This is the second of a two-part report on core stability. Part 1 defined the terms core and core stability and provided an overview of changes that occur in core muscles as a result of low back dysfunction. These changes negatively affect core stability, creating a risk for future injury to the low back and/or lower extremity. Core stability is essential for the development, transfer, and dissipation of forces throughout the kinetic chain, both from the core to the extremities and from the extremities to the core. The core-extremity relationship has been described as “proximal stability for distal mobility of the limbs.” The transfer of energy from the core to the extremities is analogous to the cracking of a whip. This transfer of forces requires adequate muscular capacity (strength and endurance) and central nervous system motor programming that produces synchronous activation of the muscles. The objectives for Part 2 are to describe the core-extremity link and to suggest strategies for improvement of core stability and integrated lower extremity function.

The Role of Muscle Endurance

Poor endurance of the core muscles negatively affects function throughout the kinetic chain. In both healthy individuals and patients with low back pain, fatigue of the paraspinal muscles has been shown to result in altered standing postural control, a forward-leaned posture, a reduction in trunk proprioception, and a decrease in neural activation of the quadriceps. Trunk displacements resulting from impaired neuromuscular control produce sudden shifts in the location of the center of mass over the base of support. Maintenance of postural stability requires the generation of internal muscle moments to counteract the external moments generated by body mass displacement. A fatigued muscle may be incapable of effectively counteracting external moments, which may increase risk for injury if joint displacement is excessive, especially in the presence of quadriceps inhibition and altered trunk proprioception.

Back muscle fatigue that results in forward body lean is a concern, because fatigue has been shown to produce earlier activation and longer duration of the flexion-relaxation response (i.e., myoelectrical silence of the erector spinae muscles when in a flexed trunk posture). Although other back muscles, such as the quadratus lumborum, may still be active, the reduced activity of the erector spinae muscle group places greater load on passive stabilizers. Furthermore, a forward leaned posture shifts the center of mass anteriorly, resulting in alteration of the external moments acting on joints throughout the lower extremity. The cascade of events resulting from fatigue of the back musculature and forward body lean may
ultimately place greater demand on the quadriceps muscles. Decreased activity of the quadriceps muscles (i.e., quadriceps inhibition) that occurs following back muscle fatigue may lead to poor attenuation of ground reaction forces (GRFs). Consequently, excessive forces may be transmitted through the knee, hip, and lumbar spine joints. There is also evidence suggesting that the hamstring muscles exhibit an adaptive response to compensate for reduced quadriceps and gluteus maximus activity, thereby exposing the hamstrings to elevated injury risk.

There is growing evidence that poor core endurance can also lead to potentially injurious lower extremity positions in the frontal and transverse planes. Inadequacy of the hip abductor mechanism to control pelvic-femoral alignment has been related to lower extremity dysfunction. Fatigue, weakness, and imbalances in hip and pelvis muscles may result in hip adduction and internal rotation (Figure 1).

This knee-valgus position has been associated with patella-femoral syndrome and noncontact ACL injuries, which has been identified as a particular concern in female athletes. Lower extremity malalignment (trunk flexion, anterior pelvic tilt, hip adduction, hip internal rotation, knee valgus, and foot pronation) has been extensively discussed in the literature as predisposing factor for development of lower extremity pathology. These findings clearly indicate a need for comprehensive assessment and a rehabilitation strategy for management of back conditions.

Perception of Fatigue

Interestingly, the perception of fatigue may not necessarily indicate the existence of an actual fatigued state of the muscles. Comparison of two fatigue protocols (rowing ergometer versus exercises targeting the paraspinal muscles) revealed that muscle activation times were increased following the muscle-specific fatigue protocol, but perception of fatigue was greater following the rowing ergometer protocol. Fatigue of the multifidus muscle initiates a chain of events that may result in the inability to effectively counteract external moments. This is a particular concern during sudden and unpredictable loading, which is a common mechanism of back injury. Fatigue alters neuromuscular control (altered afferent input to the central nervous system, inhibition of motoneurons that activate the multifidus muscles, and reduced muscle spindle-generated reflex response), which may alter the loads on the spine and leave the structures of the spine more susceptible to injury. Consequentially, an individual may continue activity while fatigued, thereby exposing the back and extremities to abnormal loading and possible injury.

