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Establishing Core Stability in Rehabilitation

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OBJECTIVES

After completion of this chapter, the rehab professional should be able to do the following:

- Describe the functional approach to kinetic chain rehabilitation.
- Define the concept of the core.
- Discuss the anatomic relationships between the muscular components of the core.
- Explain how the core functions to maintain postural alignment and dynamic postural equilibrium during functional activities.
- Describe procedures for assessing the core.
- Discuss the rationale for core stabilization training and relate to efficient functional performance of activities.
- Identify appropriate exercises for core stabilization training and their progressions.
- Discuss the guidelines for core stabilization training.

A dynamic, core stabilization training program is routinely incorporated as a component of all comprehensive functional rehabilitation programs.[1–6] For athletes at all levels, core strengthening and stability exercises have become key components of training and conditioning programs.[7] A core stabilization program improves dynamic postural control, ensures appropriate muscular balance, and affects joint arthrokinematics around the lumbo-pelvic-hip complex, thereby affecting the entire movement system. A carefully crafted core stabilization program allows for the expression of dynamic functional strength and improves neuromuscular efficiency throughout the entire kinetic chain.[4,5,8–18] A core stabilization program can enhance functional movement patterns and dynamic postural control.[19]

What Is the Core?

The core is defined as the lumbo-pelvic-hip complex.[4,8] The core is where our center of gravity is located and where all movement begins.[20–23] There are 29 muscles that have an attachment to the lumbo-pelvic-hip complex.[4,24–26] An efficient core allows for maintenance of the normal length-tension relationship of functional agonists and antagonists, which allows for the maintenance of the normal force-couple relationships in the lumbo-pelvic-hip complex. Maintaining the normal length-tension relationships and force-couple relationships allows for the maintenance of optimal arthrokinematics in the lumbo-pelvic-hip complex during functional kinetic-chain movements.[15,16,27] This provides optimal neuromuscular efficiency in the entire kinetic chain, allowing for optimal acceleration, deceleration, and dynamic stabilization of the entire kinetic chain during functional movements. It also provides proximal stability for efficient lower-extremity and upper-extremity movements.[4,6,8,15,16,20–23,28]

The core operates as an integrated functional unit, whereby the entire kinetic chain works synergistically to produce force, reduce force, and dynamically stabilize against abnormal force.[8] In an efficient state, each structural component distributes weight, absorbs force, and transfers ground reaction forces.[8] This integrated, interdependent system needs to be trained appropriately to allow it to function efficiently during dynamic kinetic chain activities.

Core stabilization exercise programs have been labeled many different terms, some of which include *dynamic lumbar stabilization, neutral spine control, muscular fusion,* and *lumbo-pelvic stabilization*. We use the phrase *butt and gut* to educate our patients, colleagues, and health care students. This catchy phrase illustrates the importance of the entire abdominal and pelvic region working together to provide functional stability and efficient movement.

Core Stabilization Training Concepts

Many individuals develop the functional strength, power, neuromuscular control, and muscular endurance in specific muscles that enable them to perform functional activities.[6,8,29,30] However, few people develop the muscles required for spinal stabilization.[28,30,31] The body's stabilization system has to function optimally to effectively use the strength, power, neuromuscular control, and muscular endurance developed in the prime movers. If the extremity muscles are strong and the core is weak, then there will not be enough trunk stabilization created to produce efficient upper-extremity and lower-extremity movements. It has been suggested that a weak core is a fundamental problem of many inefficient movements that leads to injury.[6,28,30,31] While deficits in various aspects of core stability have been identified as potential risk factors for lower extremity injuries[32], exercising the trunk muscles is supposed to prevent injuries via protection of the spinal column.[33] However, while it is generally accepted that having good core strength improves athletic performance, a correlation between trunk muscle strength and performance has not been clearly identified in the research literature.[34–37]

The core musculature is an integral component of the protective mechanism that relieves the spine of deleterious forces inherent during functional activities.[33,38] A core stabilization training program is designed to help an individual gain strength, neuromuscular control, power, and muscle endurance of the lumbo-pelvic-hip complex. But the focus of a core stabilization program should not be primarily on strength, but instead on stability, balance, and proprioception, affecting the entire movement system.[39] This approach facilitates a balanced muscular functioning of the entire kinetic chain.[8] Greater neuromuscular control and stabilization strength will offer a more biomechanically efficient position for the entire kinetic chain, thereby allowing optimal neuromuscular efficiency throughout the kinetic chain. It has been shown that core stability exercise was more effective than general exercise for decreasing pain and increasing back-specific functional status in patients with low back pain.[40]

Neuromuscular efficiency is established by the appropriate combination of postural alignment (static/dynamic) and stability strength, which allows the body to decelerate gravity, ground reaction forces, and momentum at the right joint, in the right plane, and at the right time.[5,41,42] If the neuromuscular system is not efficient, it will be unable to respond to the demands placed on it during functional activities.[8] As the efficiency of the neuromuscular system decreases, the ability of the kinetic chain to maintain appropriate forces and dynamic stabilization decreases significantly. This decreased neuromuscular efficiency leads to compensation and substitution patterns, as well as poor posture during functional activities.[11,15,16] Such poor posture leads to increased mechanical stress on the contractile and noncontractile tissue, leading to repetitive microtrauma, abnormal biomechanics, and injury.[10,11,43,44]

Clinical Pearl

Higher-level athletes require proper core strength and neuromuscular control/synchrony in order to perform total body motions necessary for their respective sport. This includes timing, efficiency, and complex motor programs used to avoid injury throughout the entire kinetic chain that is linked through the core. Picture an otherwise healthy, fit gymnast experiencing low back pain that you suspect is disc related. How could core dysfunction be contributing to her pain and lead to further complications if the core is not addressed from a neuromuscular control perspective?

Review of Functional Anatomy

To fully understand functional core stabilization training and rehabilitation, the rehab professional must fully understand functional anatomy, lumbo-pelvic-hip complex stabilization mechanisms, and normal force-couple relationships.[24–26,45]

A review of the key lumbo-pelvic-hip complex musculature will allow the rehab professional to understand functional anatomy and thereby develop a comprehensive kinetic chain rehabilitation program. The key lumbar spine muscles include the transversospinal group, erector spinae, quadratus lumborum, and latissimus dorsi (Figure 15-1B). The key abdominal muscles include the rectus abdominis, external oblique, internal oblique, and transversus abdominis (TA) (Figure 15-1A). The key hip musculature includes the gluteus maximus, gluteus medius, and psoas (Figure 15-1B).

