



Science and practice of core stability and strength testing

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Abstract

This study deals with a gap between science and practice in the testing of core stability and strength and presents our approach to solving this issue. Typical core stability tests require the subject to maintain a neutral spinal posture while under load in a quadrupedal or supine position and assess the endurance of global core muscles. However, most of these non-dynamometric tests have been developed for use in clinical and research settings. A suitable alternative represents torsional tests performed under stable or unstable conditions and instrumented tests in the form of trunk repositioning and load release tasks. Core strength is measured in terms of how much weight can be lifted, how many repetitions can be performed, or how long a neutral stable position can be maintained. In the laboratory, isometric and isokinetic dynamometers are frequently used. Isometric strength measurements are usually recommended as a standard for lifting tasks. However, such measurements underestimate the loads on the spine during dynamic movement. A deadlift to high pull exercise that involves working major muscle groups in the upper and lower body may best simulate the demands of jobs comprising of lifting tasks. Furthermore, isokinetic loading does not occur in daily human activities and is not specific to the requirements of sports. Given that rotational power is a better predictor of athlete performance, the test adapted from the wood chop exercise on a weight stack machine may provide conditions imposed by sports. One can also use a system that allows evaluation of muscle power during seated or standing trunk rotations with a barbell placed on the shoulders. These tests utilizing portable diagnostic systems may be implemented in functional diagnostics for athletes and sedentary or manual workers whose activities involve lifting tasks or trunk rotations under unloading or loading conditions; so complementing existing testing methods.

Keywords: core muscle tests, lifting task, muscle power, torsional tests, trunk rotations

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INTRODUCTION

Core strengthening and core stabilization exercises in sport and physical therapy are currently being promoted on a widespread basis. Core muscle training has been recommended as a preventive regimen, as a form of rehabilitation, and as a performance-enhancing program for various lumbar spine and musculoskeletal injuries. However, there is limited and conflicting scientific evidence regarding its efficiency for the enhancement of athletic performance or for prevention and rehabilitation of injuries. This is mainly due to lack of a standard evaluation system of core stability and core strength. Evidence is based on the biomechanical analysis of technique, the experience of conditioning specialists or cross-sectional training evidence. In addition, low reliability and sensitivity of current diagnostic methods evaluating the stability and strength of core muscles limits their practical application. Another drawback is that these methods do not target major stabilizers of the spine in spite of the fact that studies have shown that the most important stabilizers are task specific.

Measurement of core stability is more challenging to measure than core muscle strength as it requires incorporating parameters of coordination and balance. Selecting a single appropriate test to fully evaluate core stability is difficult, given the complex interaction of the lumbopelvic-hip structures and musculature. Usually trunk flexor endurance tests, recommended by the American College of Sports Medicine [1] and National Strength and Conditioning Association [2] are used. The majority of these tests require the subject to maintain a neutral spinal posture while under load in a quadrupedal or supine position [3-5]. These tests assess the control of local core muscles such as the transversus abdominus and multifidus, because it is believed to be important for the larger global core muscles to activate optimally [3,6]. Other tests assess the static endurance of several global core muscles, for example, external obliques, quadratus lumborum and erector spinae [3,7,8]. These tests are used because low back injury and pain are associated with reduced levels of muscular endurance in these muscles [8-10] because of the large torques and hence stability that these global muscles can provide in highly loaded tasks [7,11].

Core muscle strength is measured in terms of how much weight can be lifted, how many repetitions can be performed, or how long a neutral stable position can be maintained [3]. Because triaxial lumbar dynamometers are scarce [12-14], isometric and isokinetic dynamometers are frequently used [15,16]. However, the external validity of isokinetic trunk strength and isometric trunk endurance tests for physical tasks is ambiguous. While some authors have shown that measures of core strength and sports performance are related [17,18], others have not [19-21]. For instance, the synergistic relationship between the muscles of the core and limbs has been documented for a variety of sport-specific tasks, such as overhead throwing in baseball, forehand and backhand strokes in tennis, cycling, and various lifting tasks [22-28]. These studies highlight the role the core musculature plays in the transfer of torques and momentum throughout the kinetic chain during sport-specific tasks. Deficiencies in any part of the kinetic chain could lead to suboptimal performance or injury [29]. Therefore, when assessing core muscle strength, it is important to consider the demands of all joints and muscles in the kinetic chain, including those distal and proximal to the core.