Measurement of Core Endurance

Strength, endurance, and flexibility are considered to be important components of fitness. Endurance is frequently ignored in back assessments, despite the fact that poor muscle endurance appears to be more strongly related to low back dysfunction than weakness or range of motion deficits. Core endurance testing has demonstrated utility for assessment of low back dysfunction and also for identification of individuals who possess elevated risk for back and lower extremity injury. Tests such as the trunk flexion hold, wall sit hold (unilateral), and horizontal trunk hold (Figure 2),...
along with other factors, such as previous injury, have
demonstrated predictive value that supports an indi-
vidualized approach to injury prevention (e.g., risk
assessment as part of preparticipation examinations).20

Back and Lower Extremity Injury Risk
A growing body of evidence links the core muscu-
lar to functional deficiencies and elevated injury risk.
Muscles of trunk and pelvic girdle function to maintain
stability of the spine and pelvis, which is critical for the
transfer of energy from the core to distal body parts.
Poor lumbo-pelvic stability has been associated with
higher occurrence of lower extremity injuries and low
back pain.18,21-25 The hip musculature transfers forces
from the lower extremity toward the spine (and vice-
versa), and deficits in these muscles have been associ-
ated with pelvis, hip, and thigh pathology.16,17,24,26-28
Such core-lower extremity relationships have also been
established for the knee6,15,17,29-32 and the ankle.33-37
Thus, the entire core and lower extremity must be
taken into consideration in the evaluation and reme-
diation of suboptimal function, whether done on an
individual basis or for the purpose of identifying high-
risk individuals through screening of a large number
of athletes.

Stabilization Programs
Motor Learning Phases
Most core stabilization programs involve progression
through three fundamental motor learning phases
(Table 1).38 The cognitive phase (Phase I) emphasizes
conscious awareness of neutral lumbar spine position
and local muscle activation (specifically the transversus
abdominis and multifidus muscles). Basic exercises
are performed in prone, supine, and sidelying posi-
tions, and progression to the next phase occurs when
the muscle contractions can be held for 60 seconds.39
Phase II, or the associative phase, emphasizes muscle
cocontractions during movements, increasing chal-
lenges, and progression to movement patterns associ-
ated with activities of daily living and sport-specific
functional demands. Muscle endurance and aerobic
conditioning activities are implemented and are
advanced when the individual is capable of maintain-
ing lumbo-pelvic-hip control during load-bearing move-
ments.39 Subconscious local muscle contraction and
core control is the emphasis of the autonomic phase
(Phase III). Because contraction of core muscles should
become habitual, exercises should involve mental
distractions and increasingly demanding functional
challenges.39

Specific exercise selection, volume, and intensity
must be matched to the individual’s capabilities. The
point at which diminishing benefit is derived from con-
tinued progression of a core stabilization program has
not been established.39 Some individuals with chronic
back dysfunction may need to continue a maintenance
stabilization program indefinitely.

Abdominal Hollowing Versus Abdominal Bracing
Core stability involves control of spinal movements and
compensation for external loads. Specific contraction
techniques are often prescribed to address deficiencies
in the muscular system’s capacity to provide static
and dynamic stabilization to the spine. Patients are
typically instructed in either an “abdominal hollowing”
maneuver40 or an “abdominal bracing” technique.41
There is debate as to which contraction activity is
most appropriate for improving spinal stability. The
hollowing (or abdominal drawing-in) maneuver incor-
porates a breathing pattern that facilitates the isolated recruitment of the transversus abdominis and multifidus muscles. This approach is believed to provide intersegmental stability through the development of intra-abdominal pressure (IAP) and tensioning of the thoracolumbar fascia.40,42,43

An over-emphasis on muscle isolation through the hollowing maneuver has been criticized as being counterproductive, because it occurs in a single plane and is not functional.38 Rather than hollowing, some experts advocate the abdominal bracing technique, which involves an isometric contraction of all abdominal and back muscles.41,44 This approach has been shown to increase stability in all directions,45 thereby creating greater posterior-anterior stiffness than the hollowing technique.46 The bracing technique produces higher forces across the joints through greater muscle activation than hollowing.45 Thus, the abdominal hollowing technique may be most appropriate during the early phase of a stabilization program. As activation of the transversus abdominis and multifidus improves and as pain subsides, a transition to the abdominal bracing technique can be made. Spinal stability demands are specific to the task that is performed, and differing muscle activation patterns are required for different tasks. Research evidence indicates that many muscles are responsible for core stability.41,44,45 Thus, the bracing technique should be emphasized during the latter phase of rehabilitation.

