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FOCUSED REVIEW

Core Strengthening

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Core strengthening has become a major trend in rehabilitation. The term has been used to connote lumbar stabilization, motor control training, and other regimens. Core strengthening is, in essence, a description of the muscular control required around the lumbar spine to maintain functional stability. Despite its widespread use, core strengthening has had meager research. Core strengthening has been promoted as a preventive regimen, as a form of rehabilitation, and as a performance-enhancing program for various lumbar spine and musculoskeletal injuries. The intent of this review is to describe the available literature on core strengthening using a theoretical framework.

Overall Article Objective: To understand the concept of core strengthening.

Key Words: Athletic injuries; Exercise; Low back pain; Rehabilitation.

CORE STRENGTHENING HAS BEEN rediscovered in rehabilitation. The term has come to connote lumbar stabilization and other therapeutic exercise regimens (table 1). In essence, all terms describe the muscular control required around the lumbar spine to maintain functional stability. The "core" has been described as a box with the abdominals in the front, paraspinals and gluteals in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom.[1] Particular attention has been paid to the core because it serves as a muscular corset that works as a unit to stabilize the body and spine, with and without limb movement. In short, the core serves as the center of the functional kinetic chain. In the alternative medicine world, the core has been referred to as the "powerhouse," the foundation or engine of all limb movement. A comprehensive strengthening or facilitation of these core muscles has been advocated as a way to prevent and rehabilitate various lumbar spine and musculoskeletal disorders and as a way to enhance athletic performance. Despite its widespread use, research in core strengthening is meager. The present review was undertaken to describe the available literature using a theoretical framework.

Stability of the lumbar spine requires both passive stiffness, through the osseous and ligamentous structures, and active stiffness, through muscles. A bare spine, without muscles attached, is unable to bear much of a compressive load.[2,3] Spinal instability occurs when either of these components is disturbed. Gross instability is true displacement of vertebrae, such as with traumatic disruption of 2 of 3 vertebral columns. On the other hand, functional instability is defined as a relative increase in the range of the neutral zone (the range in which internal resistance from active muscular control is minimal).[4] Active stiffness or stability can be achieved through muscular cocontraction, akin to tightening the guy wires of a tent to unload weight on the center pole (fig 1).[5] Also described as the "serape effect,"[6] cocontraction further connects the stability of the upper and lower extremities via the abdominal fascial system. The effect becomes particularly important in overhead athletes because that stability acts as a torque-countertorque of diagonally related muscles during throwing.[6] The Queensland research group[1] has suggested the differentiation of local and global muscle groups to outline the postural segmental control function and general multisegmental stabilization function for these muscles groups, respectively (table 2).

ANATOMY

General Overview

Stability and movement are critically dependent on the coordination of all the muscles surrounding the lumbar spine. Although recent research[1,7,8] has advocated the importance of a few muscles (in particular, the transversus abdominis and multifidi), all core muscles are needed for optimal stabilization and performance. To acquire this cocontraction, precise neural input and output (which has also been referred to as proprioceptive neuromuscular facilitation) are needed.[9] Pertinent anatomy of the lumbar spine is reviewed below; however, readers should refer to other texts for an extensive anatomic review.[1,5,10]

Osseous and Ligamentous Structures

Passive stiffness is imparted to the lumbar spine by the osseoligamentous structures. Tissue injury to any of these structures may cause functional instability. The posterior elements of the spine include the zygapophyseal (facet) joints, pedicle, lamina, and pars interarticularis. These structures are, in fact, flexible. However, repetitive loading of the inferior articular facets with excessive lumbar flexion and extension causes failure, typically at the pars. The zygapophyseal joints carry little vertical load except in certain positions such as excessive lumbar lordosis.[10] The intervertebral disk is composed of the annulus fibrosis, nucleus pulposus, and the endplates. Compressive and shearing loads can cause injury initially to the endplates and ultimately to the annulus such that posterior disk herniations result. Excessive external loads on the disk may be caused by weak muscular control, thus causing a vicious cycle where the disk no longer provides optimal passive stiffness or stability. The spinal ligaments provide little stability in the neutral zone. Their more important role may be to provide afferent proprioception of the lumbar spine segments.[11]

Thoracolumbar Fascia

The thoracolumbar fascia acts as "nature's back belt." It works as a retinacular strap of the muscles of the lumbar spine.