This study aims to review core stability and strength tests used in a) the prevention and rehabilitation of back disorders, b) sedentary and physically demanding jobs, and c) recreational and competitive sports while presenting our approach for applications of developed testing methods in practice.

CORE STABILITY TESTS IN PREVENTION AND REHABILITATION OF BACK DISORDERS

In practice structural and performance assessments, which may or may not involve recording the voluntary surface electromyogram from the core musculature, are usually used. Clinicians often use structural assessments for patients presenting with pain or recovering from an injury. For example, in the clinical examination of patients with low back pain, assessments of range of motion

and spinal stability, followed by radiological examination, are standard. Unfortunately, the repeatability, sensitivity, and specificity of these assessments are not infallible. Clinicians repeatedly fail to diagnose lumbar spine instability using manual assessments of trunk range of motion and intervertebral segmental motion [30,31]. Moreover, such manual assessments may not reflect segmental spine movement *in vivo* [32]. While magnetic resonance imaging is an important diagnostic tool for identifying anatomical correlates of low back pain, it sometimes fails to differentiate between those with spinal abnormalities and low back pain from those without low back pain [33,34]. Structural assessments are commonly used to diagnose injury, so their usefulness in assessing healthy individuals is limited.

Performance assessments of the core musculature are routine in sports medicine because of their value in assessing injury and tracking preoperative and postoperative rehabilitation progress, and because of their prognostic value of injury risk [15,35-37]. Isometric and isokinetic dynamometers are used to assess the strength or endurance of the core musculature [15,16]. In non-laboratory conditions, the Biering-Sørensen test of lumbar extension [9] and the flexor and side bridge endurance tests [38], which are usually performed to task failure, are frequently used.

The Sorensen test is by far the most widely used and studied test for assessing trunk extensor muscles [39]. This test was first described by Hansen in 1964 [40], but it became known as the “Sorensen test” following a study by Biering-Sorensen in 1984, according to which good isometric endurance might prevent first-time low back pain occurrence [9]. In this test, the subject lies on an examining table in the prone position with the pelvis aligned with the edge of the table. Calves, thighs and buttocks are secured and upon command the subject is asked to maintain the horizontal position as long as possible with the arms folded across the chest. Dynamic variants of the Sorensen test are sometimes considered the “arch-up tests” that assess dynamic endurance of trunk extensors. These tests, performed with the subject prone with the torso cantilevered over the edge of a table, consist in flexing the trunk to a specific position (e.g. 30° trunk flexion), then returning to the initial position as many times as possible at a determined rate of arch-ups per minute [41-44].

However, most of these non-dynamometric tests have been developed for use in clinical and research settings. A suitable alternative represents torsional tests under stable or unstable conditions that can be used in rehabilitation or fitness centres. In the first, subjects take a correct push-up position with hands on the dynamometric platform while legs are supported on the bench or physioball. In the second, subjects get into the back bridge position with legs on the dynamometric platform and back supported on the bench or physioball. Both tests can also be performed in more difficult positions. In the first, subjects take a correct push-up position with one hand on the dynamometric platform while other placed over the first one, and with legs supported on the bench or physioball (Figure 1a). In the second, subjects get into the back bridge position with one leg on the dynamometric platform while other placed over the first one, and with back supported on the bench or physioball (Figure 1b). Emphasis is placed on proper positioning of the body. Subjects are instructed to maintain required position, keeping as still as possible. During both tests, basic stabilographic parameters are registered at 100 Hz using the posturography system FiTRO Sway Check based on dynamometric platform (FiTRONiC, Slovakia).



Figure 1. Measurement of sway variables during torsional tests using the FiTRO Sway Check system.



Figure 2. Assessment of postural and core stability using the FiTRO Sway Check system completed with a special program for Load Release Balance Test (a) and the FiTRO Dyne Premium system (b)

Other instrumented tests assess neuromuscular control of the core during trunk repositioning and load release tasks [45,46]. The trunk repositioning tasks require a subject to actively or passively return to a neutral spine position following a predefined displacement. Load release tasks require the subject to perform an isometric trunk contraction at a predefined intensity against an external load, which is subsequently released, and the displacement of the trunk is quantified. The voluntary surface electromyography can be recorded from the core musculature to examine the on-off activation of muscles following release. These tests are mainly used to evaluate functional impairments among elderly people and those with concurrent neck or low back pain [47-50].

