[Athletic Training] CEU

Core Stability Training for Injury Prevention

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Context: Enhancing core stability through exercise is common to musculoskeletal injury prevention programs. Definitive evidence demonstrating an association between core instability and injury is lacking; however, multifaceted prevention programs including core stabilization exercises appear to be effective at reducing lower extremity injury rates.

Evidence Acquisition: PubMed was searched for epidemiologic, biomechanic, and clinical studies of core stability for injury prevention (keywords: "core OR trunk" AND "training OR prevention OR exercise OR rehabilitation" AND "risk OR prevalence") published between January 1980 and October 2012. Articles with relevance to core stability risk factors, assessment, and training were reviewed. Relevant sources from articles were also retrieved and reviewed.

Results: Stabilizer, mobilizer, and load transfer core muscles assist in understanding injury risk, assessing core muscle function, and developing injury prevention programs. Moderate evidence of alterations in core muscle recruitment and injury risk exists. Assessment tools to identify deficits in volitional muscle contraction, isometric muscle endurance, stabilization, and movement patterns are available. Exercise programs to improve core stability should focus on muscle activation, neuromuscular control, static stabilization, and dynamic stability.

Conclusion: Core stabilization relies on instantaneous integration among passive, active, and neural control subsystems. Core muscles are often categorized functionally on the basis of stabilizing or mobilizing roles. Neuromuscular control is critical in coordinating this complex system for dynamic stabilization. Comprehensive assessment and training require a multifaceted approach to address core muscle strength, endurance, and recruitment requirements for functional demands associated with daily activities, exercise, and sport.

Keywords: trunk muscles; kinetic chain; exercises; neuromuscular control

The importance of core stability for injury prevention and performance enhancement has been popularized during the past decade with minimal supporting evidence. Even though limited evidence exists, the integration of core stabilization exercises into injury prevention programs, particularly for lower extremity, is demonstrating decreased injury rates.[31,33,37,53,60,61] However, a lack of consensus exists about the most effective exercises for optimizing core stability.

A universally accepted definition of core stability is lacking. Generally, core stability comprises the lumbopelvic-hip complex and is the capacity to maintain equilibrium of the vertebral column within its physiologic limits by reducing displacement from perturbations and maintaining structural integrity.[2,43,49,51,54,63] Clinically and practically, this definition lacks a tangible, functional perspective that translates into principles for practical application of core stability assessment and training in active, athletic populations. Several authors have proposed a more functional perspective to describe the core as the foundation of the kinetic chain responsible for facilitating the transfer of torque and momentum between the lower and upper extremities for gross motor tasks of daily living, exercise, and sport.[2,7,15,16,34] Core stability necessitates instantaneous changes by the central nervous system to elicit appropriate combinations and intensities of muscle recruitment for stiffness (ie, stability) as well as mobility demands of the system.[2,7,23,34,54,63] It is important to know the function of the relevant anatomy when developing core stabilization training for injury prevention purposes.

FUNCTIONAL CORE ANATOMY

The "core," also referred to as the lumbopelvic-hip complex, is a 3-dimensional space with muscular boundaries: diaphragm (superior), abdominal and oblique muscles (anterior-lateral), paraspinal and gluteal muscles (posterior), and pelvic floor and hip girdle (inferior).[2] The inherent nature of these muscular boundaries produces a corset-like stabilization effect on the trunk and spine.[54]

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The authors report no potential conflicts of interest in the development and publication of this manuscript.