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Table 1: Synonyms and Near-Synonyms for Core Strengthening

Lumbar stabilization
Dynamic stabilization
Motor control (neuromuscular) training
Neutral spine control
Muscular fusion
Trunk stabilization

Table 2: Muscles of the Lumbar Spine

Global Muscles (dynamic, phasic, torque producing)	Local Muscles (postural, tonic, segmental stabilizers)
Rectus abdominis	Multifidi
External oblique	Psoas major
Internal oblique (anterior fibers)	Transversus abdominis
Iliocostalis (thoracic portion)	Quadratus lumborum
	Diaphragm
	Internal oblique (posterior fibers)
	Iliocostalis and longissimus (lumbar portions)

The thoracolumbar fascia consists of 3 layers: the anterior, middle, and posterior layers. Of these layers, the posterior layer has the most important role in supporting the lumbar spine and abdominal musculature. The transversus abdominis has large attachments to the middle and posterior layers of the thoracolumbar fascia.[1] The posterior layer consists of 2 laminae: a superficial lamina with fibers passing downward and medially and a deep lamina with fibers passing downward and laterally. The aponeurosis of the latissimus dorsi muscle forms the superficial layer. In essence, the thoracolumbar fascia provides a link between the lower limb and the upper limb.[12] With contraction of the muscular contents, the thoracolumbar fascia acts as an activated proprioceptor, like a back belt providing feedback in lifting activities (fig 1).

Paraspinals

There are 2 major groups of the lumbar extensors: the erector spinae and the so-called local muscles (rotators, intertransversi, multifidi). The erector spinae in the lumbar region are composed of 2 major muscles: the longissimus and iliocostalis. These are actually primarily thoracic muscles that act on the lumbar via a long tendon that attaches to the pelvis. This long moment arm is ideal for lumbar spine extension and for creating posterior shear with lumbar flexion.[3]

Deep and medial to the erector spinae muscles lay the local muscles. The rotators and intertransversi muscles do not have a great moment arm. Likely, they represent length transducers or position sensors of a spinal segment by way of their rich composition of muscle spindles. The multifidi pass along 2 or 3 spinal levels. They are theorized to work as segmental stabilizers. Because of their short moment arms, the multifidi are not involved much in gross movement. Multifidi have been found to atrophy in people with low back pain[7] (LBP).

Quadratus Lumborum

The quadratus lumborum is large, thin, and quadrangular shaped muscle that has direct insertions to the lumbar spine. There are 3 major components or muscular fascicles to the quadratus lumborum: the inferior oblique, superior oblique, and longitudinal fascicles. Both the longitudinal and superior oblique fibers have no direct action on the lumbar spine. They are designed as secondary respiratory muscles to stabilize the twelfth rib during respiration. The inferior oblique fibers of the quadratus lumborum are generally thought to be a weak lateral flexor of the lumbar vertebrae. McGill[13] states the quadratus lumborum is a major stabilizer of the spine, typically working isometrically.

Abdominals

The abdominals serve as a vital component of the core. In particular, the transversus abdominis has received attention. Its fibers run horizontally around the abdomen, allowing for hoop-like stresses with contraction. Isolated activation of the transversus abdominis is achieved through "hollowing in" of the abdomen. The transversus abdominis has been shown to activate before limb movement in healthy people, theoretically to stabilize the lumbar spine, whereas patients with LBP have a delayed activation of the transversus abdominis.[8] The internal oblique has similar fiber orientation to the transversus abdominis, yet receives much less attention with regard to its creation of hoop stresses. Together, the internal oblique, external oblique, and transversus abdominis increase the intra-abdominal pressure from the hoop created via the thoracolumbar fascia, thus imparting functional stability of the lumbar spine.[3] The external oblique, the largest and most superficial abdominal muscle, acts as a check of anterior pelvic tilt. As well, it acts eccentrically in lumbar extension and lumbar torsion.[5] Finally, the rectus abdominis is a paired, strap-like muscle of the anterior abdominal wall. Contraction of this muscle predominantly causes flexion of the lumbar spine. In our opinion, most fitness programs incorrectly overemphasize rectus abdominis and internal oblique development, thus creating an imbalance with the relatively weaker external oblique.[14] The external oblique can be stimulated by some of the exercises described later, particularly those that emphasize isometric or eccentric trunk twists (fig 2).[15]