In the case of load release balance test, subjects stand barefoot on a force platform with their arms held horizontally forward, a shoulder width apart (Figure 2a). They are required to hold a bar in their hands with a 2 kg load fixed to the bar. A signal from the computer triggers a random release of the load over a 5 second period following the initiation of the test, thus the subject receives no cues as to when the perturbation would occur. The release of the load produces a sudden change in the external forces acting on the subject, leading to a small anterior and then a larger posterior displacement of the subject's center of pressure (CoP). The perturbation after the load fall causes only a postural sway response, i.e. the subject do not need to take a step to maintain balance. The perturbation is quantified by the maximal anterior and posterior displacement, within one second after the load drop. The recording ends 2-3 seconds after the load-drop.

A series of trials are conducted under varied conditions, i.e. bipedal stance on a force platform or a foam surface placed on a force platform with eyes open and eyes closed. Peak anterior CoP displacement, the time to peak anterior CoP displacement, peak posterior CoP displacement, the time to peak posterior CoP displacement, total anterior to posterior CoP displacement, and the time from peak anterior to peak posterior CoP displacement are registered by using the FiTRO Sway Check system, completed with a special program for Load Release Balance Test (FiTRONiC, Slovakia). Concurrently with measurement of postural stability in terms of CoP movement, trunk stability representing roughly the center of mass (CoM) movement is also monitored using the FiTRO Dyne Premium system (FiTRONiC, Slovakia) (Figure 2b).

Our previous study identified that the test-retest reliability of parameters of the load release balance test is good to excellent, with high values of ICC (0.78-0.92) and low SEM (7.1%-10.7%) [51]. The area under the ROC curve >0.80 for these variables indicates good discriminatory accuracy. The reliability of this test is comparable to static balance tests, however with a more effective potential to discriminate between groups with varied levels of physical fitness. This may be corroborated by significant between-group differences in the peak posterior CoP displacement and the time to peak

posterior CoP displacement. Their values were significantly lower in physically active as compared to sedentary young and early middle-aged adults when standing on a foam surface, and in late middle-aged adults on an unstable as well as a stable surface. However, a lack of vision did not improve differentiation between these groups either in stable or unstable conditions. From a practical point of view, primarily unstable conditions, in addition to unexpected postural perturbations, should be used because they have the ability to differentiate between groups of physically active and sedentary adults from as early as 19 years of age. This highlights the importance of conducting postural and core stability tests on young adults with a predominantly sedentary lifestyle before significant impairments occur.

Also in sports like golf or tennis, the asymmetric loading of trunk muscles may cause side-to-side imbalances in rotational muscle strength and endurance. Such imbalances may be compounded by the presence of low back pain and related injuries. They comprise 15 to 34% of all golf injuries and 5 to 25% of all tennis injuries. Yet, only few indicators of back pain were identified. For instance, golfers with low back pain demonstrate significantly less endurance in the non-dominant direction (the follow-through of the golf swing) than the healthy group [52]. If the left and right side scores in the time which the subject can hold the sidelying position differ by more than 5%, dysfunction exists. Conversely, maximal isometric strength and peak torque have shown no significant differences. However, our preliminary results showed significantly higher power during trunk rotations on the dominant than non-dominant side in golfers (11.9%) and tennis players (9.4%), whereas there were no significant side-to-side differences in a control group of physically fit individuals (6.2%). This parameter may be considered specific to the asymmetric loading during trunk rotations used in training and competition of these athletes and could eventually identify the likelihood of low back pain.

WORK-RELATED CORE MUSCLES STRENGTH TESTING

For many years, isometric strength measurements were recommended as a standard for lifting tasks [53]. This was based on evidence that low back pain is associated with inadequate isometric strength. However, the risk of an individual sustaining an on-the-job back injury increases threefold when the task- lifting requirements are equal to or beyond their strength capacity. Static strength measurements significantly underestimate the loads on the spine during dynamic lifting. The predicted spinal loads under static conditions are 33–60% less than those under dynamic conditions, depending on the lifting technique. The recruitment patterns of trunk muscles (and thus the internal loading of the spine) are significantly different under isometric and dynamic conditions. Low to moderate associations between isometric strength measurements and lifting capacity suggest that estimates of functional lifting capacity should not be based on static measurements alone [54]. Dynamic lift tests are often a better simulation of the task being assessed and may be more appropriate for a back-injured population.