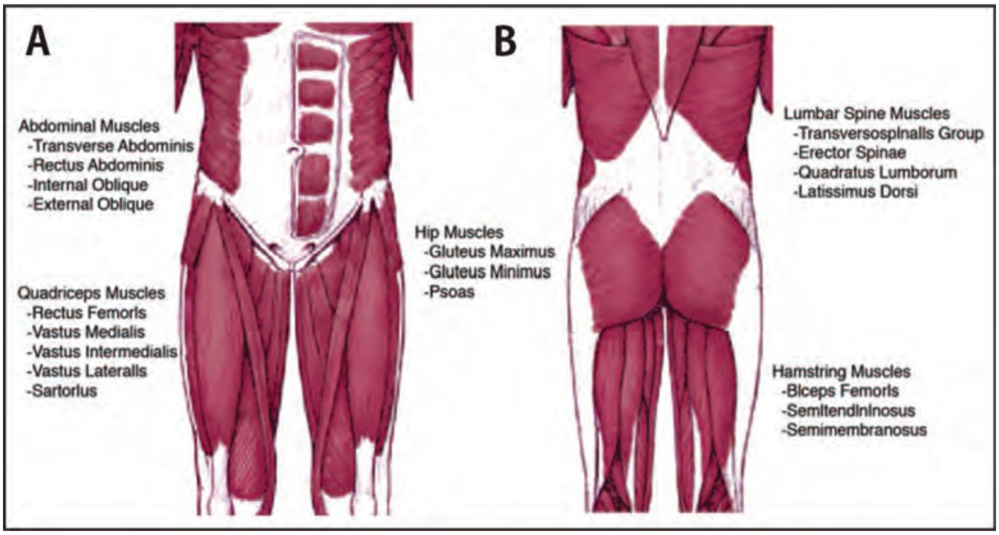

Figure 15-1 **Key core muscles**

A. Anterior view. **B.** Posterior view.

Transversospinalis Muscle Group

The transversospinalis group includes the rotatores, interspinales, intertransversarii, semispinalis, and multifidus. These muscles are small and have a poor mechanical advantage for contributing to motion.[26,33,46] They contain primarily type I muscle fibers and are therefore designed mainly for stabilization.[26,46] Researchers[26] have found that the transversospinalis muscle group contains two to six times the number of muscle spindles found in larger muscles. Therefore, it has been established that this group is primarily responsible for providing the central nervous system with proprioceptive information.[26] This group is also responsible for inter- or intrasegmental stabilization and segmental eccentric deceleration of flexion and rotation of the spinal unit during functional movements.[26,45] The transversospinalis group is constantly put under a variety of compressive and tensile forces during functional movements; consequently, it needs to be trained adequately to allow dynamic postural stabilization and optimal neuromuscular efficiency of the entire kinetic chain.[26] The multifidus is the most important of the transversospinalis muscles. It has the ability to provide intrasegmental stabilization to the lumbar spine in all positions.[47,48] Wilke and Wolf[48] found increased segmental stiffness at L4-L5 with activation of the multifidus. Additional key back muscles include the erector spinae, quadratus lumborum, and the latissimus dorsi. The erector spinae muscle group functions to provide dynamic intersegmental stabilization and eccentric deceleration of trunk flexion and rotation during kinetic chain activities.[26] The quadratus lumborum muscle functions primarily as a frontal plane stabilizer that works synergistically with the gluteus medius and tensor fascia lata. The latissimus dorsi has the largest moment arm of all back muscles and therefore has the greatest effect on the lumbo-pelvic-hip complex. The latissimus dorsi is the bridge between the upper extremity and the lumbo-pelvic-hip complex. Any functional upper-extremity kinetic chain rehabilitation must pay particular attention to the latissimus and its function on the lumbo-pelvic-hip complex.[26]

Abdominal Muscles

The abdominals are composed of four muscles: rectus abdominis, external oblique, internal oblique, and, most importantly, the TA.[26] The abdominals operate as an integrated functional unit, which helps maintain optimal spinal kinematics.[24–26,45] When working efficiently, the abdominals offer sagittal, frontal, and transversus plane stabilization by controlling forces that reach the lumbo-pelvic-hip complex.[26] The rectus abdominis eccentrically decelerates trunk extension and lateral flexion, as well as provides dynamic stabilization during functional movements. The external obliques work concentrically to produce contralateral rotation and ipsilateral lateral flexion, and work eccentrically to decelerate trunk extension, rotation, and lateral flexion during functional movements.[26] The internal oblique works concentrically to produce ipsilateral rotation and lateral flexion and works eccentrically to decelerate extension, rotation, and lateral flexion. The internal oblique attaches to the posterior layer of the thoracolumbar fascia. Contraction of the internal oblique creates a lateral tension force on the thoracolumbar fascia, which creates intrinsic translational and rotational stabilization of the spinal unit.[21,28] The TA is probably the most important of the abdominal muscles. The TA functions to increase intraabdominal pressure (IAP), provide dynamic stabilization against rotational and translational stress in the lumbar spine, and also provide optimal neuromuscular efficiency to the entire lumbo-pelvic-hip complex.[28,30,31,49,50] Research demonstrates that the TA works in a feedforward mechanism.[28] Researchers have demonstrated that contraction of the TA precedes the initiation of limb movement and all other abdominal muscles, regardless of the direction of reactive forces.[28,51] Cresswell and colleagues[47,51] demonstrated that like the multifidus, the TA is active during all trunk movements, suggesting that this muscle has an important role in dynamic stabilization.[30]

Hip Muscles

Key hip muscles include the psoas, gluteus medius, gluteus maximus, and hamstrings.[24–26] The psoas produces hip flexion and external rotation in the open chain position, and produces hip flexion, lumbar extension, lateral flexion, and rotation in the closed-chain position. The psoas eccentrically decelerates hip extension and internal rotation, as well as trunk extension, lateral flexion, and rotation. The psoas works synergistically with the superficial erector spinae and creates an anterior shear force at L4-L5.[26] The deep erector spinae, multifidus, and deep abdominal wall (transverses, internal oblique, and external oblique)[35] counteract this force. It is extremely common for patients to develop tightness in their psoas. A tight psoas increases the anterior shear force and compressive force at the L4-L5 junction.[26] A tight psoas also causes reciprocal inhibition of the gluteus maximus, multifidus, deep erector spinae, internal oblique, and TA. This leads to extensor mechanism dysfunction during functional movement patterns.[13,14,16–18,26,44] Lack of lumbo-pelvic-hip complex stabilization prevents appropriate movement sequencing and leads to synergistic dominance by the hamstrings and superficial erector spinae during hip extension. This complex movement dysfunction also decreases the ability of the gluteus maximus to decelerate femoral internal rotation during heel strike, which predisposes an individual with a knee ligament injury to abnormal forces and repetitive microtrauma.[13,14,17,38,52]

The gluteus medius functions as the primary frontal plane stabilizer of the pelvis and lower extremity during functional movements.[26] During closed-chain movements, the gluteus medius decelerates femoral adduction and internal rotation.[26] A weak gluteus medius increases frontal and transversus plane stress at the patellofemoral joint and the tibiofemoral joint.[26] A weak gluteus medius leads to synergistic dominance of the tensor fascia latae and the quadratus lumborum.[17,52,53] This leads to tightness in the iliotibial band and the lumbar spine. This will affect the normal biomechanics of the lumbo-pelvic-hip complex and the tibiofemoral joint, as well as the patellofemoral joint. Research by Beckman and Buchanan[54] demonstrates decreased electromyogram (EMG) activity of the gluteus medius following an ankle sprain. Therapists must address the altered hip muscle recruitment patterns or accept this recruitment pattern as an injury-adaptive strategy, and thus accept the unknown long-term consequences of premature muscle activation and synergistic dominance.[11,54]

The gluteus maximus functions concentrically in the open chain to accelerate hip extension and external rotation. It functions eccentrically to decelerate hip flexion and femoral internal rotation.[26] It also functions through the iliotibial band to decelerate tibial internal rotation.[26] The gluteus maximus is a major dynamic stabilizer of the sacroiliac (SI) joint. It has the greatest capacity to provide compressive forces at the SI joint secondary to its anatomic attachment at the sacrotuberous ligament.[26] It has been demonstrated by Bullock-Saxton[10,55] that the EMG activity of the gluteus maximus is decreased following an ankle sprain. Lack of proper gluteus maximus activity during functional activities leads to pelvic instability and decreased neuromuscular control. This can eventually lead to the development of muscle imbalances, poor movement patterns, and injury.

Hamstring Muscles

The hamstrings work concentrically to flex the knee, extend the hip, and rotate the tibia. They work eccentrically to decelerate knee extension, hip flexion, and tibial rotation. The hamstrings work synergistically with the anterior cruciate ligament.[26] All of the muscles mentioned play an integral role in the kinetic chain by providing dynamic stabilization and optimal neuromuscular control of the entire lumbo-pelvic-hip complex. These muscles have been reviewed so that the rehab professional realizes that muscles not only produce force (concentric contractions) in one plane of motion, but also reduce force (eccentric contractions) and provide dynamic stabilization in all planes of movement during functional activities. When isolated, these muscles do not effectively achieve stabilization of the lumbo-pelvic-hip complex. It is the synergistic, interdependent functioning of the entire lumbo-pelvic-hip complex that enhances stability and neuromuscular control throughout the entire kinetic chain.

Transversus Abdominis and Multifidus Role in Core Stabilization

Transversus Abdominis

The transversus abdominis muscle is the deepest of the abdominal muscles and plays a role in trunk stability. The horizontal orientation of its fibers has a limited ability to produce torque to the spine necessary for flexion or extension movement, although it has been shown to be an active trunk rotator.[56] The TA is a primary trunk stabilizer via modulation of IAP, tension through the thoracolumbar fascia, and compression of the SI joints.[47,57] For many decades, IAP was believed to be an important contributor to spinal control by the pressure within the abdominal cavity putting force on the diaphragm superiorly and pelvic floor inferiorly to extend the trunk.[58–60] It was hypothesized that IAP would provide an extensor moment and thus reduce the muscular force required by the trunk extensors and decrease the compressive load on the lumbar spine.[61] Research by Hodges et al[62] applied electrical stimulation to the phrenic nerve of humans to produce an involuntary increase in IAP without abdominal or extensor muscle activity. IAP was increased by the contraction of the diaphragm, pelvic floor muscles, and the TA with no flexor moment noted. Research has demonstrated that IAP may directly increase spinal stiffness.[63] Hodges et al[62] used a tetanic contraction of the diaphragm to produce IAP, which resulted in increased stiffness in the spine. Bilateral contraction of the TA assists in IAP, thus enhancing spinal stiffness.