DOI: 10.1177/1941738113481200

Crisco and Panjabi[19] illustrated the critical role of muscles for dynamic core stability by demonstrating spinal buckling at only 88 N (approximately 20 lb) of compressive force in the absence of muscular contributions, well below loads typically associated with daily activity and sport. Movement beyond the neutral zone—a region of high flexibility and little resistance around the neutral spine position—requires muscular constraints for stabilization.[51]

Panjabi's model explains mechanisms of core stabilization, which includes 3 interdependent subsystems: passive, active, and neural control.[50] The passive subsystem comprises the static tissues, including vertebrae, intervertebral discs, ligaments, and joint capsules, as well as the passive properties of muscles. The primary function of these static tissues is to stabilize in the end range of motion as tensile forces increase and mechanical resistance to movement is produced, as well as to transmit position and load information to the neutral control subsystem via mechanoreceptors.[50,51] The active subsystem consists of the core musculature[50] and provides dynamic stabilization to the spine and proximal appendicular skeleton, as well as movement information to the neural control subsystem. The neural control subsystem is the center for incoming and outgoing signals that ultimately produce and maintain core stability.[50] Importantly, no one subsystem acts or works separate from another; continuous interaction among all 3 subsystems is needed to maintain stability.[50,51] While these subsystems function to maintain core stability, targeted exercises can be integrated into training to improve the function of one of more of these subsystems.

The increased popularity of core stability has also led to the development of several classification systems to describe core muscle function for dynamic stabilization.[7,8,15,24,54] The surrounding musculature is imperative for core stability and is a primary focus of rehabilitation and injury prevention programs. The function of muscles is determined by their unique morphology, including architectural aspects of fiber length and arrangement.[54]

Initial classification systems categorized muscles as local stabilizers and global mobilizers.[8,24] The local stabilizer muscles are monoarticular deep muscles with attachments on or near the vertebrae that primarily function eccentrically to control movement and maintain static stabilization.[8,24] Conversely, the global mobilizer muscles are typically biarticular superficial muscles that connect the trunk to the extremities and function concentrically to produce large torques for movement and power.[8,24] This classification is widely accepted and remains the basis for many core stabilization exercise programs. However, Gibbons and Comerford[24] and Behm et al[7] believe that the function of relevant muscles is more complex and that no single category is more important than another.[7,15,24]

Gibbons and Comerford[24] proposed a functional model that maintained the local stabilizers and separated the global muscles into stabilizers (internal and external obliques, spinalis) and mobilizers (rectus abdominus, iliocostalis). Stabilizers generate force eccentrically to control movement throughout range of motion, while mobilizers concentrically accelerate through range of motion and act as shock absorbers, especially in the sagittal plane. Behm et al[7] also maintained the local stabilizer category and divided the global muscles into mobilizers and transfer load categories.[7,15] The transfer load group represents those muscles with axial-appendicular attachments (ie, gluteus maximus, gluteus medius, hip adductors, rectus femoris, iliopsoas, trapezius, latissimus dorsi, deltoid, pectoralis major) that transfer force and momentum between the extremities and core along the kinetic chain.[7,15] The transfer muscles are separate yet integral to core stability because they have fascial attachments that stiffen the core and transfer force through the kinetic chain.[2,16,38]

The classification systems all have merit, but some contain more detail and differentiation in muscle function,[7,15,24] whereas others are an oversimplification,[8,24] which may lead clinicians to focus on specific muscles and muscle groups rather than function and demands of the task.

INJURY RISK

Core stability exercises are implemented according to the theoretical framework that dysfunction in core musculature is related to (musculoskeletal) injury; therefore, exercises that restore and enhance core stability are related to injury prevention and rehabilitation. To date, there is no clear evidence that supports the relationship between poor core stability and musculoskeletal injury.