In assessments of neuromuscular functions during tasks such as lifting, it is essential to quantify kinetic and kinematic parameters that are able to discriminate between individuals and are sensitive to changes over time. A deadlift to high pull exercise that involves working the major muscle groups in the upper body and lower body, such as the abdomen, erector spinae, lower back and upper back, quadriceps, hamstrings and the gluteus maximus may best simulate the demands of particular sport or job comprising of lifting tasks. Recently we developed a test evaluating power performance during such a lifting task (Figure 3) and a related methodology quantifying data variability under various conditions [55]. Subjects perform deadlift to high pull either on the Smith machine or with free weights where weights increase stepwise up to a maximal power. Basic biomechanical parameters involved in the lifting exercises are monitored using the FiTRO Dyne Premium system (FiTRONiC, Slovakia). Both peak and mean values of power during the lifting are analyzed. The ICC of peak power and mean power during deadlift to high pull above 0.80, along with no significant differences between the test results obtained on the first and second test sessions signify good reliability. However, SEM >10% for peak power and SEM <10% for mean power during deadlift to high pull with free weights as well as on the Smith machine indicate that the latter represents a more reliable parameter and should



Figure 3. Assessment of muscle power during a lifting task using the FiTRO Dyne Premium system.

be used for data analysis. This fact has to be taken into account when power performance during lifting tasks is evaluated.

During the diagnostic set, the power increases from lower weights, reaches a maximum, and then toward higher weights decreases again. Maximal values of peak power are achieved at about 80% 1RM and mean power at about 70% 1RM. There are no significant differences in peak power during the deadlift to high pull on the Smith machine and with free weights from 20 kg to 45 kg. However, their values are significantly higher during deadlift to high pull with free weights than on the Smith machine when weights ≥ 50 kg are lifted. Mean power during deadlift to high pull on the Smith machine and with free weights shows a similar tendency. On the other hand, there are no significant differences in peak and mean power during upright rows with free weights and on the Smith machine. Likewise, their values do not differ significantly during deadlift with free weights and on the Smith machine.

Furthermore, there are substantial individual differences in velocity and power production during deadlift to high pull with the weight at which maximal power is achieved (e.g. 50 kg), which can be seen mainly during the second part of the exercise (i.e. while performing the upright row). This may be ascribed to a significant association ($r > 0.80$) between the power produced during deadlift to high pull and upright row on the Smith machine as well as with free weights.

In particular, the deadlift to high pull with free weights should be applied for the evaluation of power performance during lifting tasks. The movement pattern during this exercise is most likely closer to the task- lifting requirements of daily life and many sport activities when compared to the one performed on the Smith machine. It may also be more easily applied in practice as it does not require a special weight stack machine for testing. As shown, it is an acceptably reliable test when considering both stability of measurement and test-retest reliability. Mean rather than peak values of power are recommended to be used for the analysis because of their better reliability. The test is also sensitive in distinguishing lifting performance in healthy young subjects. It may be applied in the functional performance testing of healthy college graduate students and office workers with a prevalently sedentary lifestyle as well as construction workers with job demands based on lifting tasks. For instance, this test was used in the study that evaluated the effect of three months of resistance and aerobic training programs on power produced during a lifting task in overweight and obese

individuals [56]. The resistance training enhanced power outputs during a deadlift high pull with weights from 30 to 50 kg (~40-60% 1RM). However, the group that participated in the aerobic training failed to show any significant improvement of power performance during the deadlift high pull. This was the first study to demonstrate that the deadlift high pull with free weights may be a suitable test for evaluating lifting performance in the overweight and obese.

ASSESSMENT OF STABILITY AND STRENGTH OF THE CORE MUSCULATURE IN SPORT

Core strength does have a significant effect on an athlete's ability to create and transfer forces to the extremities [57]. It is obvious that the effective execution of the tennis stroke or golf swing requires not only rapid movement of the extremities but also substantial rotational power and/or velocity of trunk muscles. Trunk extensors, flexors, rotators and lateral bend agonists are active throughout the stroke in baseball and tennis. Similarly, all trunk muscles are relatively active during the acceleration phase of the golf swing with the trail-side abdominal oblique muscles showing the highest level of activity [58].