The role of the thoracolumbar fascia in trunk stability has also been discussed in the literature, and it has been theorized that the contraction of the TA could produce an extensor torque via the horizontal pull of the TA via its extensive attachment into the thoracolumbar fascia.[21] This theory was tested by Tesh and Shaw-Dunn [64] by placing tension on the thoracolumbar fascia of cadavers. No approximation of the spinous processes or trunk extension movement was noted, although a small amount of compression on the spine was noted. This small amount of compression may play a role in the control of intervertebral shear forces. Hodges et al[62] electrically stimulated contraction of the TA in pigs and demonstrated that when tension was developed in the thoracolumbar fascia, without an associated increase in IAP, there was no significant effect on the intervertebral stiffness. In the next step of that same research study, the thoracolumbar fascial attachments were cut and an increase in IAP decreased the spinal stiffness. This demonstrates that the thoracolumbar fascia and IAP work in concert to enhance trunk stability.[62]

Trunk stability is also dependent on the joints caudal to the lumbar spine. The SI joint is the connection between the lumbar spine and the pelvic region, which ultimately connects the trunk to the lower extremities. The SI joint is dependent on the compressive force between the sacrum and ilia. The horizontal direction and anterior attachment on the ilium of the TA produce the compressive force necessary for spinal stability. Richardson and Snijders[65] used ultrasound to detect movement of the sacrum and ilium while having subjects voluntarily contract their transverse abdominals. They demonstrated that a voluntary contraction of the TA reduced the laxity of the SI joint. This study also pointed out that this reduction in joint laxity of the SI joint was greater than that during a bracing contraction. The researchers did note that they were unable to exclude changes in activity in other muscles such as the pelvic floor, which may have reduced the laxity via counternutation of the sacrum.[65] The aforementioned research findings illustrate that the TA plays an important role in maintaining trunk stability by interacting with IAP, thoracolumbar fascia tension, and compressing the SI joints via muscular attachments.

Multifidi

The multifidi are the most medial of the posterior trunk muscles, and they cover the lumbar zygapophyseal joints except for the ventral surfaces.[56] The multifidi are primary stabilizers when the trunk is moving from flexion to extension. The multifidi contribute only 20% of the total lumbar extensor moment, whereas the lumbar erector spinae contribute 30%, and the thoracic erector spinae function as the predominant torque generator at 50% of the extension moment arm.[66] The multifidus, lumbar, and thoracic erector spinae muscles have a high percentage of type I fibers and are postural control muscles similar to the TA.[66] The multifidus has been shown to be active during all antigravity activities, including static tasks, such as standing, and dynamic tasks, such as walking.[48]

Clinical observation and experimental evidence confirm that when the TA contracts, the multifidi are also activated.[37] A girdle-like cylinder of muscular support is produced as a result of the coactivation of the TA, multifidus, and the thick thoracolumbar fascial system. EMG evidence suggests that the TA and internal obliques contract in anticipation of movement of the upper and lower extremities, often referred to as the feedforward mechanism. This feedforward mechanism gives the TA and multifidus muscular girdle a unique ability to stabilize the spine regardless of the direction of limb movements.[63,67] As noted previously, the pelvic floor muscles play an important role in the development of IAP, and thus enhance trunk stability. It has also been demonstrated that the pelvic floor is active during repetitive arm movement tasks independent of the direction of movement.[68]

Sapsford and Hodges [69] discovered that maximal contraction of the pelvic floor was associated with activity of all abdominal muscles and submaximal contraction of the pelvic floor muscles was associated with a more isolated contraction of the TA. In this same study, it also was determined that the specificity of the response was better when the lumbar spine and pelvis were in a neutral position.[69] Clinically, this information is helpful in guiding the patient in the process of TA contraction by instructing the patient to perform a submaximal pelvic floor isometric hold. Another interesting fact to note is that men and women with incontinence have almost double the incidence of low back pain as people without incontinence issues.[70] In summary, the lumbopelvic region may be visualized as a cylinder with the inferior wall being the pelvic floor, the superior wall being the diaphragm, the posterior wall being the multifidus, and the TA muscles forming the anterior and lateral walls. All walls of the cylinder must be activated and taut for optimal trunk stabilization to occur with all static and dynamic activities.

Clinical Pearl

Last year, a tennis player sustained a knee injury, injuring her ACL, MCL, and medial meniscus. The ACL and meniscus were surgically reconstructed/repaired. The athlete has completed her knee rehabilitation, and returned to tennis, but complains of recurrent back pain. She demonstrates poor posture and significant postural sway during stance and functional activities. How might you address these deficit? Could there be a core contribution? Remember that general exercise may not be sufficient to return athletes to high levels of function.

Postural Considerations

The core functions to maintain postural alignment and dynamic postural equilibrium during functional activities. Optimal alignment of each body part is a cornerstone to a functional training and rehabilitation program. Optimal posture and alignment will allow for maximal neuromuscular efficiency because the normal length-tension relationship, force-couple relationship, and arthrokinematics will be maintained during functional movement patterns.[4,11,13,15–17,38,43,50,53,71] If one segment in the kinetic chain is out of alignment, it will create predictable patterns of dysfunction throughout the entire kinetic chain. These predictable patterns of dysfunction are referred to as serial distortion patterns.[4] Serial distortion patterns represent the state in which the body's structural integrity is compromised because segments in the kinetic chain are out of alignment. This leads to abnormal distorting forces being placed on the segments in the kinetic chain that are above and below the dysfunctional segment.[4,6,11,38] To avoid serial distortion patterns and the chain reaction that one misaligned segment creates, we must emphasize stable positions to maintain the structural integrity of the entire kinetic chain.[4,6,10,13,14,72] A comprehensive core stabilization program prevents the development of serial distortion patterns and provides optimal dynamic postural control during functional movements.

Muscular Imbalances

An optimally functioning core helps to prevent the development of muscle imbalances and synergistic dominance. The human movement system is a well-orchestrated system of interrelated and interdependent components.[10,43] The functional interaction of each component in the human movement system allows for optimal neuromuscular efficiency. Alterations in joint arthrokinematics, muscular balance, and neuromuscular control affect the optimal functioning of the entire kinetic chain.[10,15,16] Dysfunction of the kinetic chain is rarely an isolated event. Typically, a pathology of the kinetic chain is part of a chain reaction involving some key links in the kinetic chain and numerous compensations and adaptations that develop.[43] The interplay of many muscles about a joint is responsible for the coordinated control of movement. If the core is weak, normal arthrokinematics are altered. Changes in normal length-tension and force-couple relationships, in turn, affect neuromuscular control. If one muscle becomes weak or tight, or changes its degree of activation, then synergists, stabilizers, and neutralizers have to compensate.[10–12,14–16,43]

Muscle tightness has a significant impact on the kinetic chain. Muscle tightness affects the normal length-tension relationship.[73] This impacts the normal force-couple relationship. When one muscle in a force-couple relationship becomes tight, it changes the normal arthrokinematics of two articular partners.[7,73,74] Altered arthrokinematics affect the synergistic function of the kinetic chain.[10,11,16,43] This leads to abnormal pressure distribution over articular surfaces and soft tissues. Muscle tightness also leads to reciprocal inhibition.[10,11,27,43,53,71,75] Therefore, if one develops muscle imbalances throughout the lumbo-pelvic-hip complex, it can affect the entire kinetic chain. For example, a tight psoas causes reciprocal inhibition of the gluteus maximus, TA, internal oblique, and multifidus.[17,26,31,53,76] This muscle imbalance pattern may decrease normal lumbo-pelvic-hip stability. Specific substitution patterns develop to compensate for the lack of stabilization, including tightness in the iliotibial band.[11] This muscle imbalance pattern leads to increased frontal and transverse plane stress at the knee. Dr. Vladamir Janda proposed a syndrome, named the "crossed pelvis syndrome," in which a weak abdominal wall and weak gluteals are counterbalanced with tight hamstrings and hip flexors.[17]

A strong core with optimal neuromuscular efficiency can help to prevent the development of muscle imbalances. Consequently, a comprehensive core stabilization training program should be an integral component of all rehabilitation programs. A strong, efficient core provides the stable base upon which the extremities can function with maximal precision and effectiveness. It is important to remember that the spine, pelvis, and hips must be in proper alignment with proper activation of all muscles during any core-strengthening exercise. Because no one muscle works in isolation, attention should be paid to the position and activity of all muscles during open- and closed-chain exercises.