Substantial evidence exists demonstrating core muscle recruitment alterations in low back pain (LBP) patients compared with healthy controls.[12,13,20,28,29,32] The transversus abdominus and multifidus—local stabilizer muscles—display changes in recruitment[12,13,20,28,29,32] and morphology[44] that limit their ability to effectively stabilize the spine and provide accurate proprioceptive information. Hodges et al examined core muscle recruitment patterns during upper[29] and lower[28] extremity movements in LBP patients compared with healthy controls. Consistently, the transversus abdominus was the first muscle recruited, followed by the multifidus, obliques, and rectus abdominus. All local stabilizer and global mobilizer core muscles were recruited before any extremity movement, indicating that core muscles provide proximal stability for distal mobility. In the LBP patients, transversus abdominus recruitment was delayed in upper and lower extremity movements in all directions (flexion, extension, abduction). Multifidus and internal oblique recruitment in patients with sacroiliac joint pain during an active straight-leg raise maneuver was delayed until after the leg raise was initiated, indicating a lack of preparatory activation for proximal stability. The gluteus maximus activation was also delayed, suggesting an inability to compress and stabilize the sacroiliac joint and pelvis with associated lower extremity movement. Overall, these studies[28,29,32] illustrate alterations in muscle recruitment, suggesting that deficiencies in core stabilization and load transfer muscles may be related to lower extremity function and injury.

Few studies demonstrate muscle weakness associated with injury status. Nadler et al[48] tested athletes with LBP and found that hip abductor strength deficits predicted LBP. Leetun et al[40] studied core stability and lower extremity strength test differences between men and women in relation to athletic injury during the season. They conducted preseason core stability tests and isometric strength testing of hip abduction and external rotation on 139 athletes who were tracked for injuries through one competitive season. Men had higher overall core and hip strength values than women, with significant differences in hip abduction, hip external rotation, and the side-bridge test. Athletes who suffered an injury during the season generally had lower values for hip and core strength; however, only hip strength tests were found to be significantly different. They concluded that hip external rotation strength was the strongest predictor of injury.[40] Weakness in the load transfer muscles, not local stabilizer and global mobilizer muscles, may be an injury risk that could be prevented through proper training. Interestingly, the majority of studies report alterations in muscle recruitment (ie, timing, amplitude, and endurance), not decreased strength, indicating that core dysfunction may be more of a neuromuscular control problem than a strength problem.[28,29,32]

The disproportionate rate of lower extremity injuries between men and women led to research to identify risks factors. The neuromuscular mechanisms of noncontact anterior cruciate ligament risk factors[40,64,65] and prevention programs[31,33,37,52,53,60,61] have begun to explain an association between core stability and lower extremity musculoskeletal injury. The premise for the association is based on muscle attachments. The muscles of the hip, or the load transfer muscles, have pelvic and lumbar attachments. Compromised core stability creates an unstable proximal base, thus limiting control and positioning of the lower extremity for functional movements and loads and increasing injury risk.[3,26,27,40]

There are few prospective studies examining injury risk factors relative to core stability measures. Zazulak et al prospectively measured core neuromuscular control properties of active proprioceptive repositioning[65] and trunk displacement[64] in collegiate athletes, followed by injury tracking over 3 years. Women who sustained knee ligament injuries had deficits in core neuromuscular control, measured via trunk active repositioning and maximum trunk displacement, displayed approximately 1° more absolute error and 3° more displacement, respectively, compared with uninjured women.[64,65] Each degree increase in absolute error for active trunk repositioning equates to a 2.9-fold increase in the odds ratio for a knee injury.[65] Active proprioceptive repositioning predicted knee injury status with 90% sensitivity and 56% specificity,[65] and trunk displacement predicted knee injury with 83% sensitivity and 63% specificity.[64] Error in core neuromuscular control may be associated with increased knee injury risk, particularly in female athletes.

Core stability is a primary component of functional movement, essential in daily living and athletic activities.[17,18]

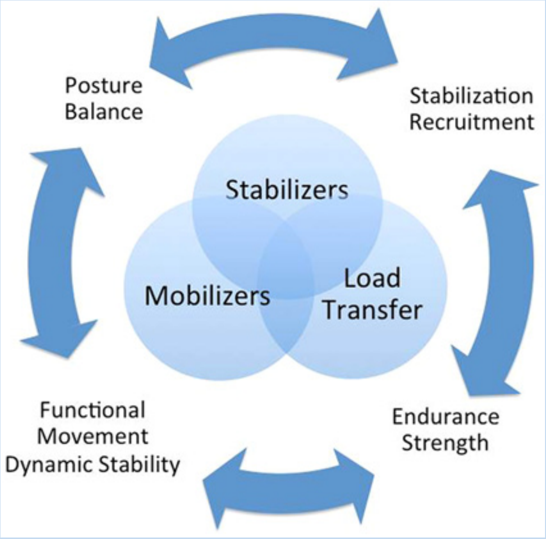

Figure 1. Functional core stability. This figure illustrates the various components and roles that interact to achieve functional core stabilization.

