extension and neck flexion. (*B*) Relieving maneuvers: introduction of head and neck extension.

for facilitating weak and inhibited muscles [32], such as with plyometrics. During the acute phase, therapeutic closed kinetic chain positions provide ways to train muscles to decelerate forces within functional ranges of motion, without causing further overload. Controlled eccentric lengthening also plays a role in treating tight muscles. Isolated stretching of tight muscles can be minimized if they are trained to lengthen eccentrically during functional activity.

The authors have found that a closed kinetic chain approach, which is based on the following principles, to be useful for safe and early mobilization:

The symptomatic and overloaded structure should not be the initial site of treatment. Faulty biomechanics elsewhere in the kinetic chain can be addressed first.

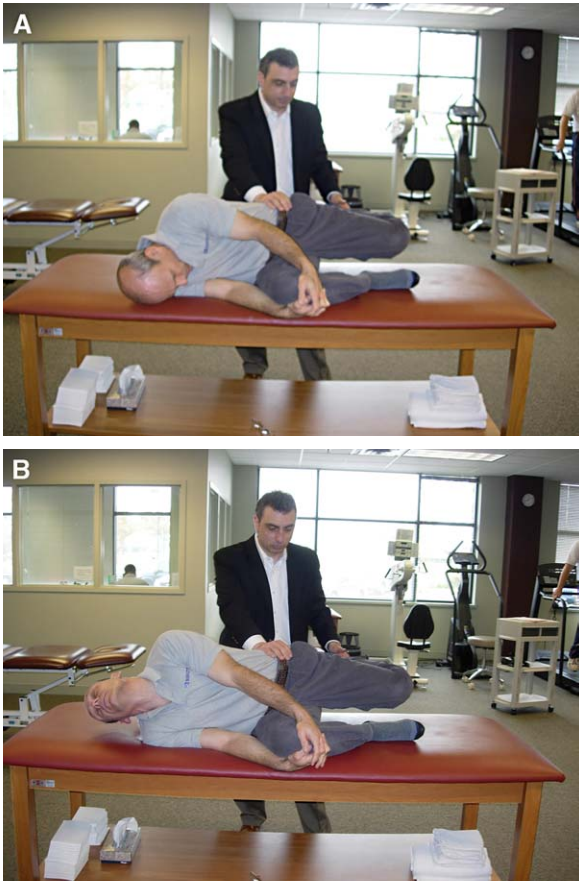

Fig. 13. Femoral nerve tension test. (*A*) Sensitizing maneuvers: introduction of knee flexion and neck flexion. (*B*) Relieving maneuver: introduction of head and neck extension.

All muscles have three planes of action. Motion that is not tolerated in one plane may be tolerated in the other two without threat of tissue overload.

All muscles are potential synergists to each other. Improving the ability of the gastroc-soleus to lengthen eccentrically with the subtalar joint inverted, as occurs at the end of stance phase, improves the ability to extend the hip. This eccentrically loads the psoas muscle to prepare it for concentric contraction in swing phase.

Closed kinetic chain activities often are tolerated better than open kinetic chain activities. Joint compression forces are reduced with closed chain proprioceptive neuromuscular facilitation exercises because it stimulates cocontraction of the muscles around the joint and make it more stable [32].

Common conditions and treatment approaches

Sacroiliac and innominate dysfunction

It is beyond the scope of this article to describe the diagnostic criteria and treatment of the 14 mechanical dysfunctions of the pelvis that were described by Greenman [33]. These respond well to muscle energy technique or high velocity low amplitude thrust. Exercise that reinforces the manual correction is necessary to prevent dependence on passive manipulative treatment. Lambert [34] developed a simplified classification of pelvic and sacral instability that is based on innominate and sacroiliac function in gait or running. The innominates demonstrate instability anteriorly or superiorly, but not posteriorly because the pelvis in gait does not rotate posteriorly beyond neutral in the sagittal plane. The sacrum flexes and rotates to the opposite side relative to the anterior leg and extends and rotates to the same side relative to the posterior leg. An exercise to mobilize the sacrum and pelvis relies on a stride position and diagonal patterns of the upper extremities (Fig. 14). Many of the same principles that are discussed below regarding treatment of causative biomechanical problems of the soft tissues of the pelvis are applicable to treatment of recurrent sacroiliac and innominate dysfunction.