Neuromuscular Considerations

A strong and stable core can optimize neuromuscular efficiency throughout the entire kinetic chain by helping to improve dynamic postural control.[15,16,28,31,73,74,77] A number of researchers have demonstrated kinetic chain imbalances in individuals with altered neuromuscular control.[10,12–15,17,18,28,30,31,38,42–44,49,53–55,71,73,76,78,79] Research demonstrates that people with low back pain have an abnormal neuromotor response of the trunk stabilizers accompanying limb movement, significantly greater postural sway, and decreased limits of stability.[30,31,79,80] Research also demonstrates that about 70% of patients suffer from recurrent episodes of back pain. Furthermore, it has been demonstrated that individuals have decreased dynamic postural stability in the proximal stabilizers of the lumbo-pelvic-hip complex following lower-extremity ligamentous injuries,[10,38,54,55] and that joint and ligamentous injury can lead to decreased muscle activity.[11,27,75] Joint and ligament injury can lead to joint effusion, which, in turn, leads to muscle inhibition. This leads to altered neuromuscular control in other segments of the kinetic chain secondary to altered proprioception and kinesthesia.[10,54] Therefore, when an individual with a knee ligament injury has joint effusion, all of the muscles that cross the knee can be inhibited. Several muscles that cross the knee joint are attached to the lumbo-pelvic-hip complex.[26] Consequently, a comprehensive rehabilitation approach should focus on reestablishing optimal core function so as to positively affect peripheral joints.

Research also demonstrates that muscles can be inhibited from an arthrokinetic reflex.[27,38,43,75] This is referred to as arthrogenic muscle inhibition. Arthrokinetic reflexes are mediated by joint receptor activity. If an individual has abnormal arthrokinematics, the muscles that move the joint will be inhibited. For example, if an individual has a sacral torsion, the multifidus and the gluteus medius can be inhibited.[81] This leads to abnormal movement in the kinetic chain. The tensor fascia latae become synergistically dominant and the primary frontal plane stabilizer.[26] This can lead to tightness in the iliotibial band. It can also decrease the frontal and transverse plane control at the knee. Furthermore, if the multifidus is inhibited,[81] the erector spinae and the psoas become facilitated. This further inhibits the lower abdominals (internal oblique and TA) and the gluteus maximus.[28,30] This also decreases frontal and transverse plane stability at the knee. As previously mentioned, an efficient core improves neuromuscular efficiency of the entire kinetic chain by providing dynamic stabilization of the lumbo-pelvic-hip complex and improving pelvofemoral biomechanics. This is yet another reason why all rehabilitation programs should include a comprehensive core stabilization training program.

Scientific ationale for Core Stabilization Training

Most individuals train their core stabilizers inadequately compared to other muscle groups.[8,82,83] Wirth et al recommend the use of classical strength training exercises in order to provide the necessary stimuli to induce desired muscular adaptations throughout the musculature of the core.[33] Although adequate strength, power, muscle endurance, and neuromuscular control are important for lumbo-pelvic-hip stabilization, performing exercises incorrectly or that are too advanced is detrimental.[82–84] Several researchers have found decreased firing of the TA, internal oblique, multifidus, and deep erector spinae in individuals with chronic low back pain.[28,30,49,79,85] Performing core training with inhibition of these key stabilizers may lead to the development of muscle imbalances and inefficient neuromuscular control in the kinetic chain. It has been demonstrated that abdominal training without proper pelvic stabilization increases intradiscal pressure and compressive forces in the lumbar spine.[1,28,30,49,86–89] Furthermore, hyperextension training without proper pelvic stabilization can increase intradiscal pressure to dangerous levels, cause buckling of the ligamentum flavum, and lead to narrowing of the intervertebral foramen.[1,86,87,89]

Research also shows decreased stabilization endurance in individuals with chronic low back pain.[1,20,21,90,91] The core stabilizers are primarily type I slow-twitch muscle fibers.[20–23] These muscles respond best to time under tension. Time under tension is a method of contraction that lasts 6 to 20 seconds and emphasizes hypercontractions at end ranges of motion. This method improves intramuscular coordination, which improves static and dynamic stabilization. To get the appropriate training stimulus, you must prescribe the appropriate speed of movement for all aspects of exercises.[2,3] Core strength endurance must be trained appropriately to allow an individual to maintain dynamic postural control for prolonged periods.[86]

Research demonstrates a decreased cross-sectional area of the multifidus in patients with low back pain, and that spontaneous recovery of the multifidus following resolution of symptoms does not occur.[81] It has also been demonstrated that the traditional curl-up increases intradiscal pressure and increases compressive forces at L2-L3.[1,86–89]

Additional research demonstrates increased EMG activity and pelvic stabilization when an abdominal drawing-in maneuver is performed prior to initiating core training.[1,2,29,49,73,76,77,86,92] Also, maintaining the cervical spine in a neutral position during core training improves posture, muscle balance, and stabilization. If the head protracts during movement, then the sternocleidomastoid is preferentially recruited. This increases the compressive forces at the C0-C1 vertebral junction. This can lead to pelvic instability and muscle imbalances secondary to the pelvo-occular reflex. This reflex is important to keep the eyes level.[43,44] If the sternoclei-domastoid muscle is hyperactive and extends the upper cervical spine, then the pelvis will rotate anteriorly to realign the eyes. This can lead to muscle imbalances and decreased pelvic stabilization.[43,44]

Assessment of the Core

Before a comprehensive core stabilization program is implemented, an individual must undergo a comprehensive assessment to determine muscle imbalances, arthrokinematic deficits, core strength, core muscle endurance, core neuromuscular control, core power, and overall function of the lower-extremity kinetic chain. Assessment tools include activity-based tests that are performed in the clinical setting, EMG with surface or indwelling electrodes, and technologically advanced testing and training techniques using real-time ultrasound. Rehabilitative ultrasound imaging (RUSI) has been used extensively in research settings and has been proven to be a reliable tool in evaluating the activation patterns of various abdominal muscles.[93,94] RUSI, although not currently readily available in clinical settings, is a great asset in the laboratory setting. Perhaps the future will allow for more use of RUSI in clinical practice.

It was previously stated that muscle imbalances and arthrokinematic deficits can cause abnormal movement patterns to develop throughout the entire kinetic chain. Consequently, it is extremely important to thoroughly assess each individual with a kinetic chain dysfunction for muscle imbalances and arthrokinematic deficits. All procedures for assessment are beyond the scope of this chapter, and the interested reader is referred to the comprehensive references provided to gain an understanding of additional assessment procedures that may be used to identify muscle imbalances. It is recommended that the interested reader use the following references to explain a comprehensive muscle imbalance assessment procedure thorough hly.[2–4,6,8,12,15,16,27,38,42,49,52,78]

Core strength can be assessed by using the *straight-leg lowering test.*[15,16,49,50,76,86] The individual is placed supine. A pressure biofeedback device called the stabilizer (Figure 15-2) is placed under the lumbar spine at about L4-L5. The cuff pressure is raised to 40 mm Hg. The individual's legs are maintained in full-extension while flexing the hips to 90 degrees (Figure 15-3). The individual is instructed to perform a drawing-in maneuver (pull belly button to spine) and then flatten the back maximally into the table and pressure cuff. The individual is instructed to lower the legs toward the table while maintaining the back flat. The test is over when the pressure in the cuff decreases. The hip angle is then measured with a goniometer to determine the angle using a rating scale developed by Kendall (Figure 15-4).[95] This test provides a basic idea of how strong the lower abdominal muscle groups (rectus abdominis and external obliques) are. Using the pressure feedback

Figure 15-2 **Stabilizer pressure biofeedback unit**

(Reproduced with permission from the Chattanooga Group.)

device ensures there is no compensation with the lumbar extensors or large hip flexors to stabilize the long lever arm of the legs.

Neuromuscular control of the deep core muscles, TA, and multifidi are evaluated with the quality of movement emphasized rather than quantity of muscular strength or endurance time. Unfortunately, no objectifiable manual muscle test exists for either of these important muscles/muscle groups; however, Hides and Richardson[96] have developed prone and supine tests to evaluate the muscular coordination of the TA and multifidus. The first test for the TA is performed in the prone position with the stabilizer pressure biofeedback unit placed under the abdomen with the navel in the center and the distal edge of the pad in line with the right and left anterior superior iliac spines (Figure 15-5). The pressure pad is inflated to 70 mm Hg. It is important to instruct the patient to relax his or her abdomen fully prior to the start of the test. The patient is then instructed to take a relaxed breath in and out, and then to draw the abdomen in toward the spine without taking a breath. The patient is asked to hold this contraction for a minimum of 10 seconds, with a slow and controlled release. Optimal performance, indicating proper neuromuscular control of the TA, is a 4 to 10 mm Hg reduction in the pressure with no pelvic or spinal movement noted. It is important to monitor pelvic and lower-extremity positioning as the patient may compensate by putting pressure through the patient's legs or tilting the patient's pelvis to elevate the lower abdomen rather than isolating the TA contraction.

