Core Stability Exercise Principles

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AKUTHOTA, V., A. FERREIRO, T. MOORE, and M. FREDERICSON. Core stability exercise principles. *Curr. Sports Med. Rep.*, Vol. 7, No. 1, pp. 39–44, 2008. *Core stability is essential for proper load balance within the spine, pelvis, and kinetic chain. The so-called core is the group of trunk muscles that surround the spine and abdominal viscera. Abdominal, gluteal, hip girdle, paraspinal, and other muscles work in concert to provide spinal stability. Core stability and its motor control have been shown to be imperative for initiation of functional limb movements, as needed in athletics. Sports medicine practitioners use core strengthening techniques to improve performance and prevent injury. Core strengthening, often called lumbar stabilization, also has been used as a therapeutic exercise treatment regimen for low back pain conditions. This article summarizes the anatomy of the core, the progression of core strengthening, the available evidence for its theoretical construct, and its efficacy in musculoskeletal conditions.*

INTRODUCTION

Core stability (or core strengthening) has become a well-known fitness trend that has started to transcend into the sports medicine world. Popular fitness programs, such as Pilates, yoga, and Tai Chi, follow core strengthening principles. Broad benefits of core stabilization have been touted, from improving athletic performance and preventing injuries, to alleviating low back pain. The purpose of this article is to review the available evidence on the benefits of core strengthening, present relevant anatomy, and outline core stabilizing exercise principles.

The core can be described as a muscular box with the abdominals in the front, paraspinals and gluteals in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom (1). Within this box are 29 pairs of muscles that help to stabilize the spine, pelvis, and kinetic chain during functional movements. Without these muscles, the spine would become mechanically unstable with compressive forces as little as 90 N, a load much less than the weight of the upper body (2). When the system works as it should, the result is proper force distribution and maximum force generation with minimal compressive, translational, or shearing forces at the joints of the kinetic chain (3). The core is particularly important in sports because it provides "proximal stability for distal mobility" (4).

Ipso facto, core stability exercises appear to be especially important in cases of spinal instability. Gross spinal instability is an obvious radiographic displacement of vertebrae, often with associated neurologic deficit and deformity. However, functional or clinical instability is not as easily defined. Panjabi describes "clinical instability as the loss of the spine's ability to maintain its patterns of displacement under physiologic loads so there is no initial or additional neurologic deficit, no major deformity, and no incapacitating pain" (5). The spine stability system consists of the following interacting elements:

- Neuromuscular control (neural elements)
- Passive subsystem (osseous and ligamentous elements)
- Active subsystem (muscular elements)

In other words, stability of the spine is not only dependent on muscular strength, but also proper sensory input that alerts the central nervous system about interaction between the body and the environment, providing constant feedback and allowing refinement of movement (6). Thus a complete core stabilizing program would consider sensory and motor components related to these systems for optimal spinal stabilization. Recently, the Queensland physiotherapy group produced research drawing a great deal of attention to the deep core musculature, specifically the transversus abdominis and multifidi, for core stability (1). However, McGill and other biomechanists emphasize larger "prime mover" muscles, such as the abdominal obliques and quadratus

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1537-890X/0701/39–44
Current Sports Medicine Reports

lumborum, in providing stability (7). It appears a coordinated contraction of all deep and superficial core muscles is needed for optimal spinal stabilization (8).

ANATOMY

The core acts through the thoracolumbar fascia, "nature's back belt." The transversus abdominis has large attachments to the middle and posterior layers of the thoracolumbar fascia (9). Additionally, the deep lamina of the posterior layer attaches to the lumbarspinous processes. In essence, the thoracolumbar fascia serves as part of a "hoop" around the trunk (7) that provides a connection between the lower limb and the upper limb (10). With contraction of the muscular contents, the thoracolumbar fascia also functions as a proprioceptor, providing feedback about trunk positioning.

Two types of muscle fibers comprise the core muscles: slow-twitch and fast-twitch. Slow-twitch fibers make up primarily the local muscle system (the deep muscle layer). These muscles are shorter in length and are suited for controlling intersegmental motion and responding to changes in posture and extrinsic loads. Key local muscles include transversus abdominus, multifidi, internal oblique, deep transversospinalis, and the pelvic floor muscles. Multifidi have been found to atrophy in people with chronic low back pain (LBP) (11). On the other hand, fast-twitch fibers comprise the global muscle system (the superficial muscle layer). These muscles are long and possess large lever arms, allowing them to produce large amounts of torque and gross movements. Key global muscles include erector spinae, external oblique, rectus abdominis muscles, and quadratus lumborum (which McGill states is a major stabilizer of the spine) (12).