Capsular and joint dysfunction of the hip

Restriction of hip motion that is noted on the core mobility examination can be confirmed, if necessary, with a joint play examination of the hip. A hard restricted capsular end feel is an indication for mobilization. The portions of the hip capsule that are tight can be mobilized manually using joint play techniques [33] or in functional positions that allow the additional mobilizing force of the patient's body weight and direction of movement. The pattern of correction can be carried over into a functional exercise (Fig. 15). The treatment of muscle imbalance that is associated with hip joint dysfunction is described below.

Overload of soft tissues

The runner who presents with hip tendonitis or strain usually has a history of a change in running surface or intensity, most often an increase in mileage. The primary disrupting force is repetitive tensile forces that result in microtrauma.

Initial management of muscle strains and tendonitis consists of ice, compression, and decreased weight bearing. Relative rest is a key concept to follow to avoid needless immobilization. Pain-free motion is allowed in planes that are not disruptive to the injury and at joints that are biomechanically linked to the affected area. Initially, eccentric loading is avoided. It is introduced gradually, as tissue repair proceeds, to minimize the chance of tissue disruption. In the latter stages of rehabilitation, rapidly applied eccentric loads are used to develop tensile strength at the

Fig. 14. Self-mobilization of the right sacral base restricted in extension and right rotation.

musculotendinous junction and at osseotendinous insertions to train the muscle to decelerate loads [35].

A closed kinetic chain paradigm of rehabilitation is presented below for the hamstrings. The basic premise of this approach, establishing and

Fig. 15. Functional mobilization of the right posterior hip capsule in a stride position.

treating causative biomechanical sources of dysfunction, are applicable to soft tissue injury elsewhere in the pelvis.

The hamstrings are subjected to high tensile load given their extensive eccentric role in running. During initial swing, the knee and hip are flexing which requires simultaneous eccentric and concentric activity of the hamstrings. During the last portion of swing, the hamstrings continue to play a dual role—controlling knee extension while extending the hip. The hamstrings work synergistically with the gluteals to stabilize, decelerate, and propel the hip in running [36]. During the propulsion phase, the medial hamstrings assist in decelerating hip external rotation. This maintains the gluteus maximus at an ideal length to act as an accelerator, along with the hamstrings, of the femur in the sagittal plane. The hamstrings, along with the rectus abdominis, also are decelerators of pelvic anterior tilt throughout stance. Given these functional relationships, it is conceivable that hamstring strain or rupture has its source in the inhibition and weakness of its closest synergists, the gluteals and abdominals [37].

It is the authors' opinion that function of the foot and ankle and scapulothoracic region has a direct bearing on muscle facilitation and inhibition of the trunk and hip. These relationships were described in the section on functional evaluation. Thus, the first step in treating muscle imbalance of the hip, regardless of the affected tissue, is to correct the biomechanical deficits of the foot and ankle that are the source of altered gait mechanics. As well, improving the mobility of the scapula and thoracic spine facilitates eccentric stimulation of the abdominals and enhances their role as pelvic stabilizers.

Hamstring retraining following the initial phase of repair starts with identifying pain-free planes of motion. Often, the hamstring can be loaded in the TP or FP using an approach that combines reaches of the upper extremity with pelvic translation. Ultimately, the hamstring must be able to handle high tensile loads, primarily in the SP, for a successful return to running [38].

Regardless of the soft tissue or joint that is injured, a milestone in the rehabilitation of the runner is the ability to control higher eccentric loads in asymptomatic planes. Closed kinetic chain loading of a muscle can be increased by using steps of different heights, displacing the body's center of mass, or adding external weight. The ability to control body weight for 10 repetitions graduates the runner to a more challenging exercise in the same plane and allow for the introduction of activities with lighter loads in previously symptomatic planes of motion. The optimal exercise cadence of eccentric to concentric muscle contraction for strengthening is 3:1 (6-second eccentric to 2-second concentric) at the maximum weight that can be controlled for 10 repetitions [39]. Once strength in a specific plane is no longer an issue, rehabilitation can focus on power training at functional speeds with a lighter load. The goal is to be able to perform strength and power exercises in all three planes of motion asymptomatically or with minimal symptoms at higher loads. At this point, rehabilitation of the runner begins to transition into performance training.

