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ARTICLE *in* THE JOURNAL OF THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS · OCTOBER 2005

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Core Stability and Its Relationship to Lower Extremity Function and Injury

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Abstract

Core stability may provide several benefits to the musculoskeletal system, from maintaining low back health to preventing knee ligament injury. As a result, the acquisition and maintenance of core stability is of great interest to physical therapists, athletic trainers, and musculoskeletal researchers. Core stability is the ability of the lumbopelvic hip complex to prevent buckling and to return to equilibrium after perturbation. Although static elements (bone and soft tissue) contribute to some degree, core stability is predominantly maintained by the dynamic function of muscular elements. There is a clear relationship between trunk muscle activity and lower extremity movement. Current evidence suggests that decreased core stability may predispose to injury and that appropriate training may reduce injury. Core stability can be tested using isometric, isokinetic, and isoinertial methods. Appropriate intervention may result in decreased rates of back and lower extremity injury.

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None of the following authors or the departments with which they are affiliated has received anything of value from or owns stock in a commercial company or institution related directly or indirectly to the subject of this article: Mr. Willson, Dr. Dougherty, Dr. Ireland, and Dr. Davis.

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J Am Acad Orthop Surg 2005;13:316-325

Although core stability is a popular topic among physical therapists, athletic trainers, and those involved in musculoskeletal research, the definition of the term can depend on individual perspective. Hip and trunk muscle strength, trunk muscle endurance, maintenance of a particular pelvic inclination or of vertebral alignment, and ligamentous laxity of the vertebral column all have been used to describe core stability. A biomechanist may define core stability as an osteoligamentous complex existing below a threshold at which buckling will occur. A therapist may describe core stability as the level of endurance or strength in particular muscle groups of the lumbopelvic-hip complex. Although both definitions are valid, neither fully describes the complex and highly coordinated interaction of passive and active elements that contribute to stability.

Despite this ambiguity, a growing body of literature suggests that core stability is an important component of nearly every gross motor activity. Authors from a variety of specialties have implicated these factors in the etiology and treatment of musculoskeletal injuries, ranging from axial sites, such as the lumbar spine,[1,2] hip,[3] and pelvis,[4] to appendicular sites, such as the shoulder,[5] knee,[6,7] and ankle.[8,9] Most of the evidence supporting the link between core stability and musculoskeletal injury is empiric. However, considering the firm theoretic foundation of that link and the volume of support in the literature, evaluating the elements of core stability is justified in a range of patients.

To understand the relationship between core stability and lower extremity function and injury, it is important to have a clear definition of core stability, how it is achieved, and the relevant anatomy. To apply this concept to injury prevention, the clinician must be able to identify patients with limited core stability, utilize current methods for testing core muscle capacity, and be able to specify an approach for advising these individuals.

Definition and Principles of Core Stability

The lumbopelvic-hip complex, or "core," is composed of the lumbar vertebrae, the pelvis, the hip joints, and the active and passive structures that either produce or restrict movement of these segments. The stability of any system is the ability to limit displacement and maintain structural integrity. Therefore, core stability can be defined as the ability of the lumbopelvic-hip complex to prevent buckling of the vertebral column and return it to equilibrium following perturbation.[10] Core stability is instantaneous; to maintain it, the involved anatomy must continually adapt to changing postures and loading conditions to ensure the integrity of the vertebral column and provide a stable base for movement of the extremities.

Both passive and active elements contribute to core stability. The contribution of passive elements results from the interaction of mechanical load on the bony architecture and the compliance of the soft tissues. Compared with that of the active, muscular component, the contribution of the passive elements to stability is quite small. For example, an in vivo lumbar spine may experience compressive loads >6,000 N during activities of daily living and still maintain stability.[11] However, without active support, the osteoligamentous lumbar spine becomes unstable under compressive loading of only 90 N.[12] Therefore, the active, muscular components of this system are critically important.