However, a number of static single-joint core stability measures and ratios were unable to distinguish resistance-trained subjects with high and low strength levels and to evaluate the efficiency of training involving complex dynamic core exercises. Implements such as the medicine ball and cable pulleys, can be very useful in developing and quantifying power as they allow motion in all three planes. Both medicine ball throws (side, overhead, scoop) and the chop and lift for rotational power assessment have shown high reliability (ICC=0.84-0.99 and 0.87-0.98, respectively) [59-62]. Rivilla-Garcia et al. [61] reported a high correlation ($r=0.90$) between a light overhead medicine ball throw (0.8 kg) and handball-throwing velocity. Conversely, Kohmura et al. [59] reported that the scoop medicine ball throw has very little shared variance with baseball fielding (throwing distance, standing long jump, and agility T-test) (~7%) compared with batting (~14%). Recently, Talukdar et al. [63] examined the role of rotational power and mobility on cricket ball throwing velocity using a linear position transducer attached to the weight stack of a cable pulley system to measure chop and lift power. According to the authors, greater ROM at proximal segments, such as hips and thoracic, may not increase throwing velocity in cricket as reduced ROM at proximal segments can be useful in transferring the momentum from the lower extremity in an explosive task such as throwing. These discrepancies may be ascribed to the task specificity and weight of the medicine ball or amount of load used during the chop and lift.

In the laboratory isokinetic machines [64-66] and electromyography [67-69] are used to measure strength characteristics during axial rotation movements. However, when using an isokinetic dynamometer with a torso rotation attachment, no significant differences in peak torque were found within or between groups of healthy individuals who do not play golf and those who are highly skilled at the sport [52]. The authors also reported no significant difference in the endurance of trunk muscles between the healthy elite golfers and the non-golfing controls. Similarly, Suter and Lindsay [70] were unable to show any significant differences in the static holding times or a decline in the electromyography median frequency between low- handicap golfers with low back pain and healthy, age-matched controls who did not golf. The limitation of these measurements is that torso rotation performed while sitting on the chair with straps around the back and legs provides artificial movement patterns.

Given that rotational power is a better predictor of athlete performance, the test that measures this component of the core may be more useful, especially because it may better mimic the demands imposed by sports. In doing so, one can use a system that allows monitoring of basic biomechanical parameters during rotational movement of the trunk. Andre et al. [71] determined the test-retest reliability of the kinetic rotational characteristics of the pulley trainer when performing a rotational exercise of the axial skeleton in the transverse plane while sitting on a box. The authors found that a pulley system and an external dynamometer can be used together as a reliable research tool to assess rotational power. Although such a test is suitable for canoeing for example, for many other sports, such as hockey or tennis, rotational movement performed during standing would be a more specific

alternative. As athletes prefer free weights or weight exercise machines to improve the strength of their trunk muscles, the testing should be as close as possible to the movement used during training and competition. Presumably, the test adapted from the wood chop exercise may provide conditions similar to those imposed in many sports involving trunk rotations (baseball, golf, hockey, karate, tennis, etc.).

Our recent study showed that evaluation of the maximal power and endurance of core muscles during the standing cable wood chop exercise on a weight stack machine (Figure 4) is both a reliable method and sensitive to differences among physically active individuals [72]. More specifically, mean power during the standing cable wood chop exercise is a reliable parameter with ICC values above 0.90 at all weights tested. It is also a sensitive parameter able to discriminate between within-group differences in the maximal values of mean power and the endurance of core muscles. Substantial individual differences are observed in the mean power produced, especially at higher weights, and in its maximal values achieved at about 75, 67, and 83% 1RM. At these weights, significant differences between the initial and the final repetitions of the wood chop exercise can also be observed. Therefore, this method of assessing (a) maximal power using maximal effort single repetitions of the standing cable wood chop exercise with increasing weights and (b) the endurance of the core muscles using a set of a predetermined number of repetitions performed at a previously established weight at which maximal power was achieved may be used in functional performance testing, namely, for athletes who require the production of rotational power in their sports.

Such a computer-based system that can be directly connected to the weights on a stack machine may be considered to be a suitable and practical alternative for sport-specific and fitness-oriented testing of trunk rotational power. However, some practitioners prefer free weights in their weight training workout routine. While machines are good for training of muscle strength they neglect key stabilization components of the core. Using free weights is a way to 'functional' training that places greater demands on stabilizing muscles. In addition, exercises with free weights allow the performance of a full range of trunk motion. Moreover, free-weight exercises are closer to many sports and daily activities, can be performed in any sporting fields and are less expensive than exercises on weight machines.