Returning to running and performance training for running

A graded program of walking and running is instrumental for correcting specific biomechanical problems and meeting the runner's psychologic need to return to his sport quickly. Running is an SP-dominant activity, but relies on muscles to provide triplanar stability and mobility at the pelvis with each stride. Use of walking and running stride patterns that incorporate TP and FP motion of the arms and trunk; frequent changes in the direction of progression; or changing the base of support are useful for training hip girdle muscles that primarily function in planes other than the SP. As a tool in rehabilitation, walking or running other than "straight ahead" may be tolerated better than conventional walking or "slow jogging." This approach can be used with cross-training to help maintain the runner's cardiovascular fitness. The runner should be encouraged to continue this form of walking and running as a warm-up and cool-down, and, whenever possible in a training run, to include these patterns of motion to keep muscles and joints active in multiple planes of motion.

Returning to running after a hip or pelvic injury requires an incremental increase in mileage and speed. A protocol by James [40] for returning to running following injury is based on missed running time. Injuries that result in at least 4 weeks of missed training require approximately 9 weeks of a combined walking and running program before the runner can return to previous training levels. A "walk to run program" [41] proposes a regimen that incorporates walking and running over a 12-week period with an increasing proportion of running relative to walking each successive week. Speed and mileage progression should be based on the runner's symptoms. Loss of bone density is a concern following a prolonged layoff from running. Therefore, an incremental progression in intensity and mileage is required to prevent stress fracture. Ideally, rehabilitation of the runner should incorporate exercises that stimulate an increase in bone density. A simple regimen of heel drops, performed at a frequency of 50 repetitions per day, increased hip and spine bone density by 3% to 4% [42].

There is no shortage of training myths and unsound training practices in running. A common misconception is that running is sufficient to increase leg strength. Hennessy and Watson [43] found that endurance training that consisted of moderate running 4 days a week for 30 minutes to 60 minutes did not improve leg strength as measured by squat testing. In the same study, a group of athletes that used strength training improved their leg strength and speed and also maintained their endurance. The need to include strength training in the athlete's training regimen after injury should be appreciated in light of the observations of Nadler et al [44] that kinetic chain functional deficits persist long after recovery from an injury.

The role of stretching for improving performance and avoiding injury is overestimated. A recent review of the literature by Thacker et al [16] found no evidence in the randomized controlled trials that stretching alone prevents injury. The investigators recommended a comprehensive program of warm-up, including stretching and conditioning exercises. Tolerance of a rapidly applied eccentric load, which can result in strain, may be the key point for preventing muscle injury. The relationship of muscle injury and muscle flexibility may be more a function of the length at which the muscle develops peak torque, rather than its ability to elongate passively [45]. It is in this respect that eccentric overloading in training plays an important role in preventing soft tissue injury at the hip. Askling et al [46] found that in male elite soccer players, eccentric training of the hamstrings that was performed once or twice per week for 10 weeks resulted in significantly less hamstring strains and increased speed and strength when compared with a matched group that did not receive this training. Appendix A describes a functional progression for injury prevention and performance enhancement that emphasizes the eccentric role of muscle activity in running.

In summary, resistance training can be used to improve running performance. This type of program can be tailored to meet the entire spectrum of performance goals from power training for sprinters to endurance training for marathoners. The common denominator from the early stage of rehabilitation to performance training is the use of a triplanar closed kinetic chain approach. The authors have found this to be the best way to prepare the hip and the entire kinetic chain for the specific demands of running.

Summary

The runner is especially at risk for development of injury to the hip and pelvis secondary to chronic repetitive microtrauma. The key to treatment is establishing complete and accurate diagnosis, and, in particular, identifying the functional biomechanical deficits in the kinetic chain that contribute to this repetitive microtrauma.