The active, muscular elements of the core contribute to the stability of the system through three mechanisms: intra-abdominal pressure, spinal compressive forces (axial load), and hip and trunk muscle stiffness. The contribution of intra-abdominal pressure to core stability is generally considered to be a consequence of abdominal muscle activity. Although this assumption is frequently accurate, recent studies suggest that increased intra-abdominal pressure can be achieved without abdominal muscle activity. Specifically, simultaneous contraction of the diaphragm and pelvic floor muscles also raises intra-abdominal pressure and increases global trunk stiffness.[13] Alternatively, increasing intra-abdominal pressure may decrease compressive loading on the spine during exertion.[14]

Increased axial load resulting from muscular co-contractions may increase core stability. Gardner-Morse and Stokes[15] estimated that submaximal coactivation of antagonistic trunk flexor and extensor muscles increased spine compression by 21%. In a subsequent study, Stokes and Gardner-Morse[16] reported that axial load raised intervertebral stiffness and that this greater stiffness improved spinal stability. Others suggest that axial loading increases spinal stability only to the extent that it increases trunk muscle activity.[17] Regardless, elevated axial load on the lumbar spine, whether from body weight or muscular co-contractions, is generally considered to contribute to the etiology of low back pain.[18] Therefore, although co-contraction of antagonistic trunk muscles may increase core stability, it does so at the expense of a load-bearing penalty to the lumbar spine, especially at high muscular recruitment levels.

The primary contribution of the active muscular elements of the core to the stability of the lumbopelvic-hip complex is to increase the stiffness of the hip and trunk. Co-contraction of antagonistic trunk muscles both in preparation for and in response to spinal loading has been reported by several authors. However, in the absence of spinal loading (or anticipated spinal loading), the muscles that increase stiffness of the hip and trunk are relatively inactive, and the stability of the system rests largely on passive elements.[19] The benefit of such a stabilization strategy is that prolonged co-contraction of antagonistic trunk muscles is metabolically inefficient, limits motion, and may increase the risk of developing low back pain. Therefore, using muscles in the hip and trunk to increase core stiffness must be highly coordinated to balance the demands of the intended physical task while limiting excessive loading. Further, a mechanism must be in place to manage unexpected events that pose a threat to the stability of the system. Such control is likely to be automatic because of the extended latency period of voluntary reaction time.

Two examples of such automatic neuromuscular control are anticipatory postural adjustments and muscle reflex responses. Anticipatory postural adjustments have been observed in several studies on key trunk muscles before self-imposed movements.[20,21] Hodges et al[21] demonstrated three-dimensional preparatory trunk motion before unilateral upper limb movements. These movements were initiated by muscle activity in the trunk as opposed to more distal segments. These anticipatory postural adjustments can affect the location of the center of gravity, which may affect balance and lower extremity joint forces during upright tasks.[20]

Trunk muscle reflexes, which are chiefly automatic, also may stiffen the trunk. However, this active adjustment of muscle stiffness in response to perturbation is innately tied to a neuromuscular delay. Therefore, this mechanism may not be sufficient to return the system to equilibrium if the perturbations are particularly large or fast. Indeed, some suggest that individuals with delayed trunk muscle response to perturbation have greater potential for core instability and may be at greater risk for chronic low back pain.[22] However, most of these patients can be trained to improve their response to sudden loads.[23]

The contribution of individual muscles to core stability has been the focus of several investigations. However, Cholewicki and Van Vliet[24] reported that no one particular muscle contributed >30% of the overall stability of the lumbar spine for a variety of loading conditions. Therefore, they suggested that the stability of the lumbar spine under different conditions depends on the activation of all trunk muscles rather than on specific muscles with unique architectural properties or mechanical advantage. As summarized by McGill et al,[25] "the relative contributions of each muscle continually changes [*sic*] throughout a task, such that the discussion of the 'most important stabilizing muscle' is restricted to a transient instant in time." These studies reflect the three-dimensional nature of functional movements and highlight the requirement of individuals to possess the capacity for stability in each of the cardinal planes of motion (sagittal, frontal, transverse).

Anatomy

Large, superficial muscles of the hip and trunk are architecturally best suited to produce movement and increase hip and trunk stiffness to resist the three-dimensional external moments that are applied to the core during functional activities. However, the contribution of smaller, intrinsic muscles adjacent to the spinal column should not be disregarded. Recent research supports the hypothesis proposed by Bergmark[26] that, at any given activation level of the smaller, intrinsic muscles, there is an upper limit to the possible activation level of the large, superficial muscles, beyond which the spine buckles.[19] This relationship between the recruitment of small, intrinsic muscles and large, torque-producing muscles further highlights the complexity of the motor control necessary to provide core stability.

