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Muscular Balance, Core Stability, and Injury Prevention for Middle- and Long-Distance Runners

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Martial artists long have recognized the importance of well-developed core musculature. One of the main differences between a novice practitioner and a black belt is the black belt's development and use of his core (called "center" or "Ki") to produce balanced, powerful, and explosive movements. For middle- and long-distance runners—whose chosen sport involves balanced and powerful movements of the body propelling itself forward and catching itself in complex motor patterns—this stable core, as well as a strong foundation of muscular balance, is essential. In many runners, however—even those at an Olympic level—this core musculature is not developed fully. Weakness or lack of sufficient coordination in core musculature can lead to less efficient movements, compensatory movement patterns, strain, overuse, and injury. This article discusses the importance of muscle balance and core stability for injury prevention and for improving a distance runner's efficiency and performance. It includes a detailed series of core exercises that can be incorporated gradually into a runner's training program. The program starts with restoration of normal muscle length and mobility to correct any muscle imbalances. Next, fundamental lumbo-pelvic stability exercises are introduced which teach the athlete to activate the deeper core musculature. When this has been mastered, advanced lumbo-pelvic stability exercises on the physioball are added for greater challenge. As the athlete transitions to the standing position, sensory motor training is

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Box 1. Common tight and inhibited muscles in runners

Postural (tendency to shortness and tightness)
Gastroc-soleus (predominately soleus)
Rectus femoris
Iliopsoas
Tensor fascia lata
Hamstrings
Short thigh adductors
Quadratus lumborum
Piriformis
Sartorius

Phasic (tendency to weakness and inhibition)
Tibialis anterior
Peroneals
Vastus medialis
Long thigh adductors
Gluteus maximus, medius, and minimus

used to stimulate the subcortex and provides a basis for functional movement exercises that promote balance, coordination, precision, and skill acquisition. The ultimate goal of core stabilization is to train "movements" and "positions" rather than muscles. Exercises are most effective when they mirror the demands of the athlete's sport.

The role of the core

In essence, the "core" can be viewed as a box with the abdominals in the front, paraspinals and gluteals in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom [1]. Within this box are 29 pairs of muscles that help to stabilize the spine, pelvis, and kinetic chain during functional movements. When the system works efficiently, the result is appropriate distribution of forces; optimal control and efficiency of movement; adequate absorption of ground-impact forces; and an absence of excessive compressive, translation, or shearing forces on the joints of the kinetic chain. This efficiency requires an integration of the myofascial, articular, and neural systems, which, in turn, requires optimal functioning of the muscles, including the muscles' ability to contract in a coordinated manner and with sufficient motor control and neuromodulation so the joints receive adequate compression through the articular structures. This model supports an integrated model of joint function [2] and leads to optimal length-tension ratios and optimal force coupling of the muscles. Addition-

Fig. 1. Foam roll for soft tissue mobilization. The athlete is positioned side-lying with the foam roller just below the hip bone. She then rolls along the outer thigh, from the top of the knee to the bottom of the hip bone. This may be painful, especially at first, so perform in moderation.

ally, this model sets the stage for optimal postural alignment, normal movement patterns, and a minimal potential for joint dysfunction. Biomechanical studies showed clearly that joint dysfunction anywhere from the spine to the feet can lead to compromise elsewhere in the kinetic chain [3].

The first stage in developing a stable core is to develop the abdominal muscles. Richardson and coworkers [1] discovered that there are two different types of muscles fibers (slow-twitch and fast-twitch) that comprise the abdominal muscles; because of this different fiber composition, different exercise regimens are required to train the abdominal muscles properly. Slow-twitch fibers primarily make up the local muscle system—the muscles of the deeper abdominal muscle layers. These muscles are closer to the center of rotation of the spinal segments and, with their shorter muscle lengths, are ideal for controlling intersegmental motion, maintaining mechanical stiffness of the spine, and are best suited to respond to changes in posture and extrinsic loads. The key muscles of this system include the transversus abdominus, multifidi, internal oblique, deep transversospinalis,

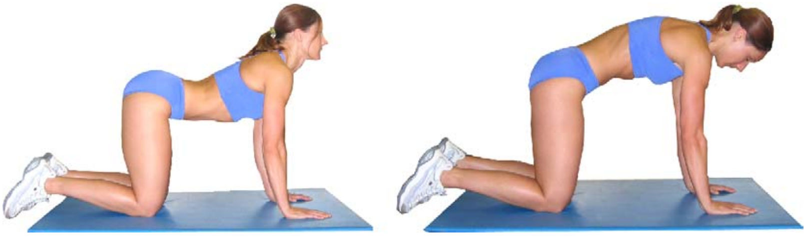

Fig. 2. Cat-Camel exercise. The athlete should lightly brace the abdominal wall. With the hands directly beneath the shoulders and the knees directly beneath the hips, the entire spine is engaged in a synchronous motion, moving in flexion and extension. Correct form requires hip motion to enable proper lumbar function. To help athletes achieve this motion in extension, McGill [4] recommends that the athlete thinks of "sticking the butt out." Six to 10 cycles of this exercise usually are sufficient.