The abdominals serve as a particularly vital component of the core. The transversus abdominis has received attention for its stabilizing effects. It has fibers that run horizontally (except for the most inferior fibers, which run parallel to the internal oblique muscle), creating a belt around the abdomen. "Hollowing in" of the abdomen creates isolated activation of the transversus abdominis. The transversus abdominis and multifidi have been shown to contract 30 ms before movement of the shoulder and 110 ms before movement of the leg in healthy people, theoretically to stabilize the lumbar spine (13,14). However, patients with LBP have delayed contraction of the transversus abdominis and multifidi prior to limb movement (14). The internal oblique and the transversus abdominis work together to increase the intra-abdominal pressure from the hoop created via the thoracolumbar fascia. Increased intra-abdominal pressure has been shown to impart stiffness to the spine (7). The external oblique, the largest and most superficial abdominal muscle, acts as a check of anterior pelvic tilt. The abdominals (and multifidi) need to engage only to 5%–10% of their maximal volitional contraction to stiffen spine segments (15).

The hip musculature is vital to all ambulatory activities, and plays a key role in stabilizing the trunk and pelvis in gait (16). Poor endurance and delayed firing of the hip extensor (gluteus maximus) and abductor (gluteus medius) muscles have previously been noted in people with LBP and other musculoskeletal conditions such as ankle sprains (17). The psoas is only a feeble flexor of the lumbar spine (9). However, it does have the potential to exert massive compressive forces on the lumbar disks. In activities that promote maximal psoas contraction, such as full sit-ups, it can exert a compressive load on the L5-S1 disk equal to 100 kg of weight (9). Tightness of the hip flexor (psoas) can cause LBP by increasing compressive loads to the lumbar disks.

The diaphragm serves as the roof of the "muscular box" of the core, and the pelvic floor serves as the floor. Contraction of the diaphragm increases intra-abdominal pressure, thus adding to spinal stability. Pelvic floor musculature is coactivated with transversus abdominis contraction (18). Recent studies (19) have indicated that people with sacroiliac pain have impaired recruitment of the diaphragm and pelvic floor. Thus diaphragmatic breathing techniques and pelvic floor activation may be an important part of a core-strengthening program.

MEASURING CORE STABILITY

Research on core stability exercises has been hampered by a lack of consensus on how to measure core strength. If core instability and core weakness can be measured, outcomes can be followed and a proper emphasis can be placed upon core strengthening in certain individuals. Delitto and others

Figure 1. Prone instability test: In this test, the patient is prone, with legs off the table and feet on the floor. The clinician applies posterior-anterior pressure over the lumbar spine and assesses for pain. The patient then engages extensors and lifts feet off the floor. The test is positive if pain is elicited with pressure and relieved with active extension, as this is thought to indicate temporary pain relief through stabilization of the spine (22).

have proposed that stabilization exercises would work best in individuals who are young, with increased flexibility (postpartum, generalized ligamentous laxity), or with exam findings suggesting an interspinal segment with increased painful movement (20,21). The prone instability test is an example of a physical exam maneuver testing for clinical instability (22) (Fig. 1). Measures can include triplanar, weight-bearing evaluation of the global core as well as isolated measures of particular muscles (4) (Fig. 2 Table 1).

DEVELOPING A CORE EXERCISE PROGRAM

Exercise of the core musculature is more than trunk strengthening. Lack of sufficient coordination in core musculature can lead to decreased efficiency of movement and compensatory patterns, causing strain and overuse injuries. Thus motor relearning of inhibited muscles may be more important than strengthening in patients with LBP and other musculoskeletal injuries.