Chief muscles of the core that function in the sagittal plane include the rectus abdominis, transverse abdominis, erector spinae, multifidus, gluteus maximus, and hamstrings.[24,27-31] Acting in isolation, these muscles produce movement in hip and trunk flexion and extension. Co-contraction of muscles on the anterior and posterior aspect of the trunk increases intra-abdominal pressure and generates greater trunk stiffness. Specifically, the rectus abdominis is active in trunk flexion; in combination with the hamstrings, it rotates the pelvis posteriorly. With the assistance of the multifidus, tonic contractions of the transverse fibers of the deeper transversus abdominis increase spinal stiffness and raise intra-abdominal pressure. The gluteus maximus is important in transferring forces from the lower extremities to the trunk. The activation level of key lower extremity muscles during jumping is governed by the activation level of this important stabilizing muscle.[32]

Chief lateral muscles of the hip and trunk that function in the frontal plane include the gluteus medius, gluteus minimus, and quadratus lumborum.[27,29] The gluteus medius and minimus are the primary lateral stabilizers of the hip. During open chain movements, they abduct the hip. However, in closed chain motion, as during stance, they assist in maintaining a level pelvis. The function of the quadratus lumborum is more robust. Although unilateral activation of this muscle elevates the ipsilateral pelvis, co-contraction with its contralateral counterpart markedly stiffens the lumbar spine. Indeed, Cholewicki and McGill[19] determined that this muscle may be architecturally best suited to stabilize the spine and that it is active during nearly all upright activites. Chief medial muscles acting in the frontal plane include the adductor magnus, adductor longus, adductor brevis, and pectineus.[27] These muscles are important for hip movement, but their contribution to core stability may be less than that of their lateral counterparts, in part because of small external femoral abduction moments relative to external femoral adduction moments during unilateral support. The greater external femoral adduction moment places greater demands on the lateral core muscles to maintain static alignment in this plane (Fig. 1).

Chief muscles of the hip acting in the transverse plane include the gluteus maximus, gluteus medius, piriformis, superior and inferior gemelli, quadratus femoris, obturator externus, and obturator internus.[27,33,34] However, the capacity of these muscles to rotate the femur is greatly affected by the degree of hip flexion. For example, the anterior fibers of the gluteus maximus, gluteus medius, and piriformis change from external rotators to internal rotators as the hip assumes a more flexed position.[33] Trunk rotation primarily is provided by the internal and external oblique muscles, the iliocostalis lumborum, and the multifidus. However, when acting bilaterally, these muscles contribute a sagittal plane moment and may also increase intra-abdominal pressure when activated simultaneously with their antagonist.

Core Stability and Lower Extremity Function

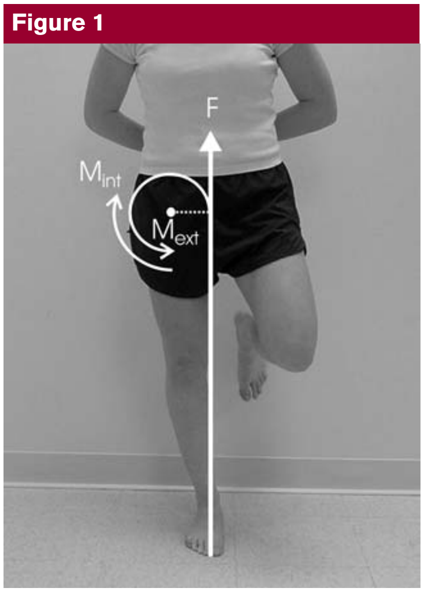
Current theories regarding the relationship between core stability and lower extremity function, performance, and injury were proposed by Bouisset.[35] He suggested that motor activity in the form of postural support must occur before the initiation of voluntary extremity movements. In addition, the support must vary according to the parameters of the planned movement, posture, and the uncertainty about the upcoming tasks. Hodges and Richardson[28] provided evidence for this theory using fine-wire electromyography (EMG) to record activity in the abdominal muscles and multifidus during voluntary movements of the lower extremity. They demonstrated that trunk muscle activity occurs before the activity of the prime mover of the limb, regardless of the direction of limb movement. Specifically, the deepest abdominal muscle, the transversus abdominis, was invariably the first muscle to be automatically activated in preparation for movement, followed closely by the multifidus. Based on these results, the authors concluded that the central nervous system creates a stable foundation for movement of the lower extremities through cocontraction of the transversus abdominis and multifidus muscles.