Fig. 3. Abdominal bracing. The abdominal bracing technique involves a submaximal isometric contraction of the three layers of the abdominal wall (rectus, obliques, and transverse) which produces a true muscular girdle around the spine to buttress against buckling and shear instability.

and pelvic floor muscles. McGill [4] described a "hoop" around the abdomen that consists of the abdominal fascia anteriorly, the lumbodorsal fascia posteriorly, and the transverse abdominis and internal obliques muscles laterally. In combination with the intra-abdominal pressure mechanism, activation of this system serves to tension the hoop and provide a stabilizing corset to the spine.

Fast-twitch fibers, conversely, primarily make up the global muscle system (superficial or outer-layer muscles). These muscles possess long levers and large moment arms that are capable of producing large outputs of torque, with an emphasis on speed, power, and larger arcs of movement [5]. The main muscles in this layer are the erector spinae, external oblique, and

Fig. 4. Supine bent-knee raises. This is a fundamental exercise for recruiting the deep abdominal muscles and for lumbo-pelvic control. The athlete lies on her back, with knees bent and feet flat on the floor. She braces the abdominal wall, holding the lumbar spine in a neutral position, and slowly raises one foot 6 to 12 in off the ground with alternate legs. Common errors when performing this exercise include rocking the pelvis, abdominal protrusion, or an inability to maintain the neutral (midrange) lumbar curve. If this happens, discontinue the exercise for a rest period. Quality is stressed more than quantity. Progression: the exercise can progress to extending the legs alternately and lowering to the ground. Once the athlete can maintain stability with alternate leg lifts, she can add alternate, overhead arm raises for greater challenge. The arm raises should be performed slowly, while maintaining lower abdominal bracing.

Fig. 5. Quadruped with alternate arm/leg raises. This exercise prepares the athlete for the proprioceptively more challenging and more dynamic exercises of the trunk. It specifically engages the multifidi—the deep transverse spine stabilizer and extensor of the lumbar spine. The athlete should position herself on all fours and brace the abdominal wall. While maintaining a midrange/neutral curve of the lumbar spine, the athlete should raise the right arm and the left leg (opposite upper and lower limbs) into a line with the trunk, while preventing any rocking of the pelvis or spine (excessive transverse or coronal plane motion). If it helps to maintain alignment, the athlete may use an object, such as a foam roller or wooden dowel, placed along the spine, for added tactile feedback. The leg should be raised only to the height at which the athlete can control any excessive motion of the lumbo-pelvic region. She then performs the exercise by raising the left arm with the right leg. Progression: a physioball underneath the trunk can provide significantly more proprioceptive challenge because of its unstable surface. The goal is to maintain lumbar stability while the opposite arm and leg are raised slowly.

rectus abdominis muscles—the muscles that are strengthened by traditional back and abdominal exercises and that assist with gross spinal movements.

Hodges and Richardson [6,7] showed that it is not simply that deep-layer abdominal muscles are recruited during stabilization of the spine, but it is how they are recruited that is important. The transverse abdominus, the innermost of the four abdominal muscles, has fibers that run horizontally (except for the most inferior fibers, which run in line with the internal oblique muscle). The transverse abdominus and the multifidi are considered "stabilizing muscles" (muscles that are modulated continually by the central nervous system and

Fig. 6. Bridging. Bridging is a fundamental core-stability and gluteal-strengthening exercise. The athlete begins the exercise on her back, in a hook-lying position, with arms resting at her sides. She activates the abdominals and squeezes the gluteal cheeks before initiating the movement. The athlete lifts the pelvis and hips off the ground while maintaining neutral lumbar alignment. There should be no rotation of the pelvis. The hips should be aligned with the knees and shoulders in a straight line. The athlete should hold the position for 10 seconds and then slowly lower the pelvis to the floor. Progression: in the lifted-bridge position, while maintaining neutral lumbar and pelvic alignment, the athlete can lift one foot off the ground and extend the leg. By placing her arms across her chest, she can increase the challenge of stabilizing the lumbo-pelvic region.

Fig. 7. Prone plank. This is a fundamental, static core stability exercise. The athlete supports herself with her forearms resting on the mat, elbows bent at 90°, and the toes resting on the mat. The athlete maintains the spine in a neutral position, recruits the gluteal muscles, and keeps the head level with the floor. She is instructed to breathe normally throughout the exercise, while maintaining the abdominal brace. We suggest holding the position for 20 seconds and working up to 1 minute for two or three repetitions. No compensatory motion should be seen, such as increased lumbar lordosis or sag. Progression: in this position, the athlete can add leg lifts for more difficulty. One leg can be lifted off the mat, held for 5 seconds, and then repeated on the opposite side. For more advanced progression, the legs (and for even greater challenge, the toes) can be balanced on a physioball.

provide feedback about joint position), whereas the global and larger torque-producing muscles control acceleration and deceleration. The investigators found that the cocontraction of the deeper-layer transverse abdominus and multifidi muscle groups occurs before any movement of the limbs. They noted that the transverse abdominus is active 30 milliseconds before movement of the shoulder and 110 milliseconds before leg movement; this neuromuscular stabilization may be delayed in individuals who have low back pain. It is believed that these muscles anticipate dynamic forces that may affect the lumbar spine and act to stabilize the spine before movement. In agreement with this, Hides and colleagues [8] documented that patients who sustained a low back injury had difficulty recruiting their transverse abdominus and multifidi muscles early enough to stabilize the spine before movement.