A core exercise program should be done in stages with gradual progression. It should start with restoration of normal muscle length and mobility to correct any existing muscle imbalances. Adequate muscle length and flexibility are necessary for proper joint function and efficiency of movement. Muscle imbalances can occur where agonist muscles become dominant and short while antagonists would become inhibited and weak. One example of a muscle imbalance pattern includes tightness and over-activity of the primary hip flexor (iliopsoas), which in turn causes reciprocal inhibition of the primary hip extensor (gluteus maximus). Further up the kinetic chain, this particular muscle imbalance leads to increased lumbar extension, with excessive force on the posterior elements of the spine. In addition, postural muscles have a tendency to become tight due to constant activity in order to fight the forces of gravity.

Then, activation of the deep core musculature should be taught through lumbo-pelvic stability exercises. When this has been mastered, more advanced lumbo-pelvic stability exercises on the physioball can be added. Finally, there should be transitioning to the standing position, facilitating functional movement exercises that promote balance and coordination of precise movement. The goal of advanced core stabilization is to train functional movements rather than individual muscles (3).

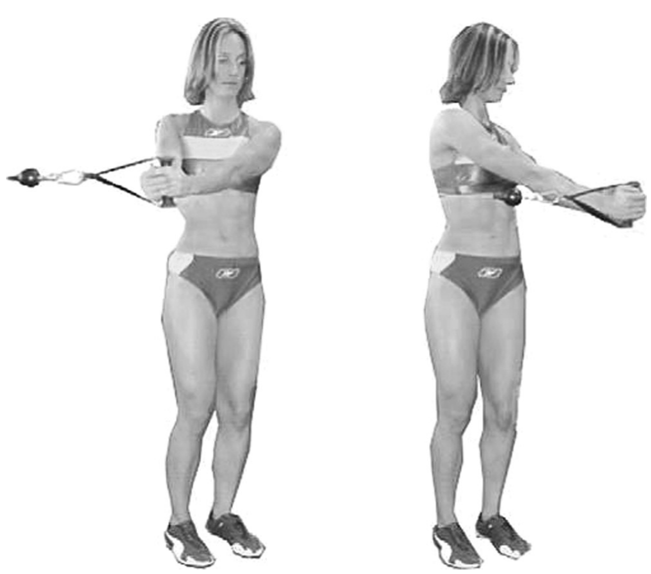

Figure 2. Advanced functional training techniques for core stability. Transverse plane core exercises in standing position. This resistive, dynamic trunk pattern challenges the core in the transverse plane. This requires strict bracing of the abdominals and locking the ribs and pelvis together to avoid unnecessary spinal torsion. The athlete activates the abdominal brace before movement. It is important to emphasize postural alignment with scapulae retracted and depressed. The athlete should maintain neutral spine angles throughout movement. Progression can involve greater resistance or weight.

TABLE 1. Measuring core stability: the core score

1.	Prone instability test
2.	Prone extension endurance test (Biering-Sorenson paraspinal endurance strength)
3.	Side bridge endurance test (quadratus lumborum endurance strength)
4.	Pelvic bridging
5.	Leg lowering test (lower abdominal strength)
6.	Trunk curl
7.	Hip external rotation strength
8.	Modified Trendelenburg test (single leg squat with observation infrontal plane)
9.	Single leg squat in sagittal plane
10.	Single leg squat in transverse plane

BEGINNING A CORE STRENGTHENING PROGRAM

Warm-up can include the "cat" and "camel" stretches and a short aerobic program. A core stability exercise program begins with recognition of the neutral spine position (midrange between lumbar flexion and extension), touted to be the position of power and balance for optimal athletic performance in many sports (8).

The first stage of core stability training begins with learning to activate the abdominal wall musculature. Individuals who are not adept at volitionally activating motor pathways or individuals with chronic low back pain and fear-avoidance behavior may require extra time and instruction to learn to recruit muscles in isolation or with motor patterns (23). Cueing individuals on abdominal hollowing, which may activate the transversus abdominis, as well as abdominal bracing, which activates many muscles including the transversus abdomin is, external obliques, and internal obliques, is an important beginning step. One study showed that performing abdominal hollowing and bracing prior to performing abdominal curls facilitated activation of the transversus abdominis and internal obliques throughout the abdominal curling activity (22,24).

Grenier and McGill, however, found little utility of the abdominal hollowing to cue the transversus abdominis into improving core stability and place more emphasis on abdominal bracing (25).