Program Effectiveness

Although different core stabilization programs may involve progression through similar phases, specific exercises may or may not be appropriate for a given patient, nor are all patients with back dysfunction good candidates for such programs. Core stabilization clinical outcomes have not been well researched. There is limited data on appropriate patient selection, dose response, program length, or functional progression, and there is a lack of consistency in terminology usage and exercise techniques. The evidence suggests that individuals who are most likely to derive benefit from a core stabilization program exhibit segmental instability in the lumbar spine.47,48 Hicks et al.48 developed a clinical prediction rule to determine which individuals would likely benefit from a stabilization program. The four factors that were identified to predict clinical success (i.e., at least 50% improvement in Oswestry Disability Index score) included age < 40, straight leg raise > 91 degrees, the presence of movement abnormalities (e.g., a painful arc with flexion), and a positive prone instability test. These four factors were associated with 67% probability of clinical success from participation in an 8-week stabilization program.48 Studies utilizing a core stabilization program have demonstrated success in patients with spondylolisthesis,49 iliotibial band friction syndrome,49 and hamstring injuries.50 Increase in the size of atrophied multifidus muscles51 and a reduced LBP recurrence following an acute LBP episode have also been reported.52

Unstable surface exercises (e.g., physioball) have been shown to improve balance, joint stability, and proprioception.53 Postural balancing exercises can increase strength and endurance of core muscles and can provide dynamic challenges that simulate sport activity.53 There is some evidence that abdominal

<table>
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<th>Table 1. Motor Learning Phases of a Core Stabilization Program38</th>
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<td>Cognitive Phase:</td>
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<tr>
<td>Cognitively-oriented problems</td>
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<td>Contract deep muscles to increase precision and skill</td>
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<tr>
<td>Associative Phase:</td>
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<tr>
<td>Progress to greater challenging positions</td>
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<tr>
<td>Consistency of performance, success, and refinement</td>
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<td>Integration of local and global muscles</td>
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<td>Autonomic Phase:</td>
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<tr>
<td>Task becomes habitual</td>
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<td>Requirement for conscious intervention is reduced</td>
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exercises involving use of special equipment appear to activate abdominal muscles in a manner similar to that achieved by exercises that do not require special equipment. Thus, special equipment may be appropriate as a means to provide exercise variety, but it may not appear to be essential for improved muscle activation.54

Myer et al.55-57 have demonstrated improved lower extremity biomechanics,55 improved hip strength,56 and reduced incidence of knee joint injury57 from neuromuscular training of the trunk and hip. The pilot work and follow-up studies that have guided development of this comprehensive neuromuscular training program appear to provide the best evidence that exists to date for development of core stability. Specific factors to consider during the performance of lower extremity exercises include the avoidance of forward trunk lean, hip adduction, and hip internal rotation. Training of the quadratus lumborum, erector spinae, and gluteus maximus should be given consideration for development of active resistance to lumbar and hip flexion. Emphasis on improved function of the abdominal muscles, gluteus medius, and minimus, and the hip external rotators can increase active resistance to anterior pelvic tilt, hip adduction, and hip internal rotation. Targeting the vastus medialis obliquus and the hip adductor muscles will assist in counteracting knee valgus. Finally, to counteract subtalar joint pronation, strengthening of the tibialis posterior muscle will facilitate an active resistance to displacement of the talar head and navicular.

Summary

The anatomic relationship between the lumbar spine, pelvic girdle, and hip joint creates a functional unit. The hip cannot be moved without concomitant motion occurring in the pelvis and the lumbar vertebrae. The research evidence supports the existence of a complex core-extremity relationship that needs to be better understood. Muscle endurance tests related to core stability appear to identify individual athletes who possess elevated risk for back and lower extremity injury. Thus, interventions that improve the function of the core musculature may decrease injury risk. Available evidence strongly supports the potential for improvement of neuromuscular control of the trunk and lower extremity through the performance of specific exercise techniques, but more research is needed to establish optimal procedures.

References


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