Testing for the TA is also performed in the supine position and relies on palpation and visualization of the lower abdomen. Instructions to the patient remain the same as the prone test and the rehab professional palpates for bilateral TA contraction just medially and inferiorly to the anterior superior iliac spines and lateral to the rectus abdominis (Figure 15-6A).

The Stabilizer pad may also be placed under the lower lumbar region to monitor whether compensation occurs with the pelvis (Figure 15-6B). The pressure reading should remain the same throughout the test. A change in the pressure reading indicates that the patient is tilting their pelvis anteriorly (pressure decreases) or posteriorly (pressure increases) in an attempt to flatten the patient's lower abdomen. The patient is asked to hold this contraction for a minimum of 10 seconds, with a slow and controlled release. With a

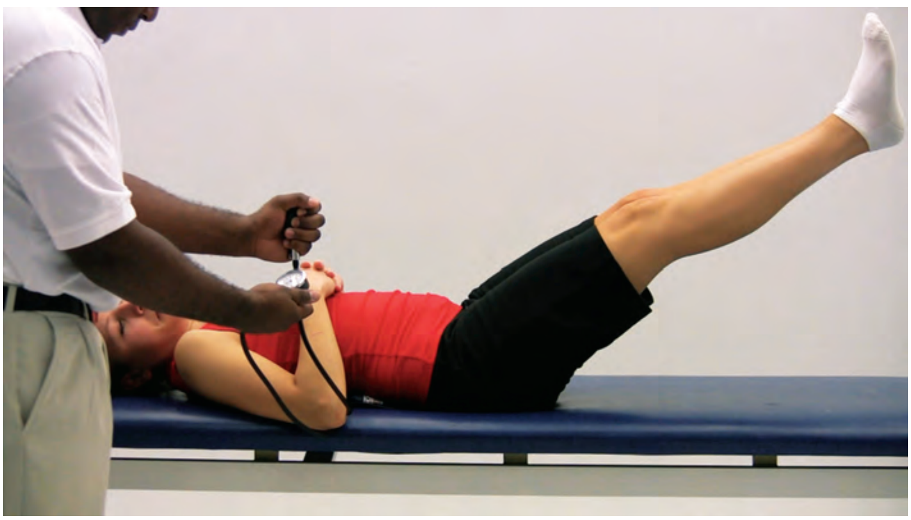

Figure 15-3 Core strength can be assessed using a straight-leg lowering test

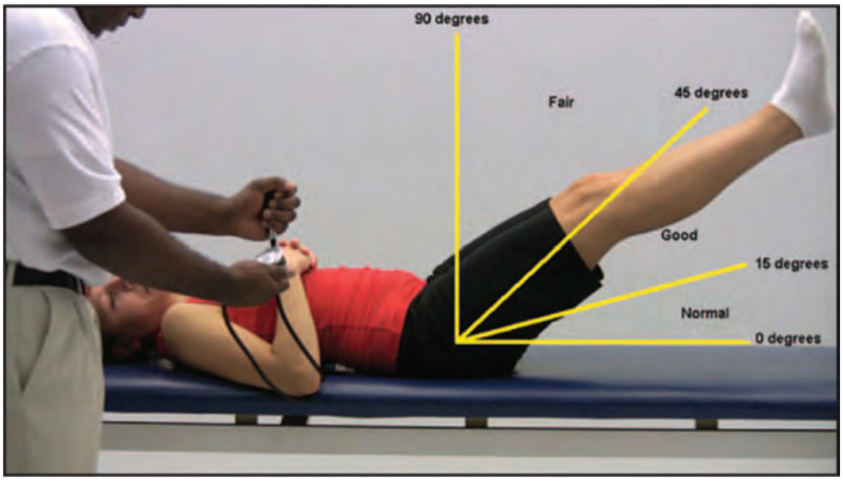

Figure 15-4 Key to muscle grading in the straight-leg lowering test

Figure 15-5 Prone transverse abdominis test

correct contraction of the TA, the rehab professional feels a slowly developing deep tension in the lower abdominal wall. Incorrect activation of the TA would be evident when the internal oblique dominates and this is detected when a rapid development of tension is palpated or the abdominal wall is pushed out rather than drawn in.

The neuromuscular control of the multifidi is examined with the patient in the prone position and the therapist palpating the level of the multifidus for muscular activation (Figure 15-7). The patient is instructed to breathe in and out and to hold the breath out while swelling out the muscles under the clinician's fingers. The patient is then asked to hold the contraction while resuming a normal breathing pattern for a minimum of

Figure 15-6 **Supine transversus abdominis test**

10 seconds. The rehab professional palpates the multifidus for symmetrical activation and slow development of muscular activation. This sequence is repeated at multiple segments in the lumbar spine. Compensation patterns may include anterior or posterior pelvic tilting or elevation of the rib cage in an attempt to swell out the multifidus.

A proper and thorough evaluation of the core muscles will lead the rehab professional in developing a proper core stabilization program. It is imperative that neuromuscular control of the TA and multifidus precedes all other stabilization exercises. These muscles provide the foundation from which all the other core muscles work.

Figure 15-7 Palpating the multifidi for muscular activation

Clinical Pearl

As a part of pre-participation screen, you want to look for athletes who may be prone to developing low back pain. The best available evidence indicates that there are no "perfect" functional core tests; however, muscle activation assessment and muscle or positional holding tests (such as the side plank) may offer insight into core function.

Core Stabilization Training Program

As previously noted, the training program must progress in a scientific, systematic pattern with the ultimate goal of training the trunk stabilizers to be active in all phases of functional tasks. These tasks may include simple static postures, such as standing or sitting, and progress to very complex tasks, such as high-intensity athletic skills.[97] Patient education is the key to a successful exercise program. The patient must be able to visualize the muscle activation patterns desired and have a high level of body awareness allowing him or her to activate his or her core muscles with the proper positioning, neuromuscular control, and level of force generation needed for each individual task.

Performing the Drawing-In Maneuver

Muscular activation of the deep core stabilizers (TA and multifidus) coordinated with normal breathing patterns is the foundation for all core exercises.[84] All core stabilization exercises must first start with the "drawing-in" maneuver (Figure 15-8). Opinions vary[56,98] in the exercise science world about the activation of the abdominal muscles during activities, as well as the ability to selectively recruit the TA and multifidi.[33]

McGill[98] is a proponent of the abdominal bracing technique where the patient is advised to stiffen or activate both the trunk flexors and extensors maximally to prevent spinal movement. He uses the training technique of demonstrating this bracing pattern at the elbow joint. He asks the patient to stiffen his or her elbow joint by simultaneously activating the elbow flexors and extensors and resisting an externally applied force that attempts to flex the patient's elbow. Once the patient has mastered that concept, the same principles are applied to the trunk.

Richardson and Hodges [56] teach the abdominal hollowing technique where the navel is drawn back toward the spine without spinal movement occurring. This technique does not ask patients to do a maximal contraction, but instead, a submaximal, steady development of muscle activation.

We have used a teaching technique that incorporates submaximal abdominal hollowing and moderate bracing of the trunk. While standing in front of a mirror, patients are asked to put their hands on their iliac crests so their fingers rest anteriorly on their transverse abdominals and internal obliques. A good way to state this to the patient is, "Put your hands on your hips like you are mad." Patients are then instructed to draw their navel back toward their spine without moving their trunk or body while continuing to breathe normally. A good verbal cue is to "Make your waist narrow like you are putting on a tight pair of jeans, without sucking in your breath." While in that position, patients are also instructed to not let anyone "Push them around," or push them off balance. This helps incorporate the total-body bracing technique and the use of the upper and lower extremities to facilitate total-body stabilization. This can be referred to as "the power position" or "home base," and these key words may be used when teaching the progression of all core exercises (see Table 15-1 for other teaching cues for proper muscular activation of core muscles).[80,82] It should be emphasized that proper muscular activation cannot be achieved if the patient is holding his or her breath.

It should also be noted that the drawing-in maneuver should not be abandoned when the patient is performing other exercises, such as weightlifting, walking, or other aerobic tasks such as step aerobics, aqua aerobics, or running.

Specific Core Stabilization Exercises

Once the drawing-in maneuver is perfected, neuromuscular control of the TA and multifidus is accomplished in the prone and supine positions as described in "Assessment of the

Figure 15-8 The drawing-in maneuver requires a contraction of the transversus abdominis

Table 15-1 **Teaching Cues for Activation of Core Muscles**

Verbal Cues

1. Draw navel back toward spine without moving your spine or tilting your pelvis.
2. Make your waist narrow.
3. Pull your abdomen away from your waistband of your pants.
4. Draw lower abdomen in while simulating zipping up a tight pair of pants.
5. Continue breathing normally while contracting lower abdominals.
6. Tighten pelvic floor.
   a. Women: contract pelvic floor so you do not leak urine.
   b. Men: draw up scrotum as if you are walking in waist deep cold water.