Figure 4. Measurement of strength parameters during the standing cable wood chop exercise on a weight stack machine (a, b) using the FiTRO Dyne Premium system (c).



Figure 5. Measurement of muscle power during standing (above) and seated (below) trunk rotations using the FiTRO Torso Premium system.

Therefore, the exercise that most closely replicates the upper/lower body rotation movements should be preferred in testing in order to assess sport-specific power. A more suitable alternative facilitates the evaluation of power performance during trunk rotations in either a standing or seated position with a barbell placed on the shoulders using a FiTRO Torso Premium system (FiTRONiC, Slovakia) (Figure 5). Peak and mean values of force, power, velocity and torque in the acceleration and the deceleration phase of trunk rotations may be analysed. Usually, single repetitions of a particular exercise with increasing weights stepwise up to a maximal power are performed to obtain individual force-velocity and power-velocity curves or to analyze power and velocity for different weights lifted. It is known that maximum force production occurs when the speed of movement is very low. As the speed of movement increases, force decreases and at very high speeds force production is very low. Consequently, maximal values of power occur at intermediate velocities when lifting moderate weights; in this case it is at 30-45% 1RM. This variation in power production at light to moderate weights in athletes of various specializations may be ascribed to the specificity of training adaptation. Hence, this exercise that closely replicates the trunk rotation should be used to assess the sport-specific rotational power.

In particular in sports involving loaded trunk rotations, standing posture should be preferred when testing an athlete's specific performance as opposite to the dynamometers in current use allowing movements of the trunk in seated and fixed positions. Seated trunk rotations reduce the involvement of the legs and the contribution of thoracic/hip mobility to the upper-body rotational power. Reduced range of motion of the hips and the thoracic spine, which allow the greatest rotation because of the orientation of the joints [73], could contribute to lower movement velocity of the trunk and consequently influence throwing or striking velocity. These sports that involve throwing motions require production of explosive movement in either the transverse or oblique planes [74]. The force is transferred sequentially from the proximal segments, such as hips, toward the more distal segments, such as the shoulders and arms. Because of the kinetic linkage of the proximal to distal sequence in throwing [75], the rotational mobility may play an important role in the production of trunk rotational power. This power transference of the proximal segments, such as the hips and upper trunk, may be crucial to throwing velocity.

However, standing rotational movement allowing more involvement of the lower body is less confined to the trunk. It is likely that it is much more effective in power production than seated trunk rotations. This assumption may be corroborated by the finding of our study that showed greater muscle power during standing as compared to seated trunk rotations, with more pronounced

differences at higher weights (≥ 10.5 kg) [76]. This may be ascribed to a greater range of trunk motion while standing as compared to sitting, which allows participants to accelerate the movement more forcefully at the beginning of rotation. As a result is a greater trunk rotational velocity and consequently also overall power outputs. This fact has to be taken into account when testing the trunk rotational power in the standing and in the seated position.

Examples of applications of measurement of core stability and strength in various populations can be found in recent reviews entitled "Assessment of power and strength of trunk muscles: from the lab to the field" [77] and „Assessment of core stability and strength: from theory to practical applications“ [78].

CONCLUSIONS

This study presents our approach to the testing of the stability and strength of core musculature in various populations and under various conditions, and applications of research findings in this field in practice. Core stability tests usually evaluate the endurance of trunk muscles (e.g., trunk flexor and extensor endurance tests and lateral bridge test) or the ability of the lumbopelvic-hip structures and musculature to withstand compressive forces on the spine and return the body to equilibrium after perturbation. In addition to these non-dynamometric tests, instrumented torsional tests performed under stable or unstable conditions and tests in the form of trunk repositioning and load release tasks complemented with measurement of trunk motion can be used. Core muscle strength is assessed in various modes (isometric, isotonic, isokinetic) and positions (standing, sitting, lying prone) under unloading or loading conditions using a variety of diagnostic systems. An example is measurement of muscle power during a lifting task in a form of deadlift to high pull on the Smith machine or with free weights and trunk rotations in the seated and standing position with a barbell of different weights placed on the shoulders or in a form of a standing cable wood chop exercise on a weight stack machine. These tests of core stability and core muscle strength using portable diagnostic systems may be implemented in functional diagnostics for athletes, sedentary and manual workers as well as individuals with back disorders and so complement existing laboratory and/or field testing methods.

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