Hip muscles also are important in lower extremity muscle performance and alignment during closed chain activities. Because of their remote location compared with the lumbar spine, these muscles have not been included in many studies of the association between extremity function and core stability. However, Bobbert and van Zandwijk[32] examined the temporal aspects of force development in the lower extremity during vertical jumping. Using surface EMG of the hip, knee, and ankle musculature, they demonstrated that the time taken by the vertical ground reaction force to increase from 10% to 90% of the maximum value (rise time) was most closely associated with the rise time of the EMG signal of the gluteus maximus. Further, the rise times of the extensor moment at the knee and the plantar flexion moment at the ankle were significantly ($P < 0.05$) related to the rise time of the gluteus maximus EMG signal. The authors suggested that this relationship exists because the knee and ankle moments depend on the hip moment to preserve the forward component of the acceleration of the center of mass during the jump task. The onset of the moments at the knee and ankle during a jump must not precede the onset of the hip moment; the knee and ankle moments rely on the hip moment and the muscles driving it with respect to the magnitude of the contraction.

Core Stability and Lower Extremity Injury

Not every lower extremity injury can be ascribed to deficiencies in core stability. However, core muscle function has been reported to influence structures from the low back to the ankle. For example, diminished back extensor endurance is a frequently reported risk factor for low back pain among working adults.[1,2] Devlin[4] reviewed the literature on injuries in the rugby union and suggested that fatigue of the abdominals was a contributing factor in hamstring injuries. Bullock-Saxton et al[8] examined patients with previous severe unilateral ankle sprains and reported that the patients exhibited a delay in the onset of firing patterns in the ipsilateral and contralateral gluteus maximus. In another study, patients with a history of ankle sprain and ankle hypermobility also demonstrated delayed latency of activation of the ipsilateral gluteus medius.[9]

Figure 1



The vertical ground reaction force (F) lies medial to the hip joint center during single limb support, creating an external abduction moment (M_{ext}) that must be opposed by an equal moment created by lateral core musculature (M_{int}) to avoid movement into femoral adduction.

Perhaps the greatest influence of core stability can be found at the knee. Ireland et al[36] studied hip strength in females aged 12 to 21 years who reported patellofemoral pain. Using hand-held dynamometers and strap stabilization, they demonstrated a deficit in peak abduction and external rotation forces of 26% ($P < 0.001$) and 36% ($P < 0.001$), respectively, in females with patellofemoral pain versus a healthy control group. The authors suggested that this strength deficit may represent a diminished capacity to resist movement into knee adduction and internal rotation, positions associated with high lateral retropatellar contact pressure.[37-39] Similarly, in their study of distance runners with iliotibial band friction syndrome, Fredericson et al[40] demonstrated femoral abduction weakness compared with the uninvolved hip and with the ipsilateral hip in a healthy control group. Following a 6-week hip abductor strengthening program, 92% of the injured group were pain free and returned to their previous level of activity.

Core stability also may contribute to the etiology of anterior cruciate ligament (ACL) injury. The report from the Hunt Valley Consensus Conference on Prevention of Noncontact ACL Injuries states that, at the time of ACL injury, the knee of the injured individual was frequently abducted and externally rotated with respect to the femur.[6] Recent studies confirm that movement into this position is associated with increased ACL strain because of impingement of the ligament against the intercondylar notch of the femur.[41] The report concluded that strength and endurance training of the hip abductors and external rotators should be included in prevention programs. Subsequent research confirms that the force necessary to move the knee into valgus is particularly sensitive to the level of hip muscle stiffness.[42]

Unfortunately, few studies have focused on the contribution of core stability to dynamic knee joint stability. Sommer[43] reported that, with fatigue, athletes tend to assume lower extremity positions during jumping that are typically associated with injury. Specifically, Sommer reported markedly greater femoral adduction and internal rotation motion with the onset of fatigue. He proposed that the cause for this movement tendency was the inability of the athletes to generate sufficient torque in the gluteal muscles, hamstrings, and abdominal muscles to resist external moments at the hip and knee. More recently, Ford et al[44] used three-dimensional motion analysis and inverse dynamics to measure knee valgus motion and kinetics during a jumping task. They found significantly greater peak knee valgus angles ($P < 0.001$) and excursion motion ($P = 0.005$) in females versus males, which the authors also interpreted as decreased dynamic knee joint stability. However, although Sommer[43] believed that valgus motion was attributed to decreased postural control because of weakness of lumbopelvic musculature, Ford et al[44] suggested that this motion was associated with the ability of thigh musculature to increase knee joint stiffness.