PROGRESSING A CORE STRENGTHENING PROGRAM

Once these activation techniques are mastered and the transversus abdominisis "awakened," training should be progressed. The beginner can then incorporate the "big 3" exercises as described by McGill. These include the curl-up, side bridge (side plank), and quadruped position with alternate arm/leg raises ("bird dog"). The prone plank and bridging also can be added at this stage (3). Pelvic bridging is particularly effective for activating the lumbar paraspinals (26).

Initial exercises are done in supine, hook-lying, or quadruped positions. It should be reiterated that the pelvis should not be tilted and the spine should not be flattened, but should maintain a neutral posture. Normal rhythmic diaphragmatic breathing also is emphasized. Once good control is demonstrated with the static core exercises, the individual can advance to exercises using a physioball. Notably, non-weight-bearing core exercises, such as ones performed on a physioball, may not translate to improved athletic performance (27). Thus, athletes should quickly advance to more functional exercises in sitting, standing, and walking positions.

ADVANCED CORE STRENGTHENING: CHALLENGING BALANCE AND MOTOR CONTOL

As progression is made through the initial stages of a core strengthening program, emphasis should be placed on developing balance and coordination while performing a variety of movement patterns in the three cardinal planes of movement: sagittal, frontal, and transverse. Exercises should be performed in a standing position and should mirror functional movements. Functional training typically requires acceleration, deceleration, and dynamic stabilization. An advanced core stabilizing program should train reflexive control and postural regulation (3).

Various unstable surfaces can be used to further challenge balance and coordination and assist with training movement patterns. These include the balance board (a whole sphere underneath the board, which creates multiplanar instability), the rocker board (a curved surface underneath the board, which allows single-plane motion), the Bosu Balance Trainer, and the Dyna Disk (the latter two, both of which are air-filled plastic discs, can be used interchangeably) (3).

The abdominal bracing technique should be initiated before performing any of the standing exercises. Initial gait training is important, emphasizing control of heel strike in the supinated position on the lateral edge of the foot, moving to pronation onto the medial foot with flexion of the first metatarsal head and toes. From there, exercises can be progressed to a controlled falling lunge onto an unstable surface, emphasizing control and spinal alignment. Multidirectional lunges can be done on the floor in multiple planes of movement. Progress can be made to jumps on one or two legs, which stimulates cerebellar activity and helps create automatic postural control (3). An example of an evidence-based core stability program is provided in Table 2 (28,29).

TABLE 2. Example of an evidenced-based core stability program

General
- Go over anatomy of the core
- Active participation emphasized

Basic exercises – isolate core muscles in different positions
- Transversus abdominus (advance if able to perform 30 reps with 8 s hold)
  - Abdominal bracing
  - Bracing with heel slides
  - Bracing with leg lifts
  - Bracing with bridging
  - Bracing in standing
  - Bracing with standing row
  - Bracing with walking
- Paraspinals/multifidi (advance if able to perform 30 reps with 8 s hold)
  - Quadruped arm lifts with bracing
  - Quadruped leg lifts with bracing
  - Quadruped alternate arm and legs lifts with bracing
- Quadratus lumborum and obliques (advance if able to perform 30 reps with 8 s hold)
  - Side plank with knees flexed
  - Side plank with knees extended
- Trunk curl

Facilitation techniques if necessary (pelvic floor contraction, visualization, palpation, identifying substitution patterns like pelvic tilt, ultrasound)

Progression
- Physioball
- Functional training positions with activation of core
- Build endurance

Compliance with home exercise program

CREATING MORE HARM THAN GOOD: PRACTICES TO AVOID

Some traditional progressive resistance strengthening of the core muscles may be unsafe to the back. Specifically, heavy resistance training of the lumbar extensors is not recommended. Roman chair exercises or back extensor strengthening machines require at least torso mass for resistance, which is a load that is often injurious to the lumbar spine (8). Traditional sit-ups also may be unsafe because they create excessive compressive forces in the lumbar spine (9,30). Caution should be used with full spinal flexion or repetitive torsion, as risk of lumbar injury is greatest with these positions (31). In addition, spinal exercise should not be done in the first hour after rising in the morning. This is due to the fact that hydrostatic pressure in the disk is increased during that time (32).

WHO SHOULD HAVE CORE STABILITY PRESCRIBED?