In an evaluation of functional movement, female collegiate athletes who scored 14 or less (out of 21) were 4 times more likely to sustain injury as those that scored above 14, similar to professional football players.[14,36] While movement screening does not isolate core stability as a measure, it may provide insight into the relationship of core stability to injury risk through its contribution to normal functional movement patterns.

The evidence supporting the association between poor core stability and injury risk continues to lag behind popular beliefs and practices. As a result, clinicians are continually challenged with best practices for assessing and training core stability.

ASSESSING CORE STABILITY

Prevention programs that target core stability focus on enhancing the recruitment of the local and global stabilizer, global mobilizer, and load transfer muscles, restoring muscle strength and endurance and regaining posture and balance through regulation of the neuromuscular control system for overall improvements in function (Figure 1).[6] Development of prevention programs must first identify specific risk factors and deficits. Core stability is a complex interaction among local, global, and load transfer muscles, neuromuscular control, and the specific demands of the task being performed. No less complex is the challenge of accurately assessing core stability. A plethora of tests measure core stability, many of which are reliable and valid.[25,34,43,45,47] These tests often measure one aspect of core stability, such as muscle recruitment, muscle strength and endurance, postural control, balance, or movement patterns. The sheer quantity of tests that assess different dimensions highlight the complex and

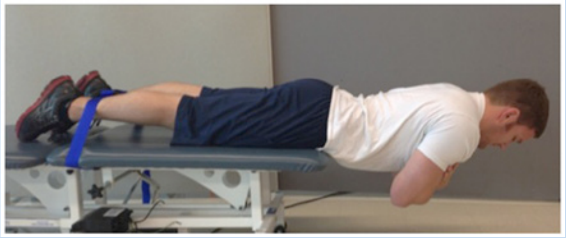

Figure 2. Extensor endurance test.

Figure 3. Side bridge test.

Figure 4. Flexor endurance test.

multidimensional role of the core along the kinetic chain for functional movements.

Muscle Recruitment

Perhaps the simplest assessment of core muscle function is determining if the athlete can produce volitional contraction of the core muscles, specifically the transverse abdominus and lumbar multifidus. Altered recruitment patterns of these muscles have been found in those with LBP or compromised core stability.[25,28,29,44] Delayed trunk muscle reflex responses may actually be a preexisting condition and not a resultant adaptation following onset of LBP.[13] Preliminary evidence suggests that neuromuscular control of the trunk muscles is reorganized at the motor cortex in individuals with LBP and that selective recruitment of the multifidi results in increased activation levels.[57,58] Voluntary contraction of the transverse abdominus is assessed by palpating the deep muscles medially and inferior to the iliac spines, just lateral to the rectus abdominus. This is done while the athlete "draws in" without taking a deep breath.[6] Assessment of the multifidus can be performed with the athlete prone and palpating the paraspinals during the drawing in maneuver. Because of the deep nature of the multifidi, this may be difficult to appreciate clinically. These initial tests may identify athletes with abnormal muscle recruitment and/or function and indicate the need for further, more comprehensive assessment.