Hip Girdle Musculature

The hip musculature plays a significant role within the kinetic chain, particularly for all ambulatory activities, in sta-

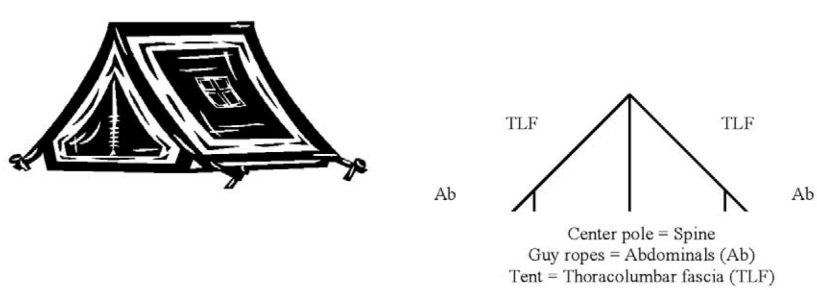

Fig 1. Muscular cocontraction via the thoracodorsal fascia produces active stability, similar to the support that guy ropes provide to a tent secured against the wind. Adapted with permission from Porterfield and DeRosa.[5]

Fig 2. Example of a movement awareness exercise: here, external oblique muscles are activated with a controlled trunk twist.

bilization of the trunk and pelvis, and in transferring force from the lower extremities to the pelvis and spine.[16] Poor endurance and delayed firing of the hip extensor (gluteus maximus) and abductor (gluteus medius) muscles have previously been noted in people with lower-extremity instability or LBP.[17,18] Nadler et al[19] showed a significant asymmetry in hip extensor strength in female athletes with reported LBP. In a prospective study, Nadler et al[20] showed a significant association between hip strength and imbalance of the hip extensors measured during the preparticipation physical and the occurrence of LBP in female athletes over the ensuing year. Overall, the hip appears to play a significant role in transferring forces from the lower extremities to the pelvis and spine, acting as 1 link within the kinetic chain.

The psoas major is a long, thick muscle whose primary action is flexion of the hip. However, its attachment sites into the lumbar spine give it the potential to aid in spinal biomechanics. During anatomic dissections, the psoas muscle has been found to have 3 proximal attachment sites: the medial half of the transverse processes from T12 to L5, the intervertebral disk, and the vertebral body adjacent to the disk.[10] The psoas does not likely provide much stability to the lumbar spine except in increased lumbar flexion.[3] Increased stability requirements or a tight psoas will concomitantly cause increased, compressive, injurious loads to the lumbar disks.

Diaphragm and Pelvic Floor

The diaphragm serves as the roof of the core. Stability is imparted on the lumbar spine by contraction of the diaphragm and increasing intra-abdominal pressure. Recent studies[21] have indicated that people with sacroiliac pain have impaired recruitment of the diaphragm and pelvic floor. Likewise, ventilatory challenges on the body may cause further diaphragm dysfunction and lead to more compressive loads on the lumbar spine.[22] Thus, diaphragmatic breathing techniques may be an important part of a core-strengthening program. Furthermore, the pelvic floor musculature is coactivated with transversus abdominis contraction.[23]

Exercise of the Core Musculature

Exercise of the core musculature is more than trunk strengthening. In fact, motor relearning of inhibited muscles may be more important than strengthening in patients with LBP. In athletic endeavors, muscle endurance appears to be more important than pure muscle strength.[24] The overload principle advocated in sports medicine is a nemesis in the back. In other words, the progressive resistance strengthening of some core muscles, particularly the lumbar extensors, may be unsafe to the back. In fact, many traditional back strengthening exercises may also be unsafe. For example, roman chair exercises or back extensor strengthening machines require at least torso mass as resistance, which is a load often injurious to the lumbar spine.[3] Traditional sit-ups are also unsafe because they cause increased compression loads on the lumbar spine.[15] Pelvic tilts are used less often than in the past because they may increase spinal loading. In addition, all these traditional exercises are nonfunctional.[3] In individuals suspected to have instability, stretching exercises should be used with caution, particularly ones encouraging end range lumbar flexion. The risk of lumbar injury is greatly increased (1) when the spine is fully flexed and (2) when it undergoes excessive repetitive torsion.[25] Exercise must progress from training isolated muscles to training as an integrated unit to facilitate functional activity.