Fig. 8. Side plank. This is a fundamental, static core stability exercise that is designed to challenge the athlete's body against gravity in the coronal/frontal plane, and is an ideal exercise to train the quadratus lumborum. The athlete lies on her right side with the right arm extended in a straight line up from the shoulder, with the forearm resting on the mat. She raises the pelvis from the floor and holds it in a straight-line "plank" position. The hips should not be allowed to sag toward the floor. We suggest holding the position for 20 seconds, working up to 1-minute holds for two or three repetitions. If this position is too difficult, bend the lower legs and allow the support to come from the elbow and knee versus elbow and lower leg/foot. Progression: the top foot can be raised to challenge the core and gluteal musculature increasingly.

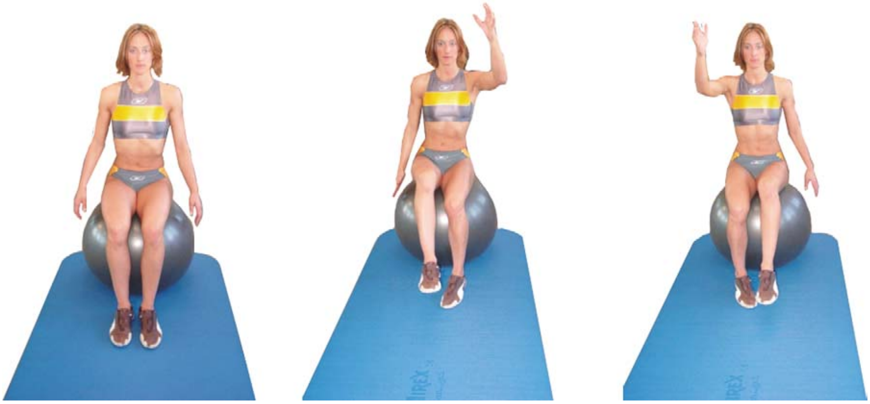

Fig. 9. Seated marching on a physioball. This exercise is more difficult because the athlete positions her body against gravity in a seated position on an unstable surface. The athlete begins by sitting upright on a physioball, with the lumbar spine in a neutral position (midrange). She places her feet hip-width apart. While bracing the abdominal muscles, she lifts one leg and foot off the ground. (The limb does not need to be lifted high, just enough to be off the ground—∼2 inches to start.) The athlete should focus on controlling the weight shifting to the weight-bearing limb while maintaining lumbopelvic stability. Progression: once lumbo-pelvic stability can be maintained with alternate leg lifts, the athlete can add opposite arm lifts.

For a more detailed discussion on the theoretic basis for core strengthening, the reader is referred to a recent review article by Akuthota and Nadler [9].

Muscle imbalances

Stability work should be started only after the athlete has achieved good mobility, because adequate muscle length and extensibility are crucial to proper joint function and efficiency. Also required is a proper relationship between the prime movers, synergists, and stabilizers. A prime mover is the muscle that provides most of the force during a desired body movement. Stabilizers and synergists are muscles that assist in the motion by means of control or neutralizing forces. Proper timing and coordinated effort of these muscles is paramount to the runner, and the functional exercises included here stress these relationships.

A thorough evaluation of the muscular system should include an assessment of the muscles for overactivity, shortening, weakness, inhibition, and quality of motion. This is accomplished best by using muscle-length tests, strength tests, and tests for the efficiency of basic movement patterns and neuromuscular control. A thorough postural observation and video-taping of the athlete's running gait will help in assessing and identifying any movement imbalances.

Muscles that are used frequently can shorten and become dominant in a motor pattern. If a muscle predominates in a motor pattern, its antagonist