Muscle Strength and Endurance

Beyond volitional contraction of the core muscles, numerous tests measure core strength and endurance.[4-6,25,42,43,45,54] Three core stability tests that have been widely used by clinicians include the right and left side bridge, the flexor endurance test, and the extensor endurance test.[45]

The extensor endurance test, modified from the Biering-Sorenson test, places the athlete prone with the lower body fixed to an examination table and with the hips and upper body extended over the edge of the table (Figure 2). The athlete is asked to hold a horizontal position with arms crossed over the chest for as long as possible.[45] In the side bridge, the person is in a side-lying position and then raises the hips to support the body on the feet and flexed elbow, on both right and left sides (Figure 3).[45] The flexor endurance test has the athlete in a seated position with hips and knees flexed to 90° and the torso at a 60° angle relative to the table (Figure 4). A toe strap or other stabilization is used for the feet. The test requires the athlete to hold this 60° angle position for as long as possible. Mean endurance times and ratios between tests provide guidance for interpreting results.[45]

The McGill assessments evaluate isometric strength of the core.[45] Muscle endurance, rather than muscle strength, may be a more important factor in core stability.[11,39] Despite widespread acceptance of the importance of core muscle endurance, these tests may not accurately reflect muscle function during athletic activity. The McGill tests were not an adequate predictor of lower extremity injury, which suggests the need for tests that are conducted in more physiologic and functional positions and are more dynamic in nature.[40] A more functional position that replicates athletic activity may be more beneficial when assessing core stability.[34,40]

Kibler et al[34] recommends evaluating core stability in functional positions by testing in multiple planes of motion, closed versus open chain testing, and concentric versus eccentric muscle contractions (1-leg standing balance, single-leg squat, and single-leg standing with 3-plane excursion).[34]

Standing balance can be assessed for deviations such as a Trendelenburg posture, arms to maintain balance, or control of postural sway.[34,62] Deviations suggest deficits in proximal core stability, including the transfer load muscles of the hip.[34] Single-leg balance can be progressed to a single-leg squat, in which the quality of movement is evaluated. Deficiencies in core stability include the use of arms for balance, excessive trunk motion, or excessive knee valgus moment during the test.[34]

Three-plane excursion testing evaluates the core and spinal muscles during sagittal, frontal, and transverse plane movement. The athlete is placed approximately 8 cm away from a wall and asked to move in all 3 planes to produce a controlled touch of the wall with the head or shoulder. Tests can be progressed from double-limb stance to single-leg stance.[34] These tests assess core stability during functional positions and movements; however, good reliability based on observation and grading scales is lacking.[34,62]

Functional Movement Assessment

Muscle recruitment, strength, and endurance testing may reflect isolated components of core stability but often fail to provide a complete picture of the athlete's overall core stability under different loads, positions, and tasks.

Recently, a shift toward screening and assessment of movement patterns has emerged, adding another perspective to isolated assessments of muscle function, strength, and endurance. Screening movement patterns examine components of stability and mobility and quantify functional capacity. In these tests, core stability provides a stable base for transfer of load along the kinetic chain to and from the extremities. Core stability is a key factor of fundamental movement patterns.[17] This takes into consideration facets of function, including neuromuscular control, proprioception, joint stability, mobility, strength, and balance.

The Functional Movement Screen (FMS) was developed as an injury risk screening tool.[17,18] Several studies have identified FMS scores below 14 as risk factors for injury.[14,36] In addition, preliminary studies suggest that intervention programs targeted at improving general mobility and core stability can improve movement patterns.[14,36,52] The movement patterns and injury history of 433 fire fighters were examined before and after a flexibility and core stability training program was implemented.[52] FMS scores correlated significantly with previous injury history. After intervention, with core strengthening exercises, time lost and number of injuries to the low back and lower extremities were reduced up to 62%.[52] In professional football players, improvements in FMS scores were achieved through an off-season exercise program that focused on mobility and core stability.[35] Significant improvements were seen in their scores, as well as a reduction in right/left asymmetry. Reliability of FMS shows promise and may be a beneficial way to screen athletes for injury risk.[14,47]

Regardless of which assessments are used to evaluate core stability, a balanced approach is needed toward muscular strength, endurance, and the sensorimotor system in various postures.