The neutral spine has been advocated by some as a safe place to begin exercise.[26] The neutral spine position is a pain-free position that should not be confused with assuming a flat back posture nor the biomechanic term "neutral zone" described by Panjabi.[4,27] It is touted as the position of power and balance. However, functional activities move through the neutral posi-

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tion, thus exercises should be progressed to nonneutral positions.

Decreasing Spinal and Pelvic Viscosity

Spinal exercises should not be done in the first hour after awakening because of the increased hydrostatic pressures in the disk during that time.[28] The "cat and camel" and the pelvic translation exercises are ways to achieve spinal segment and pelvic accessory motion before starting more aggressive exercises. As well, improving hip range of motion can help dissipate forces from the lumbar spine. A short aerobic program may also be implemented to serve as a warmup. Fast walking appears to cause less torque on the lower back than slow walking.[29]

Grooving Motor Patterns

The initial core-strengthening protocol should enable people to become aware of motor patterns. Some individuals who are not adept at volitionally activating motor pathways require facilitation in learning to recruit muscles in isolation or with motor patterns. As well, some individuals with back injury will fail to activate core muscles because of fear-avoidance behavior.[30] More time will need to be spent with these people at this stage. Prone and supine exercises have been described to train the transversus abdominis and multifidi. Biofeedback devices were used by the Queensland group and others to help facilitate the activation of the multifidi and transversus abdominis.[1] Verbal cues may also be useful to facilitate muscle activation. For example, abdominal hollowing is performed by transversus abdominis activation; abdominal bracing is performed by cocontraction of many muscles including the transversus abdominis, external obliques, and internal obliques. However, most of these isolation exercises of the transversus abdominis are in nonfunctional positions. When the trained muscle is "awakened," exercise training should quickly shift to functional positions and activities.

Stabilization Exercises

Stabilization exercises can be progressed from a beginner level to more advanced levels. The most accepted program includes components from the Saal and Saal[31] seminal dynamic lumbar stabilization efficacy study (table 3). The beginner level exercises incorporate the "big 3" (figs 3A–C) as described by McGill.[3] These include the curl-up, side bridge, and the "bird dog." The bird dog exercise (fig 3C) can progress from 4-point kneeling to 3-point to 2-point kneeling. Advancement to a physioball (fig 4) can be done at this stage (table 4). Sahrmann[14] also describes a series of lower abdominal muscle exercise progression (table 5).

Functional Progression

Functional progression is the most important stage in the core-strengthening program. A thorough history of functional activities should be taken to individualize this part of the program. Patients should be given exercises in sitting, standing, and walking. Sitting is often a problematic position, particularly with lumbar disk injury. Sitting with lumbar lordosis totally flattened shifts the center of gravity anteriorly, relative

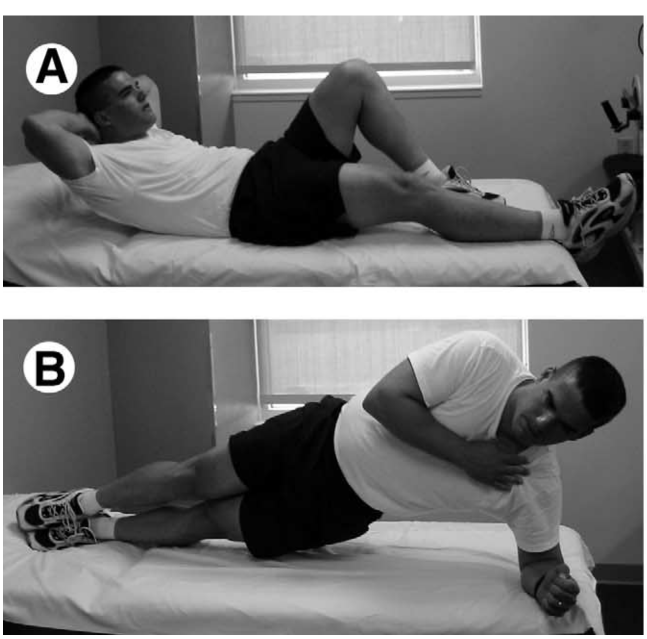

Fig 3. The basic exercise triad for most stabilization programs consists of the (A) curl-up, (B) side bridge, and (C) bird dog exercises.