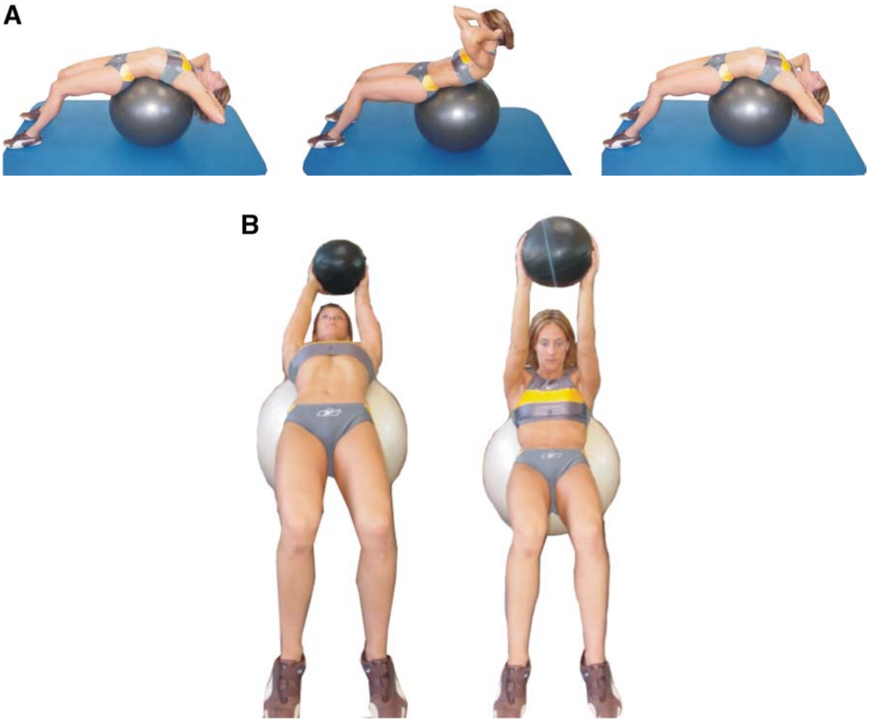

Fig. 10. (*A*) Spinal flexion on fit-ball. The athlete preactivates her abdominal brace in the starting position and maintains this as she rolls back into spinal extension. She slowly raises the body, focusing the rotation in the thoracic spine. Picture the head and neck as a rigid block on the thoracic spine to prevent flexing the cervical spine. The athlete concentrates on attempting to touch the bottom of her ribs to her pelvis anterior superior iliac spine. The hands can be placed over the ears to eliminate pulling on the neck. (*B*) Progression: a 5- to 10-pound medicine ball is held in front of the chest with the arms extended. By reaching up and diagonally, the oblique muscles can be emphasized.

may become inhibited and cause a muscle imbalance. An example of this is tightness in the iliopsoas muscle—the primary hip flexor that has its origins at the anterolateral aspect of the lumbar vertebral bodies and its transverse processes. When the iliopsoas muscle is tight or shortened, it is believed to inhibit the deep abdominals and the primary hip extensor—the gluteus maximus. Inhibition of the gluteus maximus muscles may result in inadequate stabilization of the lumbar spine, with increased anterior shear and extension forces on the lower lumbar vertebrae.

Muscles are divided into two types: postural and phasic (Box 1). Postural muscles are used for standing and walking. Phasic muscles are used for running; they propel the runner. Although 85% of the gait cycle is spent on one leg when walking [10], when running, there is a double-float phase during which both legs are off the ground—one at the beginning and one at

Fig. 11. Alternate leg bridge with shoulders on ball. The athlete starts this exercise by sitting on the physioball and walking forward with her feet on the ground, slowly leaning back until her back rests on the ball. This is called the bridge position. The head, neck, and shoulder blades should be supported on the ball. Knees should be bent at a 90° angle, with feet on the ground. While bracing the abdominal muscles, the athlete raises the foot and extends the leg off the ground. The weight is be shifted to one side, and the athlete should focus on maintaining stability of the lumbo-pelvic region. The athlete should strive for stability and balance, while holding this position for 10 seconds and alternating lower limbs. Progression: lift the arms up in the air or out to the sides.

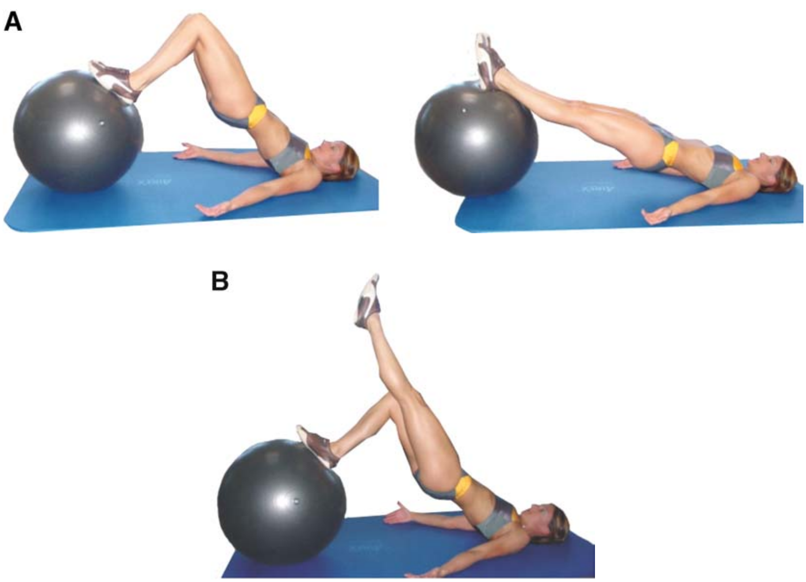

Fig. 12. (*A*) Leg curls on a physioball. The purpose of this dynamic core stabilization exercise is to recruit both actions of the hamstrings—hip extension and knee flexion—while maintaining dynamic stability of the lumbar spine. In a supine position on the floor, the athlete places both feet on the physioball. (Shoes should be removed to allow increased proprioception from the exteroceptors of the feet.) The athlete keeps her arms on the floor at the sides of the body for balance and raises the hips off the ground until the knees, hips, and shoulders create a straight line. She should focus on holding the spine in a neutral midrange position. In this position, the athlete pushes the ball forward with the feet while maintaining the bridge. The goal is to keep the pelvis elevated (hip extension) as both legs extend and flex at the knees. While the knees extend and flex from this elevated bridge position, the athlete focuses on maintaining lumbopelvic stability. (*B*) Progression: continue with single-leg hamstring curls in the same position.