Physical Cues

1. Use mirror for visual feedback.
2. Put your hands on your waist like you are mad, draw abdomen away from fingertips while still breathing normally.
3. Tactile facilitation.
   a. Use tape on skin for cutaneous feedback.
   b. String tied snugly around waist.
4. EMG biofeedback unit.
5. Electrical muscular stimulation.
6. Isometric contraction and holding of pelvic floor and hip adductors.

Core" previously. Then progression of exercises into other positions can take place. Quadruped is a good starting position for the patient to learn and enhance his or her power position (Figure 15-9). This facilitates the patient keeping his or her body steady and minimizing trunk movement. The patient is instructed to keep the trunk straight like a tabletop and then draw the stomach up toward the spine (activating the TA and multifidus) while maintaining the normal breathing pattern. This position is held for a minimum of 10 seconds and progressed in time up to 30 to 60 seconds, working on endurance of these trunk muscles.[91,97] The patient is advised to release the contraction slowly in an eccentric manner and no spinal movement should occur during this release phase. When this position is mastered by the patient and the rehab professional feels that the patient is ready, the difficulty of the exercise can be progressed, limited only by the capabilities of the patient.

Clinical Pearl

You have a patient who is an assembly line worker who works 8 hours a day lifting (approximately 6″) and replacing 8# parts from one line to another. This work-related motion requires some spinal rotation. rotation. She has been progressing well in her core stabilization program in quadruped and sitting. It is important to challenge her in a work relevant posture such as standing in order to prepare her for return to work. Her dynamic stabilization training should include rotation!

Figures 15-10 through 15-12 illustrate the exercises used in a comprehensive core stabilization training program. Exercises may be broken down into three levels in the progressive core stabilization training program: Level 1—stabilization (Figure 15-10); Level 2— strengthening (Figure 15-11); and Level 3—power (Figure 15-12). The patient is started with the exercises at the highest level at which the patient

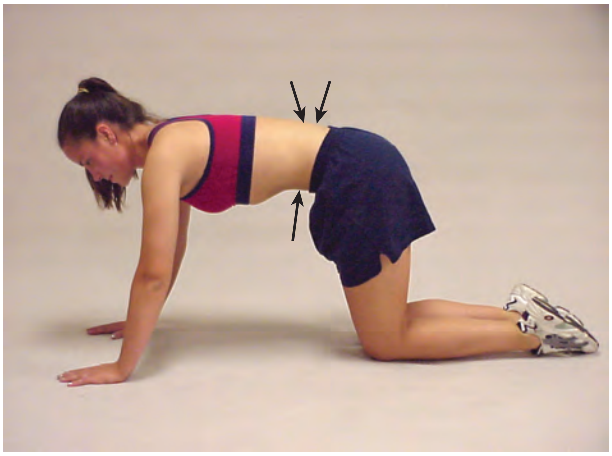

Figure 15-9 **Quadruped position for mastering the "drawing-in" maneuver or power position**

can maintain stability and optimal neuromuscular control. The patient is progressed through the program when the patient achieves mastery of the exercises in the previous level.[1,2,6,8,11,12,22,23,38,41,43,45,47,49,57,59,60,62,66,69,90,97,99–102]

Clinical Pearl

You have been working with a softball player on a "low-level" core training program for 1 week including recruiting and utilizing her deep core muscles. She has been making improvements; however, you know you need to add to her program to prepare her for a return to sport. Applying the F I T T Principle would help you to safely individualize, apply, and progress the core program for this athlete:

F—Frequency
I—Intensity
T—Time
T—Type

Manipulation of these factors will allow for functional progression of the core exercise program.

Guidelines for Core Stabilization Training

A comprehensive core stabilization training program should be systematic, progressive, and functional. The rehabilitation program should emphasize the entire muscle contraction spectrum, focusing on force production (concentric contractions), force reduction (eccentric contractions), and dynamic stabilization (isometric contractions). The core stabilization program should begin in the most challenging environment the individual can control. A progressive continuum of function should be followed to systematically progress the individual.

The program should be manipulated regularly by changing any of the following variables: plane of motion, range of motion (ROM), loading parameters (Physioball, medicine ball, Bodyblade, power sports trainer, weight vest, dumbbell, tubing, kettlebell), body position, amount of control, speed of execution, amount of feedback, duration (sets, reps, tempo, time under tension), and frequency (Table 15-2).

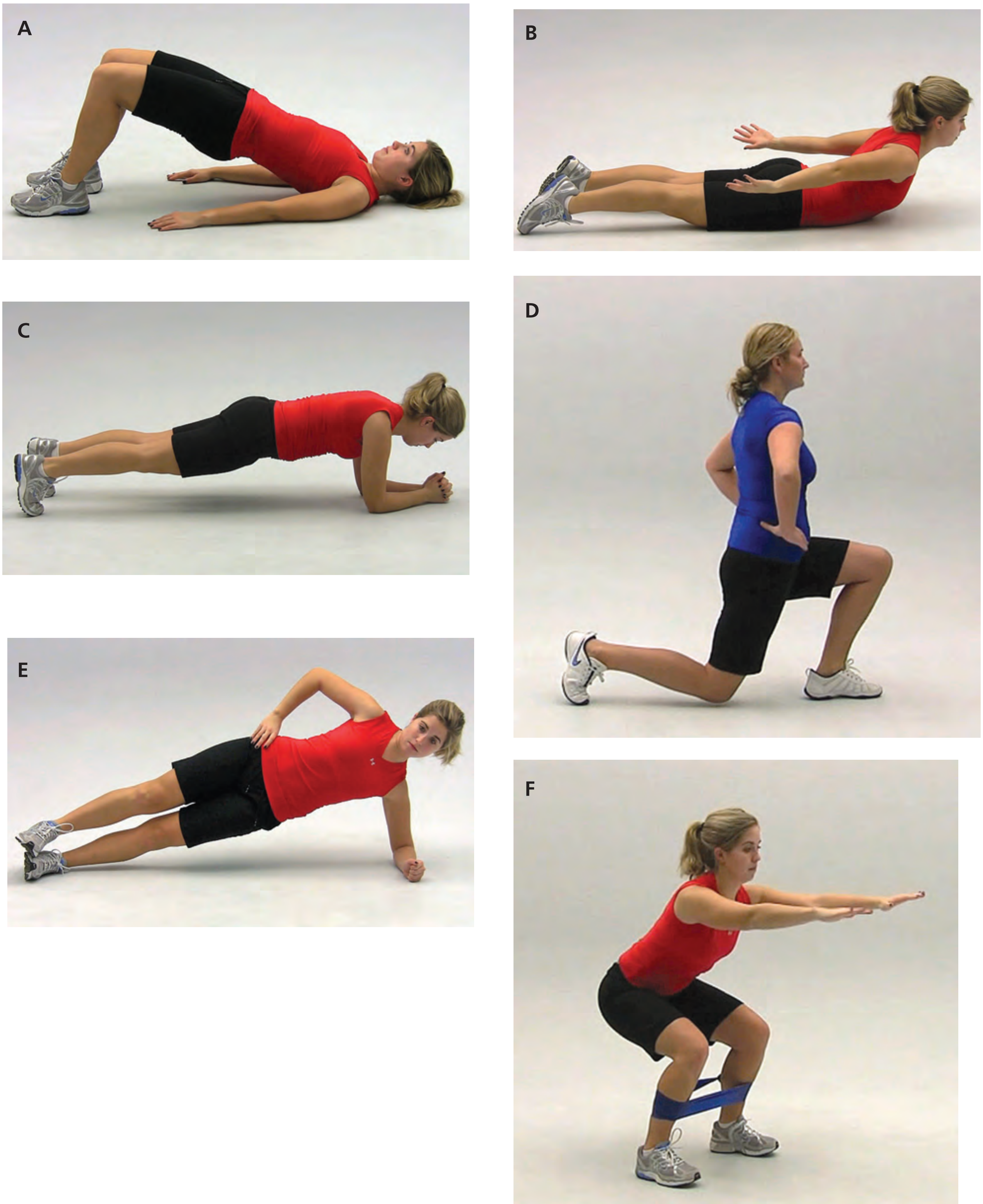

Figure 15-10 **Level 1 (stabilization) core stability exercises**

A. Double-leg bridging. **B.** Prone cobra. **C.** Front plank. **D.** Lunge. **E.** Side plank. **F.** Squats with Thera-Band.