Fig 4. The pelvic bridging exercise performed with a physioball.

to the standing position. This shift, in addition to increased hip flexor activity (such as with sitting at the edge of a chair), causes increased compressive loads on the lumbar spine.[14] Education on proper sitting and standing ergonomics, along with so-called "movement awareness" exercises, also have been advocated by some to thwart LBP.[32] Juker et al[15] performed a seminal study on quantitative electromyographic activity with different positions and exercise. Although quiet standing requires little electromyographic activation of core musculature, sitting with an isometric twist or sitting with hip motion produces more activation of core musculature. Core musculature should be trained to endure these functional activities.

Core Strengthening for Sports: Moving Past Remedial Core Training

Because sports activity involves movement in the 3 cardinal planes—sagittal, frontal, and transverse—core musculature must be assessed and trained in these planes. Often, transverse or rotational movements are neglected in core training. Assessment tools for functional evaluation of these movements (lunge, step-down, single leg press, balance, reach) have not been well validated but have proven to be reliable.[33] However, the multidirectional reach test and the star-excursion balance test (multidirectional excursion assessments in all cardinal planes) are both reliable and valid tests of multiplanar excursion.[34,35] Single-leg squat tests (with or without step downs) also serve as validated tools of assessment.[35] These evaluative tools help one select an individualized core training program, emphasizing areas of weakness and sports-specific movements.

Core training programs for sports are widely used by strengthening and conditioning coaches at the collegiate and professional levels. An example of Gambetta's program[36] is provided (table 6, fig 5). Core strength is an integral component of the complex phenomena that comprise balance. Balance requires a multidimensional interplay between central, peripheral, sensory, and motor systems. Training the domain of balance is important for functional activities. Progression to labile surfaces may improve balance and proprioception. Different fitness programs[37] incorporate various aspects of core strengthening and may be a useful way to maintain compliance in many individuals (table 7).

Table 4: Physioball Exercises for the Core

Abdominal crunch
Balancing exercise while seated
"Superman" prone exercise
Modified push-up
Pelvic bridging

Table 5: Sahrmann's Lower Abdominal Exercise Progression

Base position cue	Supine with knees bent and feet on floor; spine stabilized with "navel to spine"
Level 0.3	Base position with 1 foot lifted
Level 0.4	Base position with 1 knee held to chest and other foot lifted
Level 0.5	Base position with 1 knee held *lightly* to chest and other foot lifted
Level 1A	Knee to chest (>90° of hip flexion) held actively and other foot lifted
Level 1B	Knee to chest (at 90° of hip flexion) held actively and other foot lifted
Level 2	Knee to chest (at 90° of hip flexion) held actively and other foot lifted and slid on ground
Level 3	Knee to chest (at 90° of hip flexion) held actively and other foot lifted and slid *not* on ground
Level 4	Bilateral heel slides
Level 5	Bilateral leg lifts to 90°

Data from Sahrmann.[14]

Efficacy of Core-Strengthening Exercise

The clinical outcomes of core-strengthening programs have not been well researched. Studies are hampered by the lack of consensus about what constitutes a core-strengthening program. Some describe remedial neuromuscular retraining, whereas others describe sports-specific training and functional education. To our knowledge, no randomized controlled trial exists on the efficacy of core strengthening. Most studies are prospective, uncontrolled, case series.