Fig. 13. Abdominal rollout. This is an excellent exercise to train the abdominals eccentrically. The athlete kneels behind the ball, with both hands on the ball. Keeping the abdominals braced and lower back in a neutral position, she rolls the ball away from her body a short distance until there is a straight line from the shoulder to hips. While maintaining alignment, she pulls the ball back towards them a short distance, then pushes it away a short distance. The movement should occur only at the shoulders, not the back. Progression: gradually straighten the body until up on the toes. There should be a straight line from the back of the head to the knees. Now move the ball away and back toward the body a short distance with the arms.

the end of swing phase. Running mechanics demand efficient firing patterns from the postural muscles, whereas phasic muscles do the work of propelling the runner forward. Because postural muscles are being activated constantly in the human body to fight the forces of gravity, they have a tendency to shorten and become tight. In runners, because of training and prolonged use, certain postural muscles are particularly likely to tighten, shorten, and become hypertonic. This occurs predominately in muscles that

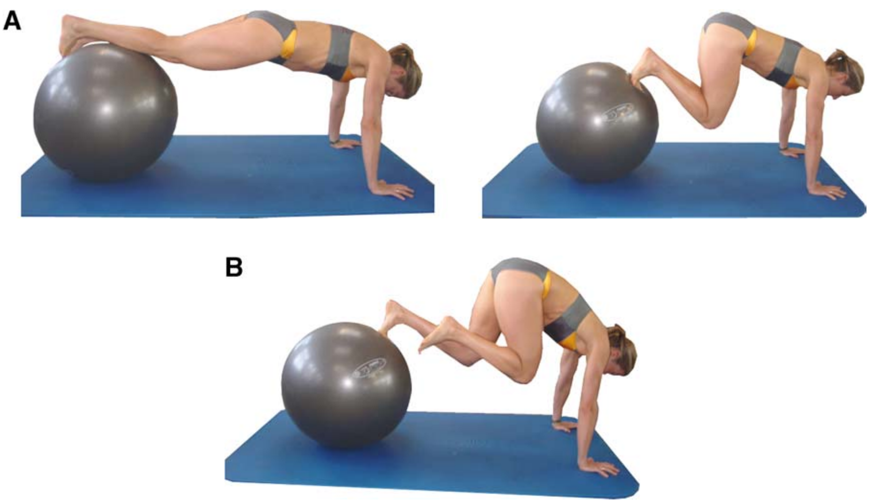

Fig. 14. (*A*) Squat ball thrust. Keeping the abdominals braced and lower back and shoulder blades in a neutral position, the athlete uses her abdominal contraction to move the ball forward and back. Keep the spine in neutral alignment throughout the movement. If the exercise is too challenging, start with the shins instead of the toes on the ball. (*B*) Progression: perform the exercise with only one foot on the ball.

Fig. 15. Forward/backward rocking. In this exercise, the rocker board is used to challenge balance in a frontal plane of motion. Standing on the rocker board with both feet in perfect postural alignment, the athlete gently rocks forward and backward. (To maintain ideal posture, the athlete can create an imaginary line through the joints of the ankle, knee, hip, and shoulder. The ear should align in a straight line with these joints, with no excessive extension [swayback] of the lumbar spine or anterior pelvic rotation.) While rocking, there should be no excess body movement in the coronal or transverse planes. This exercise should be performed for several minutes. The goal is to align the spinal curves and lower extremities optimally. Progression: the athlete can progress to a slight flexed-knee position, with fast and slow movements to stimulate the righting reflexes and balance reactions. She also can progress the stepping motion to the three axes of motion.

cross more than one joint [11]. We commonly see this in the gastroc-soleus (predominantly the soleus), rectus femoris, iliopsoas, tensor fascia lata, hamstrings, adductors, quadratus lumborum, piriformis, and sartorius. Restricted extensibility of muscles also can lead to decreased circulation and ischemia, which contributes to overuse injury [12].

In comparison, phasic muscles (the more global muscles) typically may remain in an elongated state. It was shown that elongated muscles may lack force in shortened-range test positions [13]. Weak phasic muscles might allow excessive motion to occur at the joints upon which they act. In our experience, common phasic muscles that have a tendency to develop weakness or become inhibited in runners are the tibialis anterior; peronei; vastus medialis; long thigh adductors; and the gluteus maximus, medius, and minimus.

Beginning a core strengthening program

The first step in a preventive or performance-enhancing program is to assess which muscles have become tight and shortened. These deficits can be

Fig. 16. Single-leg balance: three planes. This next exercise progresses the athlete to a single-leg stance. The rocker board is used in the three planes of motion. This exercise also can be performed with a balance board, which is more demanding because it incorporates all planes of motion simultaneously. The athlete takes one step forward while maintaining alignment and balance, controlling aberrant motion, and mimicking a forward running motion. The goal is to maintain lumbo-pelvic alignment. The athlete controls movement in the three planes of motions by placing her feet in various positions on the board. The athlete alternately steps forward and backward onto the rocker board. Progression: once the athlete achieves static stability and can remain stable while standing on the rocker board, she can add an accessory motion. The athlete can swing the arm and the nonweight-bearing opposite leg (as though mimicking running). No excessive motion in the pelvis or lumbar spine should occur during the swing phase.

addressed with stretching exercises and soft tissue mobilization techniques. Following this, the clinician should seek to activate inhibited, or strengthen any weak, muscle groups. The challenge for the clinician is to design an individualized program that addresses these imbalances.