A long-term successful outcome and prevention of reinjury are more likely if the focus of rehabilitation is on the restoration of the functional kinetic chain, rather than on a specific injured tissue. For example, the typical treatment of ‘‘iliotibial band syndrome’’ is a stretching protocol that frequently is unsuccessful in the long-term improvement of symptoms. A functional biomechanical approach might identify that the injured runner has lack of calcaneal eversion and a structurally rigid supinated foot. These functional biomechanical deficits would lead to inadequate internal rotation of the tibia and femur and result in inhibition or decreased recruitment of the gluteal muscles, in particular the gluteus medius. Restoring pronation throughout the lower extremity would require joint play techniques or functional joint mobilizations for the foot and ankle. In addition, a running shoe with a cushioned heel may be necessary to promote pronation and to attenuate shock. Exercises that integrate foot and hip function, including balance reaches, lunges and step-downs, are prescribed to stimulate the gluteus medius and other gluteals in positions that simulate running. Activities that are done in this manner activate the entire functional kinetic chain of muscles and joints.

The nonoperative sports medicine specialist, in particular the physiatrist and physical therapist, are in an excellent position to integrate treatment of the entire functional kinetic chain through a thorough biomechanical evaluation and comprehensive rehabilitation of the injured runner. Additional training in the areas of biomechanical evaluation and functional biomechanical deficits should be sought, because residency and even many fellowship-trained programs often overlook these important areas.

Finally, the injured runner is best taken care of in a setting in which different sports medicine specialists are available and work well as a team. No one sports medicine specialist can provide all of the needs to the injured runner.

Appendix A

Functional Progression for Performance Enhancement and Injury Prevention

I. Combined Stretching and Strengthening

A. Squat Progression–Technique is head and chest up, neutral or extended spine, and hips translated posteriorly.

1. Two-legged on stable surface–20 reps (Figure 16)
2. Two-legged on unstable (wobble board or disco-sits) surface–10 reps (Figure 17)
3. One-legged on stable surface–10 reps (Figure 18)
4. One-legged on unstable surface–5 reps (Figure 19)

All above squats are done with good technique, to fatigue, working up to specified repetitions.

B. Balance/reach with progression to step-downs.

1. May be done in one of three planes at 6 second eccentric/2 second concentric phases to build strength the fastest [39].
   a. Anterior (Figure 20)
   b. Medial (Figure 21)
   c. Posteromedial rotational (Figure 22)

Works whole lower extremity by 3D stretching and strengthening.

C. Balance/reach in step-downs with bilateral upper extremity (UE) 3-D reaches for integrated core, scapulo-thoracic, and lower extremities (LE).

Fig. 16. Bilateral squat—stable surface.

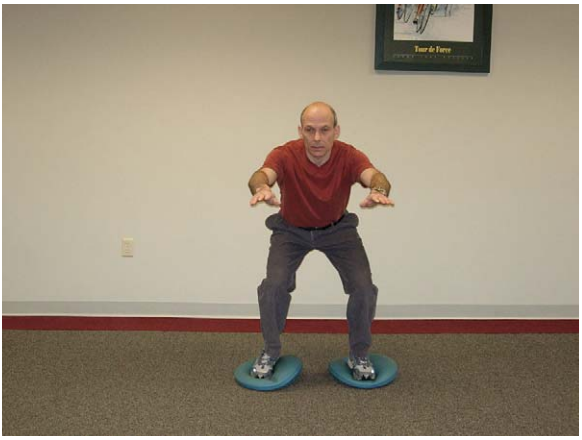

Fig. 17. Bilateral squat—unstable surface.

Fig. 18. Unilateral squat—stable surface.

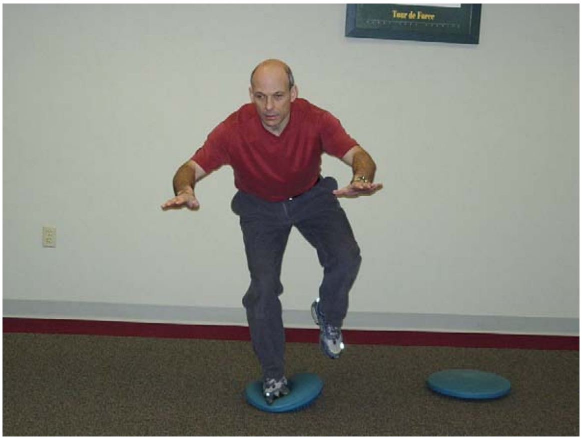

Fig. 19. Unilateral squat—unstable surface.