Figure 15-10 (*Continued*)

G. Pelvic tilts on stability ball. **H.** Diagonal crunches. **I.** Alternating opposite arm-leg. **J.** Single-leg lunge with abdominal bracing. **K.** Sit-to-stand with abdominal bracing.

Figure 15-11 **Level 2 (strength) core stability exercises**

A. Bridge with single-leg extension. **B.** Front plank with single leg-extension. **C.** Supine alternating arms and legs (aka: dying bug). **D.** Push-up to side plank. **E.** Bridging on stability ball. **F.** Stability ball diagonal crunches.

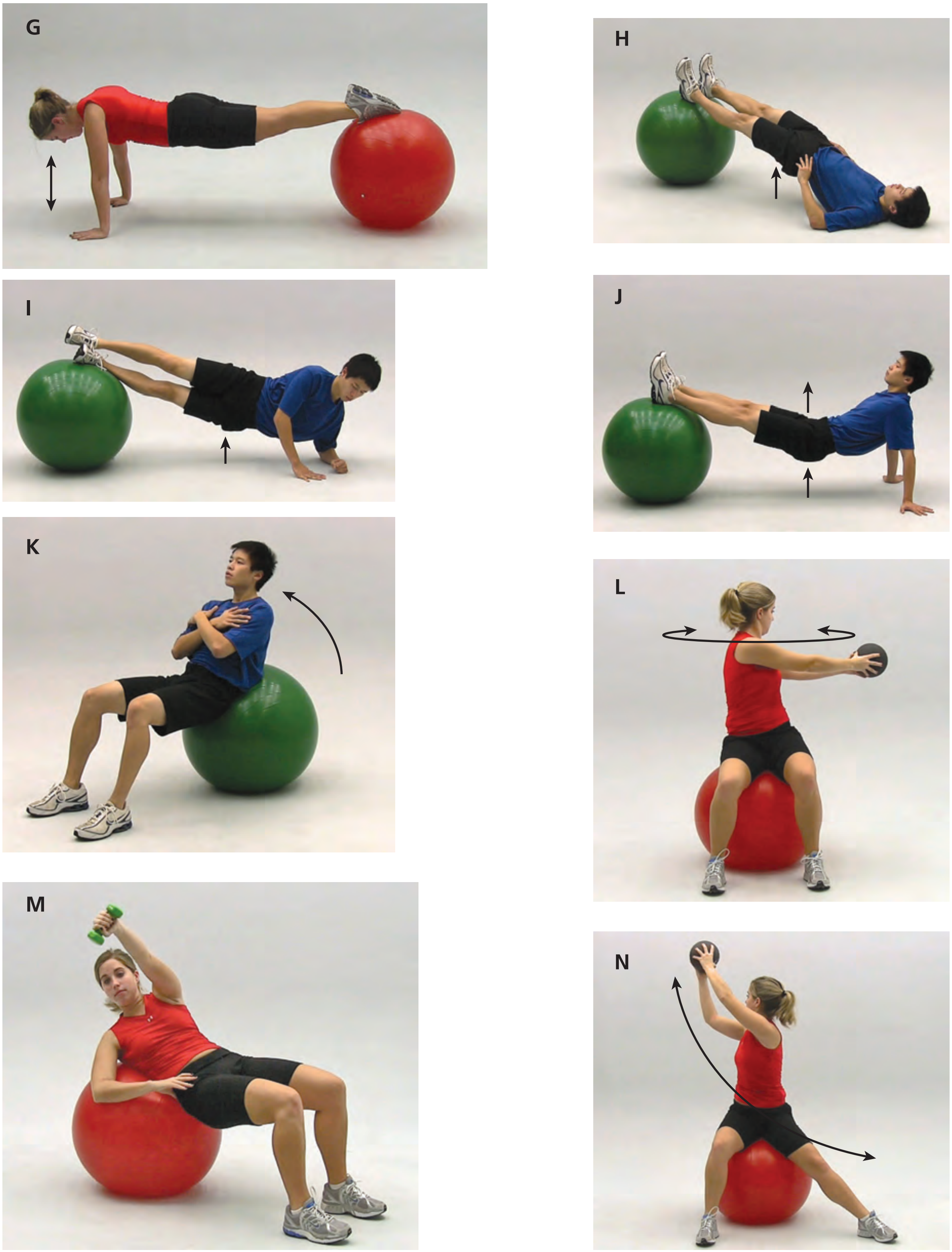

Figure 15-11 ***(Continued)***

G. Push-ups on therapy ball. **H.** Stability ball hip-ups. **I.** Stability ball side plank. **J.** Stability ball pike-ups. **K.** Stability ball crunches. **L.** Stability ball rotation with weighted ball. **M.** Stability ball single-arm dumbbell press with rotation. **N.** Stability ball diagonal rotations with weighted ball.

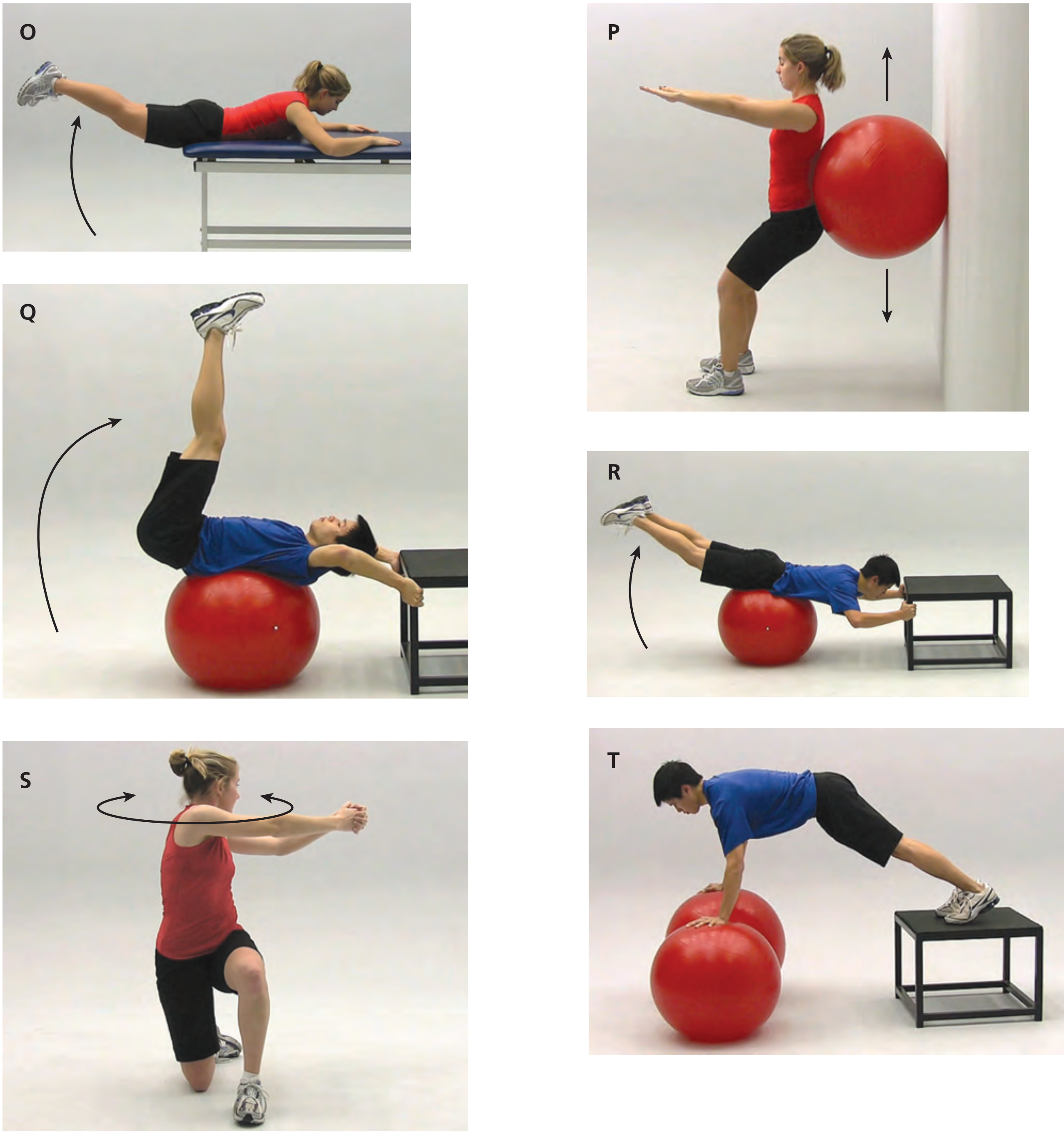

Figure 15-11 ***(Continued)***

O. Prone hip extension. **P.** Stability ball wall slides. **Q.** Stability ball straight-leg raise. **R.** Stability ball hip extension. **S.** Half-kneeling rotation. **T.** Stability balls two-arm support.

