ASSESSMENT OF CORE STABILITY AND STRENGTH: FROM THEORY TO PRACTICAL APPLICATIONS

POSUDZOVANIE STABILITY A SILY SVALOV TRUPU: OD TEÓRIE K APLIKÁCII V PRAXI

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Abstrakt

Táto prehľadová štúdia poukazuje na možnosti posudzovania stability a sily svalov trupu. V terénnych podmienkach je na tento účel možné využívať batériu motorických testov. Tieto sú však častokrát zaťažené vysokou chybou merania a nie sú dostatočne citlivé na odhalenie zmien parametrov stability a sily svalov trupu počas cvičebných programov. Možno ich však použiť ako doplnkovú informáciu komplexného hodnotenia telesnej zdatnosti. Objektívnu možnosť posudzovania týchto schopností predstavuje laboratórna funkčná diagnostika. Mnohé zariadenia si však vyžadujú vysoké finančné náklady (napr. zariadenia umožňujúce registráciu základných biomechanických parametrov v izokinetickom režime), potrebný je skúsený personál k ich obsluhe a sú aj

časovo náročné na samotnú diagnostiku a následnú analýzu a interpretáciu dát. Vhodnú alternatívu predstavujú relatívne jednoduché, prenosné, počítačom riadené diagnostické zariadenia, ktoré možno využívať v rehabilitačných a fyzioterapeutických centrách, resp. fitnes centrách pre bežnú populáciu. V tejto práci upriamime pozornosť predovšetkým na diagnostické zariadenia a metódy využívané v našich podmienkach. Ako príklad posudzovania stability a sily svalov trupu predstavujeme torzionálne testy s dodatočným posudzovaním parametrov stability vo vopred určených polohách tela, ďalej testy stability postoja po jej neočakávanom narušení doplnené o meranie pohybu pomyselného ťažiska tela, test sily chrbtového svalstva umožňujúci posudzovať maximálnu izometrickú silu aj silový gradient ako ukazovateľ schopnosti generovať silu v čo najkratšom čase a na záver test svalového výkonu produkovaného pri príťahoch činky zo zeme ku brade (simulácia zdvíhania bremena), ktorý umožňuje komplexné posúdenie úrovne výbušnej sily jedinca. Takáto diagnostika poskytuje možnosť porovnania stability a sily svalov trupu u jedincov s určitým ochorením alebo po zranení so zdravou populáciou, ako aj ich zmeny počas cvičebného programu, čím pomáha posúdiť účinnosť použitých tréningových prostriedkov a metód zameraných na ich zlepšenie. Pravidelné posudzovanie telesnej zdatnosti súčasnými testovými batériami doplnenými o posudzovanie stability postoja a trupu, ako aj svalového výkonu produkovaného pri silových cvičeniach so závažím predstavuje dôležitý predpoklad zefektívňovania cvičebných programov.

Kľúčové slová: torzionálne testy, test stability postoja po jej neočakávanom narušení, test maximálnej sily chrbtového svalstva, test svalového výkonu pri príťahoch činky k brade

The „core“ is 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 (Richardson et al., 1999). While the term of core strength refers to the strength of these muscles, core stability is the ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, tranfer and control of force and motion to the terminal segment in integrated kinetic chain activities (Kibler et al., 2006).

Core strengthening and core stabilization exercises in sport and physical therapy are currently being promoted on a widespread basis. Core muscles training 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. For instance, Kim and Lee (2013) examined the effects of deep abdominal muscle strengthening exercises on respiratory function and lumbar stability. The authors found that deep abdominal muscle training was effective at enhancing respiratory function and lumbar stabilization. According to the authors, the clinical application of deep abdominal muscle strengthening exercises along with lumbar stabilization exercises should be effective for lower back pain patients in need of lumbar stabilization. Other study by Cavaggioni et al. (2015) determined the effects a new modality of core stabilization exercises based on diaphragmatic breathing on pulmonary function, abdominal fitness, and movement efficiency. The authors reported that compared with traditional abdominal exercises, core stabilization exercises based on breathing and global stretching postures are more effective in improving pulmonary function and abdominal fitness. The authors suggest that further research is needed to compare abdominal breathing with other core exercises in order to clarify the combination of breath and abdominal exercises in treating painful disorders (low back pain, neck pain) and improving motor control in fitness and rehabilitation programs. In particular, improvement of transversus abdominis function is a key goal in prevention and treatment of low back pain (Hodges et al., 2003; Hides et al., 2008). While individuals without a history of low back pain activate the transversus abdominis before movement of the trunk or extremities, those with low back pain activate the transversus abdominis after the movement is initiated (Hodges et al., 2003). Training these recruitment patterns, especially recruitment of the transversus abdominis, might help prevent low back pain.