Preliminary stretches for shortened, predominant muscles should include proprioceptive neuromuscular facilitation–type or contract-relax stretches that strive for isometric contraction, followed by end-range stretching. These are effective techniques for maintaining muscle length and joint mobility. Active Release Techniques [12], (a specialized method for soft tissue mobilization) when used in conjunction with stretching techniques, have shown great promise in restoring muscle length and soft tissue extensibility. Athletes also can do self-mobilization with the use of a foam roll. One example of this technique, which targets the iliotibial band, is shown in Fig. 1.

Middle-distance runners have unique and specific training programs that demand strength, power, and endurance. These runners place terrific demands for balance and precise functioning of structures all the way from the core to the feet. Specific exercises for the runner should progress from mobility to stability, reflexive motor patterning, acquiring the skills of fundamental movement patterns, and finally, progressive strengthening.

Fig. 17. Weight transfers with proper alignment. The preceding exercise progresses to "falling" onto an unstable surface. Pictured is a rocker board and "falling" onto a circular balance board. Again, emphasis is on spinal alignment from the head to the sacrum. The athlete steps forward quickly and catches himself from falling over with a quick forward movement of the leg onto the board.

These sequences may not be applicable to all athletes; therefore, the key is to analyze the individual in each exercise category and then to tailor an exercise regimen that will best suit that runner's needs. For example, it was shown that runners who are prone to iliotibial band syndrome often have weakness in their hip abductors that predisposes them to increased stress on the iliotibial band [14]. Thus, a preventative training program for runners who have this syndrome must target the hip abductors, particularly the posterior aspect of the gluteus medius that assists external rotation or in decelerating adduction of the hip. Other muscles that prove weak or inhibited on evaluation also should be strengthened on a case-by-case basis.

The stages of core training

Warm-up

Before beginning the basic core strengthening exercises, the athlete should warm-up the spine with the Cat-Camel motion (Fig. 2).

Fundamental lumbo-pelvic stability

The purposes of the fundamental core stabilization exercises are to gain stability, but more importantly, to gain coordination and timing of the deep abdominal wall musculature. It is extremely important to do these basic exercises correctly because they are the foundation of all other core exercises and movement patterns. These basic exercises emphasize maintaining the lumbar spine in a neutral position (which is the midrange position between

Fig. 18. Power runner with resistance. This exercise provides a functional movement pattern that is similar to running. The exercise seeks to increase stability of the lower abdominals while using a forward motion at the hip. The exercise is designed to develop sagittal plane control. While balancing on one leg, the athlete imitates a running motion. As the upper thigh is lifted forward in a running motion, the athlete concentrates on maintaining the abdominal brace and lumbo-pelvic stability while avoiding excessive anterior or posterior pelvic rotation. The athlete raises the opposite arm simultaneously into flexion, while maintaining postural alignment with an erect spine, and allowing only the extremities to move. Progression: once the athlete can maintain lumbar spine stability without effort, she can attach a pulley or resistive cord to the ankle to increase the challenge to the hip flexors.

lumbar extension and flexion.) This alignment allows for the natural curvature of the spine. All of these exercises are best done with light loads and high repetitions.

This first stage of core stability training begins with the athlete learning to stabilize the abdominal wall. Proper activation of these muscles is considered crucial in the first stages of a core stability program, before progressing to more dynamic and multiplanar activities. We recommend the abdominal bracing technique as described by McGill (Fig. 3) [4].

The exercise program should progress sequentially through the initial fundamental movements as detailed in Figs. 4 through 8. These fundamental exercises are to be performed three times a week to maximize results. The athlete begins with two sets of 15 repetitions and progresses to three sets of 15 to 20 repetitions to develop fully the requisite muscle endurance for higher level performance. Initially, these exercises are taught in a supine, hook-lying position or an all-fours quadruped position. The athlete can progress to more functional standing exercises as control is developed. Important concepts that are taught at this stage include not tilting the pelvis or flattening the spine. We also emphasize normal rhythmic breathing.

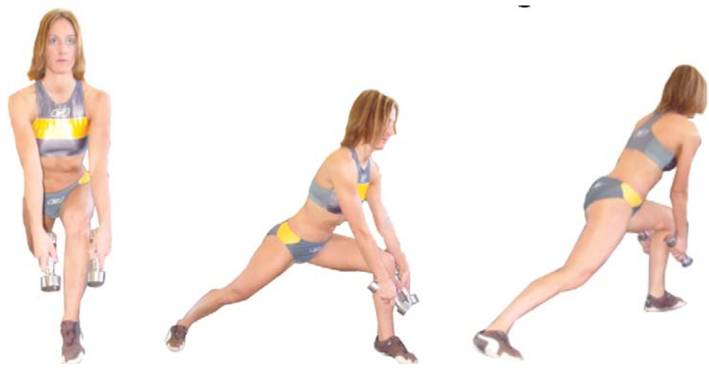

Fig. 19. Multidirectional lunges. The athlete begins this exercise with a forward lunge. Again, emphasis is on maintaining a neutral spine position and abdominal brace throughout the entire movement. The athlete steps forward, limiting knee flexion of the forward leg to 90°. The knee joint should be over the ankle joint and the patella should be aligned with the second toe. The lower part of the leg should be perpendicular to the ground. Progression: once strength and stability in the forward (sagittal) plane have been achieved, the athlete can begin stepping out at oblique angles, creating a narrower lunge or a wider lunge in the coronal or transverse planes.