Fig. 20. Anterior step-down.

Fig. 21. Medial step-down.

Fig. 22. Posteromedial step-down.

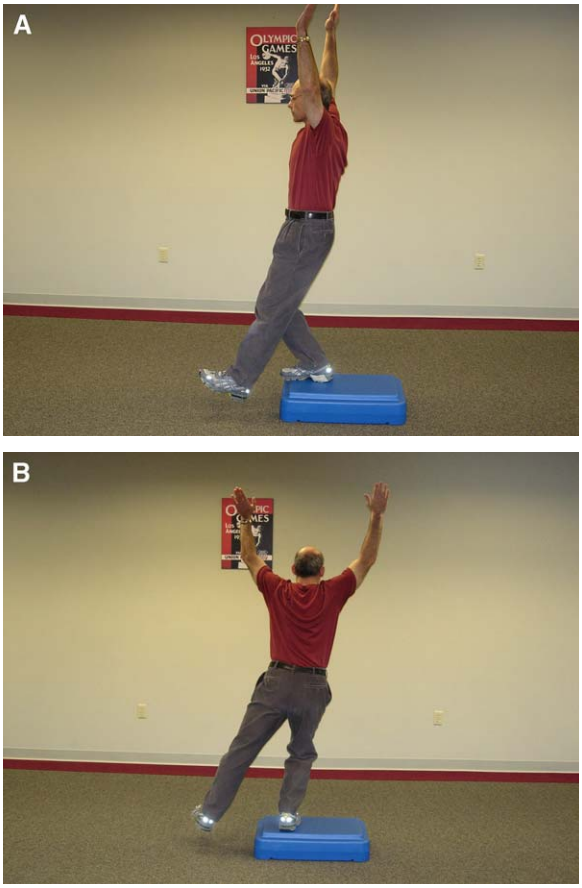

Fig. 23. (*A*) Anterior step-down with bilateral upper limb overhead reach. (*B*) Medial step-down with bilateral upper limb overhead reach. (*C*) Posteromedial step-down with bilateral upper limb overhead reach.

Fig. 23 (*continued*)

1. Above three balance and reach and/or step-downs maneuvers combined with:
a. Bilateral overhead UE reaches (Figures 23 a–c)
b. Bilateral overhead/sidebending UE reaches (Figures 24 a–c)
c. Bilateral rotational UE reaches at hip height (Figures 25 a–c)
d. 3-D lunges with UE 3D stretches (Figures 26–29 a–c)
1) Dynamically stretches and strengthens LE and core musculature.
D. Landing drills for eccentric control of initial landing phase of running (from 2”-8”). All done with slow eccentric (6 second phase)
1. Bilateral jump-downs
2. Unilateral hop-downs
Above two exercises with combined 3-D UE reaches at hip, shoulder, and overhead heights at this frequency and intensity of the 3-D functional exercises:
a. Frequency
1) Injury Recovery Phase:
(a) Runner is walking, but not running yet.
(b) Minimum 2 and maximum 3 times a week.
2) Walk/Run Phase:
(a) 2 times per week.
3) Peak Running Performance Phase
(a) 1 time per week.
(b) 4–5 days per week of running.
(c) 1–2 days per week of rest, depending on age and responses to this training program.
b. Intensity
1) Intrinsic Weight:
(a) Body weight and gravity.