Figure 15-11 ***(Continued)***

U. Stability ball Russian twist. **V.** Stability ball prone cobra. **W.** Weight shifting on stability ball. **X.** Proprioceptive neuromuscular facilitation (PNF) Bodyblade™.

Specific Core Stabilization Guidelines

When designing a functional core stabilization training program, the rehab professional should create a proprioceptively enriched environment and select the appropriate exercises to elicit a maximal training response. The exercises must be safe and challenging, stress multiple planes, incorporate a multisensory environment, be derived from fundamental movement skills, and be activity specific (Table 15-3).

The rehab professional should follow a progressive functional continuum to allow optimal adaptations.[4,6,59,103] The following are key concepts for proper exercise progression: slow to fast, simple to complex, known to unknown, low force to high force, eyes open to eyes closed, static to dynamic, and correct execution to increased reps/sets/intensity (Table 15-4).[2,4–6,29,103–105]

The goal of core stabilization should be to develop optimal levels of functional strength and dynamic stabilization.[1,8] Neural adaptations become the focus of the program instead of striving for absolute strength gains.[4,38,76,78] Increasing proprioceptive demand by using a multisensory, multimodal (tubing, Bodyblade, Physioball, medicine ball, power sports

Figure 15-12 **Level 3 (power) core stability exercises**

A. Weighted ball single-leg jump. **B.** Weighted ball diagonal to PNF pattern. **C.** Weighted ball double-leg jump. **D.** Overhead extension. **E.** Overhead weighted ball throw. **F.** Weighted ball one-arm chest pass with rotation. **G.** Weighted ball double-arm rotation toss from squat.

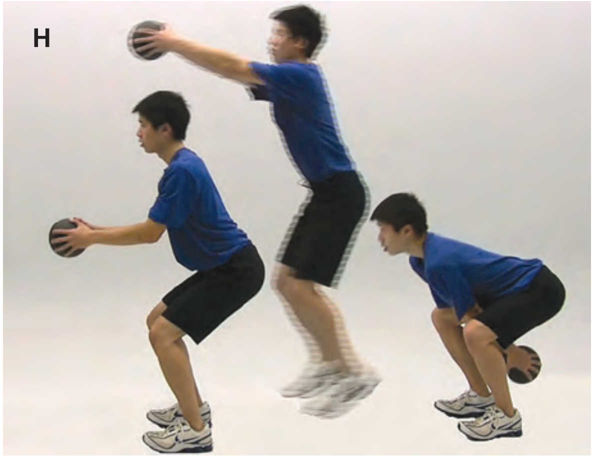

Figure 15-12 (*Continued*)

H. Weighted ball forward jump from squat. **I.** Stability ball pullover crunch with weighted ball.

Table 15-2 Program Variation Summary

1. Plane of motion
2. Range of motion
3. Loading parameter
4. Body position
5. Speed of movement
6. Amount of control
7. Duration
8. Frequency

Table 15-3 Exercise Selection Summary

1. Safe
2. Challenging
3. Stress multiple planes
4. Proprioceptively enriched
5. Activity specific

trainer, weight vest, cobra belt, dumbbell, kettlebell) environment becomes more important than increasing the external resistancer.[103,104] The concept of quality before quantity is stressed. Core stabilization training is specifically designed to improve core stabilization and neuromuscular efficiency. You must be concerned with the sensory information that is stimulating the patient's central nervous system. If the patient trains with poor technique and neuromuscular control, then the patient develops poor motor patterns

Table 15-4 **Exercise Progression Summary**

1. Slow to fast
2. Simple to complex
3. Stable to unstable
4. Low force to high force
5. General to specific
6. Correct execution to increased intensity

and stabilization.[4,6] The focus of the program must be on the function. To determine if the program is functional, answer the following questions:

- Is it dynamic?
- Is it multiplanar?
- Is it multidimensional?
- Is it proprioceptively challenging?
- Is it systematic?
- Is it progressive?
- Is it based on functional anatomy and science?
- Is it activity specific?[4–6]

In summary, the core strengthening program should always start with the drawing-in maneuver that produces neuromuscular control of the TA and multifidus. Abdominal strength is not the key; rather, it is abdominal endurance within a stabilized trunk that enhances function and may prevent or minimize injury. The trunk must be dynamic and able to move in multiple directions at various speeds, yet have internal stability that provides a strong base of support so as to support functional mobility and extremity function. The rehab professional is only limited by the rehab professional's own imagination in the development of core stabilization exercises. If the power position is maintained throughout the exercise sequence and the exercise is individualized to the needs of a patient, then it is an appropriate exercise! The key is to integrate individual exercises into functional patterns and simulate the demands of simple tasks and progress to the highest level of skill needed by each individual patient. Finally, an efficient and strong core is key to the function of the entire movement system, and should be considered in most if not all patients and clients as a part of functional rehabilitation.

Clinical Pearl

Consider a golfer with a strain of the latissimus dorsi. He has been out of competition for several weeks, and you have been progressing him through a core stability program. Note that your progression must include variation in position, speed, and correct execution in golf-specific postures in order to be functional for him.

SUMMARY

1. Functional kinetic chain rehabilitation must address each link in the kinetic chain and strive to develop functional strength and neuromuscular efficiency in order to promote efficiency of the movement system.

2. A core stabilization program should be an integral component for all individuals participating in a closed kinetic chain rehabilitation program.
3. A core stabilization training program will allow an individual to gain optimal dynamic neuromuscular control of the lumbo-pelvic-hip complex and may allow the individual with a kinetic chain dysfunction to return to activity more quickly and safely.
4. The important core muscles do not function as prime movers; rather, they function as stabilizers.
5. There are some clinical methods of measuring the function of the TA and multifidus function; however, dynamic functional tests for the core are not fully agreed upon.
6. Real-time ultrasound is an effective research tool for assessment of core stabilizers.
7. The Stabilizer is a useful adjunct for clinical examination and training of the core.
8. Many possibilities exist for core training progressions. Progression is achieved by changing position, lever arms, resistance, and stability of surfaces.
9. Utilize trunk flexion activities sparingly, as they are not necessary to high-level core function, and may be counterproductive. Consider functionally based dynamic stabilization in multiple planes to positively impact core stability.

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SOLUTIONS

5-1 Decreased stabilization endurance in individuals with low back pain with decreased firing of the transversus abdominis, internal oblique, multifidus, and deep erector spinae. Training without proper control of these muscles can lead to improper muscle imbalances and force transmission. Poor core stability can lead to increased intradiscal pressure. Core training will improve the gymnast's posture, muscle balance, and static and dynamic stabilization.

5-2 It could be that she has poor postural control because of a weak core. She probably never regained neuromuscular control of her core following the knee injury. Tennis requires a lot of upper-body movement, so she would probably benefit from core strengthening that would allow her to control her lumbo-pelvic-hip complex while she plays. In choosing her exercises, you should make sure that they are safe and challenging and stress multiple planes that are functional as they are applied to tennis. The exercises should also be proprioceptively enriched and activity-specific.

5-3 Individuals with poor core strength are likely to develop low back pain due to improper muscle stability. The straight leg lowering test is a good way to assess core strength. The athlete should lie supine on a table with hips flexed to 90 degrees and lower back completely flat against the table. To decrease the lordotic curve, instruct the patient to perform a drawing-in maneuver. The patient then lowers the legs slowly to the table. The test is over when the back starts to arch off of the table. A blood pressure cuff can be used under the low back to observe an increase in the lordotic curve. Someone with a weak core will not be able to maintain the flattened posture for very long while lowering the legs.

5-4 To progress the patient and keep her interested in her rehabilitation program, change her program frequently. Consider these variables as you plan changes: plane of motion, ROM, loading parameter (Physioballs, tubing, medicine balls, body blades, etc.), body position (from supine to standing), speed of movement, amount of control, duration (sets and reps), and frequency.

5-5 Your ultimate goal with core strengthening is functional strength and dynamic stability. As the athlete progresses, the emphasis should change in these ways: from slow to fast, from simple to complex, from stable to unstable, from low force to high force, from general to specific, and from correct execution to increased intensity. Once the patient has gained awareness of proper muscle firing, encourage her to perform her exercises in a more functional manner. Because activities in most sports require multiplane movement, design her exercises to mimic those requirements.

5-6 Dynamic PNF with a power ball would be ideal for him. The ball will provide a loading parameter, and his ROM will be functional for the demands of his sport. Adding a twisting component is important so that he is not just training in a single plane of motion prior to swinging his club.

Please see videos on the accompanying website at www.healio.com/books/sportsmedvideos.