Advanced lumbo-pelvic stability

Once the athlete demonstrates good stability with all static core exercises, they can be replaced with more advanced exercises as detailed in Figs. 9 through 14. The use of the physioball requires the athlete to work on proprioception and higher level core stabilization. These exercises should be performed two to three times weekly to maximize results. Again, the athlete begins with one or two sets of 15 repetitions and progresses to three sets of 15 to 20 repetitions. Quality is more important than quantity. Make sure that the lumbar spine does not go into extension or the cervical/thoracic spine into flexion and maintain the spine in perfect alignment.

As the athlete progresses through a core exercise program, the emphasis always should be on correct postural alignment as athletes challenge themselves with a variety of movement patterns in the three planes of movement: sagittal, frontal, and transverse. Although runners move predominately in the sagittal plane, there still is body movement in the transverse and frontal planes that must be controlled adequately by the neuromuscular system. During midstance of the running gait cycle, the foot and ankle unlock to allow absorption of ground reaction forces. During this phase, the body is challenged most to control excessive or aberrant motion in the frontal and transverse planes. Functional exercises on one leg are used to best simulate the neuromuscular demands of running. The athlete is trained with increasingly challenging functional patterns, with continued emphasis on postural control and core stabilization. The ultimate goal of core stabilization is to train "movements" and "positions," rather than

Fig. 20. Power runner with resistance and step-up. Continued progression: strength and stability with previous lunges must be achieved before starting this exercise. These exercises use a sports cord to resist shoulder and hip flexion while doing step-ups. The movement pattern is similar to the athlete's running gait. The opposite arm and leg are resisted simultaneously to increase strength and coordination of this movement pattern.

muscles. Exercises are most effective when they mirror the demands of the athlete's sport.

Development of balance and motor control

The following movements require reflexive control. The athlete can accomplish this control by using the numerous proprioceptors in the soles of the feet and the exteroceptors of the skin, and by activating the neck muscles; these are highly contributory to postural regulation. This sensory-motor stimulation is an attempt to provide the subcortex with a basis for movement that is progressively more challenging. It involves exercises that stimulate balance, coordination, precision, and skill acquisition.

The following exercises should be performed while standing (Figs. 15–17). We instruct the athlete to control the feet, pelvis, and head consciously, with the goal of making sure that the feet are aligned properly.

These exercises use a rocker board. A rocker board is a board with a hemisphere underneath that allows single-plane rocking. (The board was designed by Dr. Vladimer Janda to promote balance and stability of the spine, www.optp.com).

Common errors or abnormal compensations to look for when attempting these exercises include increased anterior pelvic tilt, increased lumbar lordosis, increasing internal rotation of the hip, excessive valgus at the knee, and hyperpronation at the foot. Therefore, when teaching these exercises, it

Fig. 21. Multidirectional resisted alternate arm/leg step-ups. Continued progression: once strength and stability are achieved in the frontal plane of motion the athlete can begin stepping up at 45°.

Fig. 22. Standing pulley or medicine ball rotation. This resistive, dynamic trunk pattern challenges the core with a rotational movement pattern while the athlete maintains stability in the hips and pelvis. It requires strict bracing of the abdominals and locking the rib cage and pelvis together to avoid unnecessary torsional stress on the spine. The athlete stands with feet about shoulder-width apart and knees slightly bent. She activates the abdominal brace before the movement. It is important to emphasize postural alignment, with the scapulae retracted and depressed. The athlete should maintain neutral spinal angles throughout the movement. Holding a straight-arm position (elbows extended) while grasping the pulley handle or medicine ball with both hands, the athlete rotates the trunk by activating the abdominal obliques and spinal rotators. She concentrates on keeping the arms extended in front of the chest. It is important that the pelvis remains stable in the movement. Resistance is perpendicular to the body. Progression: This exercise can be done in the same manner using increasing weight on the pulley or a 5- to 10-pound medicine ball.