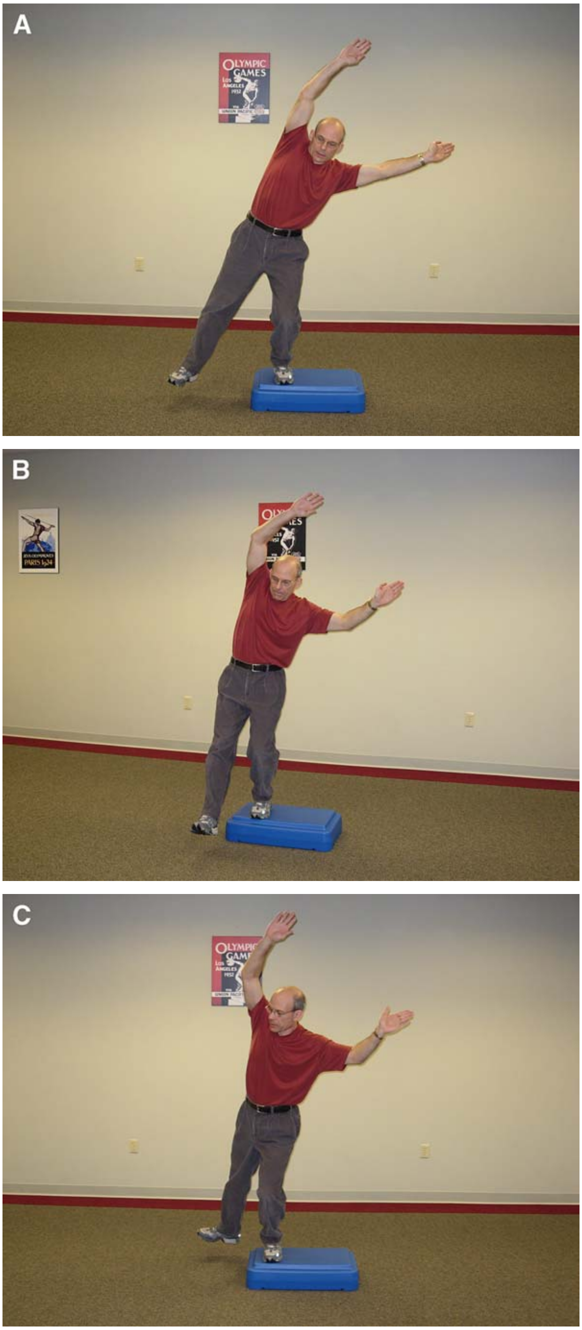

Fig. 24. (*A*) Anterior step-down with bilateral upper limb side-bending reach. (*B*) Medial step-down with bilateral upper limb side-bending reach. (*C*) Posteromedial step-down with bilateral upper limb side-bending reach.

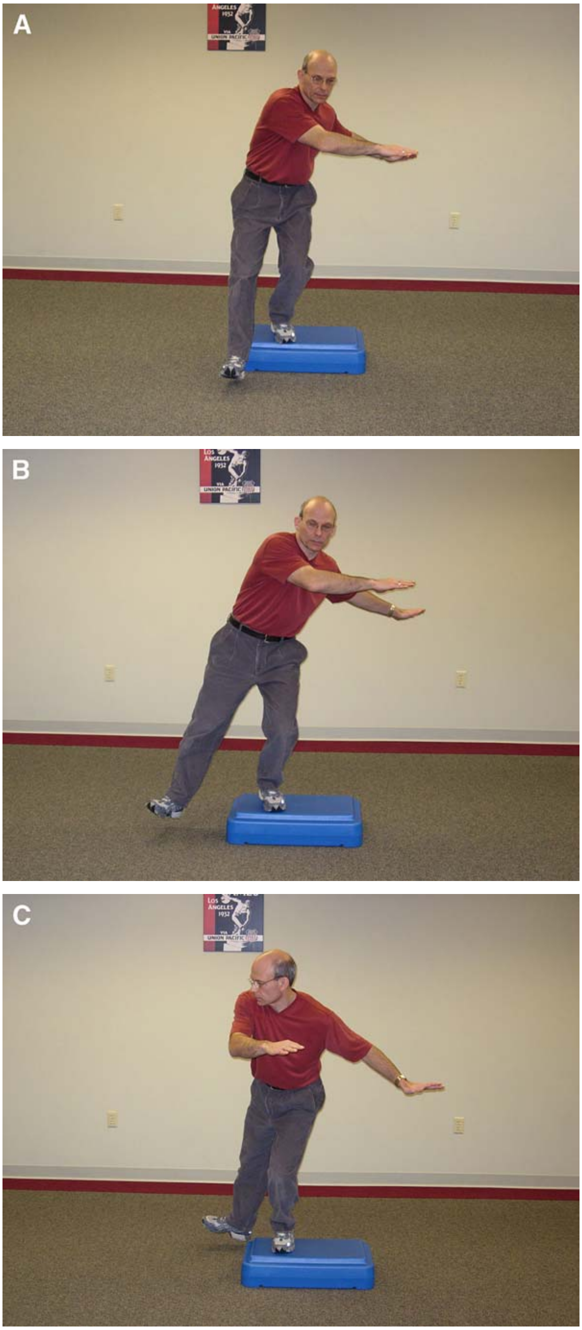

Fig. 25. (*A*) Anterior step-down with bilateral upper limb rotational reach. (*B*) Medial step-down with bilateral upper limb rotational reach. (*C*) Posteromedial step-down with bilateral upper limb rotational reach.