Certain predictors can be used to determine which patients will be more likely to benefit from lumbar stabilization programs. One study (28) found the following factors could be used to assess which patients would be likely to respond favorably to core stabilization:

- Younger age (<40)
- Greater general flexibility (hamstring length greater than 90°, postpartum)
- Positive prone instability test
- Presence of aberrant movement during spinal range of motion (painful arc of motion, abnormal lumbopelvic rhythm, and using arms on thighs for support)

Stuge *et al.* also proposed the following physical maneuvers as predicting a good response from stabilization exercise in postpartum women (33):

- Positive posterior pelvic pain provocation (P4) test (also called thigh thrust test)
- Positive active straight leg raise
- Positive pain provocation (persists greater than 5 s after palpation) with palpation of PSIS region (long dorsal sacroiliac ligament)
- Positive pain provocation (persists greater than 5 s after palpation) with palpation of pubic symphysis
- Positive Trendelenburg sign

EFFICACY OF CORE-STRENGTHENING EXERCISE FOR TREATMENT OF BACK PAIN

There is ample evidence that individuals with chronic LBP and sacroiliac pain lack proper recruitment of core muscles and exhibit core weakness (6,11,14,26,34,35). There also is evidence of increased fatigability, decreased cross section, and fatty infiltration of paraspinal muscles in patients with chronic LBP (6). Even high-level athletes show signs of core instability, and this may set them up for more musculoskeletal injuries (4,36–39). Female athletes may be particularly susceptible to injury to the anterior cruciate ligament if core weakness is found (36–38). In addition, these patients seem to have increased difficulty with balance and decreased ability to compensate for unexpected trunk perturbation. Patients with back pain also seem to over-activate superficial global muscles whereas control and activation of the deep spinal muscles is impaired. Thus core stability exercises have strong theoretical basis for prevention of different musculoskeletal conditions and the treatment of spinal disorders.

Level 1 evidence for stabilization exercises is mixed and mainly comes from studies on LBP. To our knowledge, there have been five randomized trials that have supported stabilization exercises for LBP (33,40–43). However, there are some methodological flaws in some of these studies, including lack of true controls, significant attrition rate, and statistical vagaries (21,44). Two other randomized trials further question the superiority of stabilization exercises (29,45). The control groups in both of these studies included generalized strengthening components in addition to other features (21). Systemic reviews also have come to the conclusion that stabilization is helpful for spinal disorders but may not be superior to other therapeutic exercise regimens (46–48).

CORE STRENGTHENING AND INJURY PREVENTION

Some evidence in the literature supports the notion that core stabilization programs may be used to help prevent injury in athletics. Leeton and colleagues (36) performed a prospective study looking at 140 male and female intercollegiate basketball and track athletes. They found that injured athletes [injuries included anterior cruciate ligament (ACL) rupture, iliotibial band syndrome, patellofemoral pain, and stress fracture in the lower extremity] had significantly decreased strength in hip abduction and external rotation compared with non-injured athletes. Hip external rotation strength was most useful in predicting injury (36).

Some literature supports using neuromuscular training to prevent ACL injuries in athletes. These programs include muscle co-contraction to provide joint stability, balance and perturbation training, and plyometric exercises. Hewitt and colleagues conducted a prospective study comparing injuries in female high school athletes with preseason neuromuscular training, including single-leg functional core stability training, with a control group of female and male athletes without preseason neuromuscular training (37). Non-contact ACL injury risk was significantly less in the group of female athletes with neuromuscular training. In a similar study, Heidt and colleagues found that preseason neuromuscular training in female high school soccer players led to significantly fewer injuries overall, but no difference in ACL injuries between groups (39).

Specific core stability programs in prevention of athletic injuries have not been well studied. Additionally, core programs have not been proven to enhance athletic performance. Despite these facts, many of these programs have been promoted in lay literature for use in performance enhancement.

CONCLUSIONS

Core strengthening has a strong theoretical basis in treatment and prevention of LBP, as well as other musculoskeletal afflictions, as is evidenced by its widespread clinical use. Studies have shown that these programs may help decrease pain and improve function in patients with LBP. However studies are limited, and some show conflicting results. Future studies are needed to elucidate precise core strengthening programs and their effects on treatment and prevention of LBP, in comparison with other exercise training programs.

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