Core Strengthening to Prevent Injury and Improve Performance

In 2002, Nadler et al[38] attempted to evaluate the occurrence of LBP both before and after incorporation of a core-strengthening program. The core-strengthening program included sit-ups, pelvic tilts, squats, lunges, leg presses, dead lifts, hang cleans, and Roman chair exercises. Although the incidence of LBP decreased by 47% in male athletes, this reduction was not statistically significant; the overall incidence of LBP slightly increased in female athletes despite core conditioning. This negative result may have resulted from the use of some unsafe exercises, such as Roman chair extensor training.[3,39] Further,

Table 6: Advanced Core Program Used by Gambetta[36]

Body weight and gravitational loading (push-ups, pull-ups, rope climbs)
Body blade exercises
Medicine ball exercises (throwing, catching)
Dumbbell exercises in diagonal patterns
Stretch cord exercises
Balance training with labile surfaces
Squats
Lunges

the exercises chosen for the study included only frontal and sagittal plane movements, which may have affected the results. Future studies incorporating exercises in the transverse plane may help to clarify the relation between surrounding core-strengthening exercises and LBP.

Most other research on musculoskeletal injury prevention has focused on decreasing the incidence of anterior cruciate ligament injury. Those training programs[40] work on providing a proprioceptively rich environment at various planes and degrees. Muscle cocontraction is stimulated using short-loop proprioception to provide joint stability. In short, preventative training programs are activations of neuromuscular control patterns.

Research[40] shows that a few essential ingredients can enhance neuromuscular control. These components include joint stability (cocontraction) exercises, balance training, perturbation (proprioceptive) training, plyometric (jump) exercises, and sports-specific skill training. All these regimens should be preceded by a warmup. Perturbation programs, described by Caraffa et al,[40] feature exercises that challenge proprioception via wobble boards, roller boards, disks, and physioballs. These programs work at the afferent portion of the neuromuscular control loop and provide stimulation of different proprioceptors. In a prospective study, Hewett et al[41] developed a plyometric jump training program that reduced knee injuries in female athletes. Plyometric training emphasizes loading of joints and muscles eccentrically before the unloading concentric activity. Plyometrics use the biomechanic principles of triplanar pronation and supination. Pronation is a physiologic multiplanar motion, typically described for the ankle and foot joints. It involves eccentrically decelerating joints so that shock absorption and potential energy are created. On the other hand, supination involves concentrically created acceleration so that propulsion is achieved.[37] Specific core stability programs as a form of prevention of lower-extremity injury have not been well studied. Further, there are no focused studies of core-strengthening or similar programs that show improved performance with functional activity or sporting activity. Nonetheless, the lay literature has promoted many different programs for performance enhancement.

Fig 5. Example of a core-strengthening exercise in a sports program: here, the lunge is performed on a labile surface.

Table 7: Fitness Programs That Follow Core-Strengthening Principles

Pilates
Yoga (some forms)
Tai Chi
Feldenkrais
Somatics
Matrix dumb-bell program[37]

Core Strengthening for Treatment of Back Pain

The seminal article[31] describing a core stability program was performed as an uncontrolled prospective trial of "dynamic lumbar stabilization" for patients with lumbar disk herniations creating radiculopathy. The impact of therapeutic exercise alone was difficult to ascertain because of the offering of other nonsurgical interventions, including medication, epidural steroid injections, and back school. The exercise training program was well outlined and consisted of a flexibility program, joint mobilization of the hip and the thoracolumbar spinal segments, a stabilization and abdominal program (see table 2), a gym program, and aerobic activity. Successful outcomes were reported in 50 of 52 subjects (96%). The described dynamic lumbar stabilization program resembles the current concept of a core stability program without the higher level sports-specific core training. Several other authors[42,43] have described similar programs.

Work-hardening or functional restoration programs have also been used for the injured worker with back pain.[44] The exercise training program uses Nautilus equipment for progressive resistance strengthening of isolated muscle groups. An emphasis is placed on reaching objective goals. The training program differs from the current concept of core strengthening in that it emphasizes nonfunctional isolation exercises over motor relearning.

Although a recent Cochrane review found that exercise is an effective treatment of LBP, no specific exercise programs showed a clear advantage for that application.[45]

CONCLUSIONS

Core strengthening has a theoretical basis in treatment and prevention of various musculoskeletal conditions. Other than studies in the treatment of LBP, research is severely lacking. With the advancement in the knowledge of motor learning theories and anatomy, core-stability programs appear on the cusp of innovative new research.

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