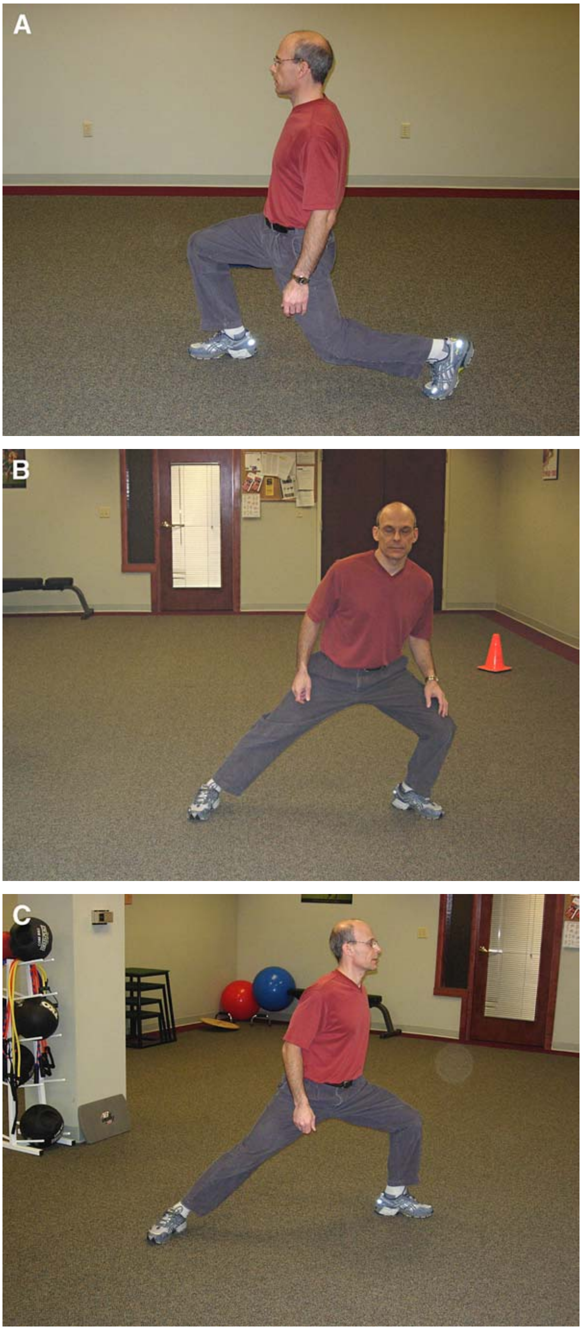

Fig. 26. (*A*) Anterior lunge. (*B*) Lateral lunge. (*C*) Posterolateral rotational lunge.

Fig. 27. (*A*) Anterior lunge with bilateral upper limb overhead reach. (*B*) Lateral lunge with bilateral upper limb overhead reach. (*C*) Posterolateral rotation lunge with bilateral upper limb overhead reach.

Fig. 28. (*A*) Anterior lunge with bilateral upper limb side-bending reach. (*B*) Lateral lunge with bilateral upper limb side-bending reach. (*C*) Posterolateral rotational lunge with bilateral upper limb side-bending reach.

Fig. 29. (*A*) Anterior lunge with bilateral upper limb rotational reach. (*B*) Lateral lunge with bilateral upper limb rotational reach. (*C*) Posterolateral lunge with bilateral upper limb rotational reach.

(b) Extrinsic weight: barbells, dumbbells, medicine and kettle balls, weighted vest, etc.
(c) Strength progression guidelines:
 –8–10 reps
 –Increased weight when good control and technique can be performed
 –Start with 60–80% of 1 rep_{max}
(d) Endurance progression: 20–25 reps with increasing speed at 10–15% of 1 rep_{max}.

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