Further studies are necessary to delineate the relative contribution of key core muscles to this potentially harmful knee valgus movement tendency. Zeller et al[45] recently examined the kinematics and electromyographic activity in intercollegiate male and female athletes during a single-leg squat and also reported significantly greater femoral adduction ($P < 0.001$) in women versus men. Based on their results, the authors concluded that kinematic differences between the sexes are most closely related to hip muscle differences rather than to differences in quadriceps activation, as previously suggested.

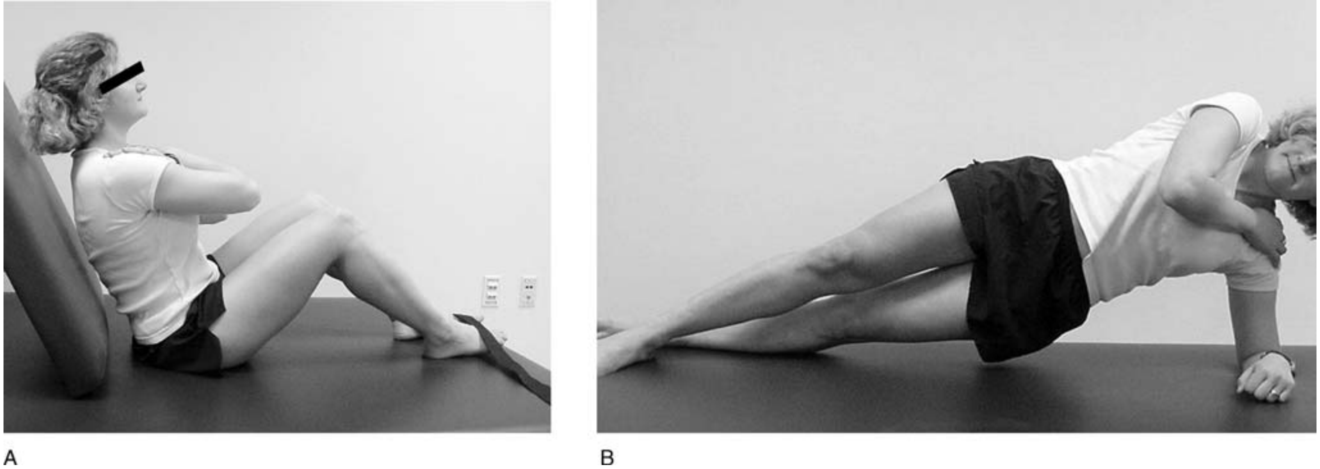
The evidence supporting a relationship between decreased core muscle capacity and lower extremity injury is largely retrospective or cross-sectional. Therefore, it is not possible to discern whether these injuries were a cause or an effect of the core deficiency. Considering the predominance of type II (postural) muscle fibers in the trunk and the tendency for muscle atrophy to most significantly affect type II fibers, it is likely that the injuries in the previously mentioned studies[8,9,36,40] caused decreased core muscle capacity. However, a recent prospective study suggests that deficiencies in core muscle capacity may increase the risk of lower extremity injury. Leetun et al[46] measured femoral abduction and external rotation isometric force as well as abdominal, back extension, and quadratus lumborum endurance in intercollegiate athletes before the beginning of their competitive season. Compared with the men in the study, the women demonstrated significantly decreased femoral abduction ($P = 0.04$) and external rotation strength ($P < 0.001$) (normalized to body weight) and significantly decreased quadratus lumborum endurance ($P < 0.001$). Athletes who sustained an injury during the season possessed significantly less preseason femoral abduction ($P = 0.02$) and external rotation strength versus the athletes who remained injury free ($P = 0.001$).