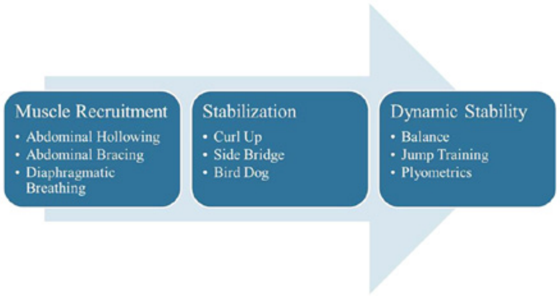

Figure 5. Sample core stability training program progression.

TRAINING CORE STABILITY FOR INJURY PREVENTION

The evidence for prevention programs effectively reducing injury rates is conflicting.[22,30,33,37,55,59-61] However, 2 recent systematic reviews[31,53] suggest that anterior cruciate ligament injury programs are effective in reducing injury rates up to 25% in female and 85% in male athletes on the basis of relative risk ratios.[53] The ideal injury prevention program components could not be identified, but it does appear that multifaceted programs (Table 1) incorporating strength, endurance, balance/posture, and neuromuscular control of the core and lower extremity are needed to reduce injury rates.[31]

A progressive program that begins with neuromuscular control of the local stabilizers, moves to stabilization exercises to promote co-contraction of local and global stabilizers, and then progresses to dynamic functional activities that require and challenge core stability may be successful (Figure 5).[1,2] Core stability tests can determine where in this continuum the athlete should begin their training.

Neuromuscular Control and Muscle Recruitment

The neutral spine position is pain free and where core stability training should begin. This position is midway between lumbar flexion and extension and is the position of power and balance for exercise and sport activities.[2] It is often the safest position for initiating core stability training. Athletes can find neutral spine position through manual repositioning exercises: in neutral spine, anterior and posterior pelvic tilts are repeated and then returned to the neutral position. With time, the athlete gains proprioceptive and kinesthetic awareness of the neutral position.

Based on the functional classification of core musculature, local stabilizers are recruited before larger global stabilizers and mobilizers.[10,24] Abdominal hollowing and abdominal bracing exercises are commonly used to improve the neuromuscular control of the local stabilizers.[1,2,6,10] Altered neuromuscular control is a predisposing factor in LBP.[2,41,58] Tsao et al[58] notes that such altered neuromuscular control is a predisposing factor rather

Table 1. Common components of injury prevention programs

Core stabilization exercises[33,55,59,60]	Plank Side bridge Supine bridge
Balance exercises[33,55,59]	Single-leg stance Single-leg stance partner toss/catch Single-leg stance on wobble board
Jump training/ plyometric exercises[22,33,55,59,60]	Forward/backward double-leg jumps Forward and backward single-leg jumps Lateral double-leg jumps Lateral single-leg jumps Single-leg zig-zag jumps Bounding
General strengthening exercises[22,33,60]	Lunges Body weight squats Nordic hamstring curls

than a result of LBP. Selective recruitment exercises can help to reorganize motor control patterns in the central cortex to improve muscle recruitment patterns.[41,57] These exercises can be performed by palpating the deep anterior muscles and then either "drawing in" (abdominal hollowing) or co-contracting (abdominal bracing) the core musculature.[10]

In addition to voluntary recruitment of the local stabilizers, diaphragmatic breathing exercises can improve core stability.[2] The diaphragm serves as the superior boundary of the abdominal cavity. Contracting the diaphragm increases intra-abdominal pressure and generates a co-contraction of the pelvic floor muscles (pubococcygeus, puborectalis, and iliococcygeus) and transverse abdominus.[2]

Stabilization

Once volitional contraction of the core stabilizers and proprioceptive awareness are established, stabilization exercises that improve muscular strength, endurance, and neuromuscular control become the focus (Table 2). The most widely incorporated exercises are "the big 3": curl-up (flexor challenge),[12,46,54] side bridge (frontal plane challenge),[9,12,21,46,54,55] and bird dog (extensor challenge).[12,21,43,46,52,54,56] Other commonly used stabilization exercises include the plank,[56] supine bridge,[9,21,52,54,56] and dead bug.[12,46,52]