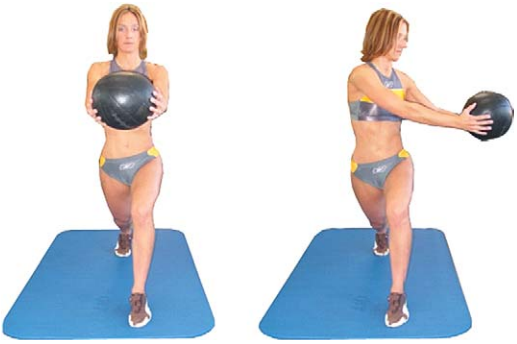

Fig. 23. Forward lunge with a medicine ball with trunk rotation. This exercise uses a resistive movement of the trunk with a lunge that demands a high level of lumbo-pelvic and lower extremity stability as the athlete moves the ball in a diagonal pattern across the body. Athletes need approximately 30 yards to complete this exercise. The athlete stands upright, holding onto a 5- to 10-pound medicine ball, with arms outstretched, perpendicular to the body. The athlete steps forward with the medicine ball in front of the chest with the arms extended. Once the lunge portion is completed, the athlete rotates the trunk by bringing the ball across the body toward the same side as the front leg and then returns the ball to midline as the next step is made. It is important that the knee joint on the stepping limb does not come forward past the vertical angle relative to the ankle joint. The second toe is aligned perpendicular with the patella. The purpose of this exercise is to challenge the trunk muscles with appropriate weight shift, balance, and control on one leg.

is imperative to instruct the athlete on proper spinal alignment. To aid in this, we recommend initiating the abdominal bracing technique before performing the stepping forward-and-backward motions of any of these exercises (which train correct weight transfer over the feet). Additionally, it is important to instruct the athlete on proper gait. The focus here should be on controlling the initial heel strike in a supinated position on the lateral edge of the foot, into pronation on the medial aspect of the foot, with flexion of the first metatarsal head and toes. Continuing proper gait instruction, we teach a falling-forward position into a lunge (with perfect control). The athlete then progresses to jumps on one or two legs, assuring that there is no increased lumbar lordosis or increased valgus moment at the knee. This stimulates vestibular and cerebellar activity, which, in turn, leads to automatic postural control—an important part of our training. (Readers will note the increased muscle activity of the ankles and muscles that control the lower extremity chain and spine.) The athlete can progress to standing on one leg, with alternating arm movements.

Various devices are useful to challenge balance progressively, moving the athlete from conscious to subconscious control of the muscles that are responsible for postural maintenance and gait. These devices include a balance board (a whole sphere underneath the board, which creates multiplanar instability) or a rocker board (a curved surface underneath the board, which allows single-plane motion). Dynamic foam rollers are an

Fig. 24. Standing reverse wood chop with a medicine ball. This exercise is a resistive diagonal pattern of the trunk that demands a high level of lumbo-pelvic stability and combines upper- and lower-chain integration as the ball is moved in a diagonal pattern across the body. The athlete stands, holding onto a 5- to 10-pound medicine ball with both hands, with the feet approximately shoulder-width apart. While holding the arms in front of the body with elbows extended, the athlete moves the ball from a lower position at the hip, raising it across the body to the opposite shoulder, simulating a wood-chopping motion. The motion is then reversed by starting at the lower knee position and bringing the ball diagonally across the body, ending overhead toward the opposite shoulder. This exercise also can be performed with resistive cords or a pulley system that simulate the same motions. Progression: the athlete can progress to standing on one leg, using the opposite arm to complete the motion.

inexpensive alternative to the boards that also can be used to challenge balance, proprioception, and stability. These include half-rollers and full-sized rollers. Two other items that are invaluable to challenge balance and core stability and aid proprioceptive training in the standing position are the Bosu Balance Trainer and the Dyna Disk (these can be used interchangeably). The Bosu has two functional surfaces that integrate dynamic balance with sports-specific or functional training: the domed surface is convex, the other side is flat and can be used for less challenge. The Dyna Disk is an air-filled plastic disc that can be inflated firmly. It has a smaller diameter than the Bosu and can be used like the Bosu Trainer because it creates an increased proprioceptive challenge to the athlete while standing on it. The Dyna Disk is unstable and does not have a base like the Bosu Trainer.

Functional movement training

Functional movements require acceleration, deceleration, and dynamic stabilization. Figs. 18 through 24 present an array of functional, diagonal exercises for the trunk and extremities that are essential for runners. Exercises should be safe, challenging, and stress multiplanar motions. These training exercises encourage functional strength, which depends on the

Table 1
Periodization of core training program

Summer/Fall—base training (3×/wk, 3 sets of 15–20 repetitions for each exercise)	Winter—sport specific (2–3×/wk, 2–3 sets of 10–15 repetitions for each exercise)	Spring/Summer—competition (1–2×/wk, 2–3 sets of 8–12 repetitions for each exercise)
Restore mobility/address any muscle imbalances Fundamental core stability exercises Sensory motor stimulation	Advanced core stability exercises Functional movement training	Similar to sports specific training with addition of plyometric exercises

neuromuscular system's ability to produce dynamic eccentric, concentric, and isometric contractions during movement patterns.

A functional exercise regimen that is specific to the demands of running includes single-leg drills, three-dimensional lunges, resistive diagonal patterns of the upper and lower extremities, drills that involve plyometrics, and triplanar movement sequences. Athletes can progress through the three planes of motion by performing similar exercises on balance boards, the Dyna Disk, or Bosu-type trainers, after static trunk and core stability have been mastered.

Summary

This article is intended to provide an understanding of the importance of core musculature to runners and to offer exercises that will help them achieve desired mobility, stability, muscular balance, and neuromuscular control. Please see Table 1 for an example of how to incorporate these exercises into a periodized training program. It is highly recommended, however, that athletes consult a skilled practitioner to address individual needs and maximize results from a program of this nature.

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