Based on conclusions from such studies, it is not surprising that many researchers and clinicians believe that improving core stability may be important in preventing lower extremity injury. However, few core stability intervention studies support this commonly held belief. Hewett et al[47] demonstrated that females who participated in a neuromuscular training program experienced a 72% decrease in the incidence of serious knee ligament injuries compared with female athletes who did not participate in the program ($P = 0.05$). Neuromuscular training seems to reduce knee adduction and abduction moments during landing from a jump.[48] Further studies are necessary to determine whether these smaller moments are a consequence of increased quadriceps and hamstring strength or whether they are the result of anticipatory postural adjustments and greater activation of the hip abductors and external rotators before contact with the ground.

Clinical Tests for Core Stability

Core stability is a complex phenomenon, and no single test accurately measures the ability of an individual to demonstrate this skill. Researchers can look for evidence of core instability using sophisticated EMG and modeling techniques. However, because of the time and expense involved, clinicians typically choose tests that are portable, inexpensive, and quick. Although many of these clinical tests have acceptable to excellent reliability,

Figure 2



Timed isometric flexor endurance **(A)** and side bridge **(B)** tests.

questions exist regarding their construct validity. These tests often are used interchangeably for the single purpose of measuring core muscle capacity. Studies show a low correlation between these tests, indicating that they may represent different determinants of core stability.[49,50] Therefore, deciding which test to administer largely depends on which determinant of core muscle capacity is important to the clinician.

Isometric Testing

Timed tests of trunk muscle endurance are the most frequently investigated and reported tests in the literature. For example, the Biering-Sørensen test is commonly used to measure global back extension endurance.[1,2] For this test, subjects are generally positioned in prone and asked to maintain an unsupported trunk position for as long as possible. Its widespread use may be a reflection of its simplicity and cost-effectiveness. Further, most reports reveal an acceptable level of both test-retest and interrater reliability.[51] On average, women tend to display greater endurance than men (mean age 23 ± 2.9 years), and healthy subjects perform better than individuals with low back pain.[29,52] The test results have been positively correlated with activity level and physical work history and negatively correlated with age, weight, height, and percent body fat.[49,50] Unfortunately, this test may be associated with a high failure rate because of pain during the testing of subjects with low back pain.[1,50]

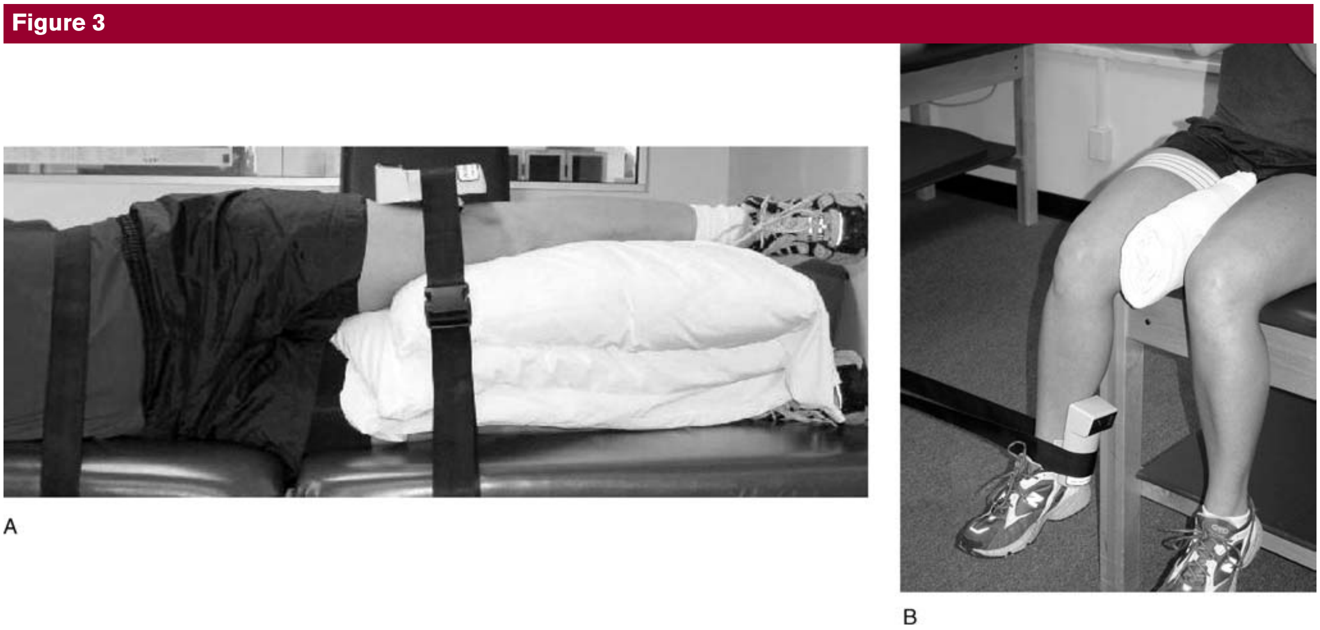
Timed tests of isometric muscle capacity also have been used to quantify trunk flexor and trunk lateral flexor endurance. McGill et al[29] advocate using the flexor endurance test and side bridge test (Fig. 2). They organized a table of normative scores for these tests and the Biering-Sørensen test among healthy young adults. These tests are reported to have excellent test-retest reliability, but their predictive value has not been determined.