Ekstrom et al[21] analyzed recruitment of core musculature during common core stability and hip-strengthening exercises. The bridge, unilateral bridge, side bridge, plank, and quadruped arm/leg lift (bird dog) successfully recruit the gluteus medius, gluteus maximus, longissimus thoracis, lumbar multifidus, external oblique, and rectus abdominus for training endurance and stabilization. However, these may not increase strength owing to the lower levels of contraction, and they may not translate well into athletic activities or preventing injury.

Dynamic Stability and Progressions

Various progressions can be used to increase the intensity of exercises and the stability demands on the core. Recommended progressions include extremity movements during stabilization exercises, instability on devices or surfaces, and functional sport-specific training.

Stabilization progressions from isometric contractions to limb movements improve muscle recruitment and may better translate to athletic activities.[46] Recommended progressions include left side bridge to plank or plank to right side bridge while maintaining good alignment. Also, progressing quadruped (bird dog) exercises from single arm/leg raises to simultaneous contralateral arm/leg raises may be beneficial.[46]

The use of instability devices is effective in challenging the core musculature and neuromuscular control systems.[7] Performing traditional strength training activities (chest press, curl-up, and bridge) on a Swiss ball improves local stabilizer recruitment and core stability.[7] Swiss ball exercises successfully recruit a wide range of core musculature, including local and global stabilizers and global mobilizers.[23] However, such exercises may not translate well into athletic activities.[7]

CONCLUSION

Core stability focuses on maintenance of neutral spinal alignment, optimal trunk position, and the transfer of loads along the kinetic chain. A variety of assessment tools can be utilized to evaluate core stability. A multifaceted approach is recommended utilizing tests for muscle recruitment, endurance, neuromuscular control, and fundamental functional movement patterns. Core stability should be trained in a progressive fashion, beginning with local muscle recruitment, moving to core stabilization in a variety of postures, and then transitioning into total body dynamic movements.

Table 2. Common stabilization exercises for core stability

Exercise	Description	Primary Muscles Recruited
Supine bridge[9,21,52,54,56]	Supine, knees flexed ~90° with feet flat on floor; raise hips to create straight line between shoulder and knees	Gluteus maximus Gluteus medius Longissimus thoracis Lumbar multifidus
Supine unilateral bridge[21,52,56]	Perform supine bridge; lift 1 leg into full knee extension	External oblique Gluteus maximus Gluteus medius Hamstrings Longissimus thoracis Lumbar multifidus
Side bridge[9,12,21,46,54,55]	Side lying with upper body supported on forearm with elbow flexed to 90°; lift trunk to create straight line between shoulders and feet	External oblique Gluteus medius Longissimus thoracis Lumbar multifidus Rectus abdominus
Plank[21,55]	Prone on elbows; lift trunk to create straight line between shoulders and feet	External oblique Gluteus medius Rectus abdominus
Bird dog[12,21,42,46,52,54,56]	Quadruped with neutral spine alignment; can perform unilateral arm/leg raises, progressing to simultaneous contralateral arm/leg raises	External oblique Gluteus maximus Gluteus medius Hamstrings Longissimus thoracis Lumbar multifidus

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy
A: consistent, good-quality patient-oriented evidence
B: inconsistent or limited-quality patient-oriented evidence
C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Core stability should be assessed with a combination of tests to identify deficits in volitional muscle contraction, isometric muscle endurance, stabilization, and fundamental functional movement pattern screening.[1,17,18,34,45]	C
Interventions for improving core stability should be individualized on the basis of assessments. Generally, training begins with improving muscle recruitment, followed by stabilization exercises and dynamic functional activities.	C
Effective injury prevention programs use a multifaceted approach that includes exercises targeting strength, endurance, balance/posture, and neuromuscular control along the kinetic chain.	C

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