Isometric tests may be used in conjunction with a hand-held dynamometer to determine the peak force development of muscles in the hip and trunk. Subjects are simply positioned in traditional manual muscle test positions and asked to move the body segment of interest into the resistance of the dynamometer, which is traditionally fixed by the examiner. Similar to the isometric endurance measures, this measure is also very quick, portable, and inexpensive. However, although good test-retest reliability normative values have been documented for hip strength measures using this method,[53-55] relatively poor reliability has been demonstrated for trunk strength measures with this technique.[56] Stabilization straps recently have been implemented in place of manual resistance to measure femoral abduction and external rotation strength[56] (Fig. 3). This modification may minimize error caused by inherent tester strength variability and may improve the clinical utility of hand-held dynamometry.

Isokinetic Testing

One of the major drawbacks of isometric testing is that the interpretation of the results is limited to the capacity of muscles at one length. Perhaps because of this, isokinetic evaluation of hip and trunk muscle performance has gained popularity over the past three decades. Isokinetic evaluation measures muscle work performed at a constant velocity. This sort of testing is unique because it measures muscle torque at constantly changing angles and associated muscle moment arms, which is presumed to more closely represent a dynamic spinal loading event. Isokinetic test results abound in the current literature for a variety of

Figure 3



Isometric femoral abduction strength test **(A)** and isometric femoral external rotation strength test **(B)** using a hand-held dynamometer and strap stabilization. (Reproduced with permission from Ireland ML, Wilson JD, Ballantyne BT, Davis IM: Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther* 2003;33:671-676.)

subject populations, especially with respect to trunk flexion as well as extension strength and endurance.[49,50]

However, there are several drawbacks to isokinetic testing. Isokinetic dynamometers tend to be large, immovable devices that are expensive to purchase and maintain. Patient setup and instruction is often time-consuming. Perhaps more important, however, several reports suggest that the reliability of these devices is questionable, especially at speeds >60° per second.[57,58] Further, these reports suggest a significant learning effect between testing sessions that may require testers to repeat the evaluation to obtain a valid measure.[57]

Isoinertial Testing

Isoinertial contractions are a type of muscle work that is performed against a constant resistance. One example of an isoinertial test of core muscle capacity is the curl-up test of the Canadian Standardized Test of Fitness, which has gained widespread acceptance. This test requires subjects to perform their maximum number of curl-ups to an objective end point at a consistent tempo. The test ends when the subject can no longer maintain the required tempo. The test has acceptable test-retest reliability, and normative values for the test are available for males and females over a large age range.[59] The American College of Sports Medicine currently endorses this particular measure as an appropriate field test of trunk flexor endurance.[60] Unfortunately, few other tests of this nature have been proposed or tested for reliability with respect to hip and trunk muscle capacity. Moreland et al[56] reported good intertester reliability for an isotonic test of repetitive trunk extensor endurance. However, determination of normative values or test-retest reliability was not a component of that study.

The single-leg squat test is a very simple qualitative isoinertial test of core stability that can be performed in a busy practice setting (Fig. 4). During this test, patients are asked to stand on one leg and squat to a predetermined depth. A contralateral pelvic drop and femoral adduction or internal rotation are considered evidence of decreased hip muscle capacity. Compensatory strategies to decrease the demand on the gluteus medius are common. For example, patients may use more proximal muscles to elevate the pelvis or shift their weight over the supporting leg to decrease the lever arm for the center of mass.[61] The examiner may have the patient repeat this test movement several times to obtain a more complete assessment of lower extremity alignment in the setting of hip and thigh muscle fatigue. Although this test is intuitively sound, more research is required to determine the reliability, validity, and normative values for this test.

Intervention Approach

A recent trend in core stability training is to focus on recruiting the transversus abdominis and lumbar multifidus muscles during function-

Figure 4

Single-leg squat test. This subject is demonstrating excessive movement of the right femur into adduction and internal rotation, both of which are positive signs of decreased core muscle capacity.

Figure 5

Partial curl-up for abdominal strengthening using a therapeutic exercise ball.

al activities. The benefit of this approach is that through co-contraction of these muscles, individuals increase trunk stiffness and intra-abdominal pressure with minimal load penalties to the lumbar spine. Unfortunately for many patients, a static, isolated contraction of the transversus abdominis and lumbar multifidus is difficult to achieve. Often, the activation of muscles such as the rectus abdominis, external obliques, or thoracic erector spinae dominate during general exercise techniques.

Several techniques have been described for teaching isometric co-contractions of the lumbar multifidus and transversus abdominis.[62] Patients are instructed to gently "draw in" or "hollow" the abdominal wall while using the multifidus to maintain a neutral spinal position. Critchley[63] reported that cues to have patients simultaneously contract their pelvic floor musculature during the drawing-in maneuver also may lead to greater transversus abdominis activation. Pressure biofeedback units are frequently used to illustrate the drawing-in action in the prone and supine positions. Despite these reeducation techniques, it is important to remember that the goal for all patients is to reproduce this action independently. As such, the amount of external feedback should be appropriately reduced as patients learn the appropriate activation pattern.

Progression of core stability exercises generally is determined by the ability of the patient to consistently reproduce the gentle drawing-in action. Patients then must learn to maintain this contraction and dissociate movements of the extremities from a stable trunk. This process is initiated in positions of greater support (prone, supine, four-point kneeling), before progressing to more functional positions (sitting, standing). Extremity movements typically begin in straight planes and progress to multidimensional activities. Equipment including physioballs, foam rollers, cuff weights, platforms, and balance boards are commonly used in this phase to further increase external torque and to challenge core musculature (Fig. 5).

Intervention strategies also should include strengthening exercises for weakness in chief core muscles identified during the objective examination. Strength training of these weak core muscles will foster appropriate dissemination of external loads through the extremities during functional tasks by maintaining proper alignment. For the trunk, strengthening of the rectus abdominis, quadratus lumborum, and lumbar extensors is done using curl-ups, side planks, and bird dog exercises, respectively, as recommended by McGill.[64] Particular attention should be paid to weakness identified in femoral abduction or external rotation because of the role of these muscles in maintaining appropriate lower extremity alignment in the frontal and transverse planes. Patients are encouraged to avoid positions of femoral adduction or internal rotation during closed kinetic chain exercises, especially those that include knee flexion during upright support. Training often begins with slow, controlled movements (eg, step-downs) and progresses to faster, dynamic actions (eg, jumping and landing).

The final step in core stability training is integrating the use of these core muscles into daily tasks and sport-specific activities. Patients initially require frequent cues for postural muscle activation and lower extremity alignment. However, they generally draw from previous experiences to progress rapidly in this phase. Patients who display appropriate activation of core musculature, good global core muscle strength, and an ability to incorporate the action of these muscles into activities specific to their functional goals possess the critical components of core stability.

Summary

Core stability is necessary to maintain the integrity of the spinal column, provide resistance to perturbations, and furnish a stable base for movement of the extremities. The ability of individuals to demonstrate core stability is determined through a complex relationship between hip and trunk muscle capacity and motor control. Current literature suggests that lower extremity injuries may diminish core stability measures. Additionally, a preexisting core deficiency may increase the risk of lower extremity injury. The identification of and appropriate intervention for individuals with diminished core stability measures may more fully prepare these individuals for work or athletics.

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