Despite widespread use of core strengthening exercises in athletic training and rehabilitation, there is limited and conflicting scientific evidence on their efficiency. Many studies have proposed that optimal core stability is vital for injury prevention, in as much as poor core stability predicts injury. Poor core stability, which is typically defined as muscle weakness in a specific group of core muscles (e.g., hip abduction), is predictive of anterior cruciate ligament injury, patellofemoral pain, iliotibial band syndrome, low back pain, and improper landing kinematics (i.e., knee valgus) (Fredericson et al., 2000; Nadler et al., 2000, 2001; Ireland et al., 2003; Leetun et al., 2004; Jacobs et al., 2007; Pollard et al., 2007). While these studies support the adoption of core training programs for injury prevention, they do not suggest that such training programs will improve physical fitness. This is mainly due to a lack of standard testing methods evaluating the effect of training programs for improving core stability and strength. Rather, they are 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 strength of lower back muscles limits their practical application. Another drawback is that current methods do not target the 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 the single appropriate test to fully evaluate core stability is difficult, given the complex interaction of the lumbopelvic-hip structures and musculature. Common core stability tests include isometric measures of endurance and isokinetic measures of strength and work (Deplitto et al., 1991; Luoto et al., 1995; McGill et al., 1999; Keller et al., 2001). Core stability is also assessed using field tests of trunk flexor endurance recommended by the American College of Sports Medicine (Franklin et al., 2000) and National Strength and Conditioning Association (Baechle, Earle, 2002). In fact, a variety of core stability tests has been developed for use in both clinical and research settings. The majority of these core stability tests require the subject to maintain a neutral spinal posture while under load in a quadrupedal or supine position (Faries, Greenwood, 2007; Gamble, 2007; Liemohn et al., 2005) or assess the static muscular endurance tests of several global core muscles, for example, external obliques, quadratus lumborum, and erector spinae (Faries, Greenwood, 2007; McGill, 2002; McGill et al., 2003). The quadrupedal and supine exercises are done to assess the control of local core muscles such as the transversus abdominus and multifidus, with such activity believed to be required for the larger global core muscles to activate optimally (Faries, Greenwood, 2007; Urquhart et al., 2005). The static core stability global muscular endurance tests are used because lower back injury and pain are associated with reduced levels of muscular endurance in these muscles (Biering-Sorensen, 1984; McGill et al., 2003; Schellenberg et al., 2007) and because of the large torques and hence stability that these global muscles can provide in highly loaded tasks (McGill, 2002; McGill, 2004).

Instrumented torsional tests

Subjects can perform torsional tests under stable or unstable conditions. 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 positions of the body. Subjects are instructed to maintain required position as still as possible. Laboratory assistant stand behind the subject to impede a possible fall. During both tests, basic stabilographic parameters are registered at 100 Hz using the posturography system FiTRO Sway Check based on dynamometric platform (FiTRONiC, Slovakia).

a b

Figure 1 Instrumented torsional tests using the FiTRO Sway Check system

There are also other instrumented tests used to assess neuromuscular control of the core during trunk repositioning and load release tasks (Reeves et al., 2006; Silfies et al., 2007). 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 (Michaelson et al., 2003; Jørgensen et al., 2011; Karayannis et al., 2013; Sturnieks et al., 2013).

Previous study identified that 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%) (Zemková et al., 2016a). 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. In both unstable and stable conditions, lack of vision did not improve differentiation between these groups. These findings indicate that unstable conditions, in addition to unexpected postural perturbations, have the ability to differentiate between groups of physically active and sedentary adults as early as from 19 years of age. This highlights the importance of conducting postural stability tests on young adults with a predominantly sedentary lifestyle before significant impairments occur.

Load release balance test

Subjects stand barefoot on a force platform with their arms hold 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 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 three trials are conducted in random order under varied conditions: (a) bipedal stance on a force platform with eyes open, (b) bipedal stance on a force platform with eyes closed, (c) bipedal stance on a foam surface placed on a force platform with eyes open, and (d) bipedal stance on a foam surface placed on a force platform with eyes closed. The best result of each of the three trials is selected for evaluation. Peak anterior displacement of the subject´s CoP, the time to peak anterior displacement of the subject´s CoP, peak posterior displacement of the subject´s CoP, the time to peak posterior displacement of the subject´s CoP, total anterior to posterior displacement of the subject´s CoP, and the time from peak anterior to peak posterior displacement of the subject´s CoP, are registered by using the FiTRO Sway Check system, completed with a special program for Load Release Balance Test (FiTRONiC, Slovakia). The force platform data are sampled at a frequency of 100 Hz. Concurrently with measurement of postural stability in terms of CoP movement, trunk stability representing roughly the CoM movement is also monitored using the FiTRO Dyne Premium system (FiTRONiC, Slovakia) (Figure 2b).

a b

Figure 2 Load release balance test using the FiTRO Sway Check system completed with a special program for Load Release Balance Test (a) and the FiTRO Dyne Premium system (b)

These core stability tests 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 rather than the strength and power component of the core. Given that strength may be a better predictor of back and lower extremity injury than endurance, the tests that measure the strength or power component of the core may be more useful, especially because they may better mimic the demands imposed by sports or occupational tasks.

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 fail to repeatedly diagnose lumbar spine instability using manual assessments of trunk range of motion and intervertebral segmental motion (Binkley et al., 1995; Hicks et al., 2003). Moreover, such manual assessments may not reflect segmental spine movement in vivo (Landel et al., 2008). 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 spine abnormalities and low back pain from those without low back pain (Iwai et al., 2004; Okada et al., 2007). 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 (Flory et al., 1993; Nadler et al., 2000, 2001; Ireland et al., 2003). The majority of current tests assess the strength or endurance of the core musculature. Isometric and isokinetic dynamometers are used to assess strength, whereas endurance tests, which are exclusively performed isometrically, are performed to task failure (Flory et al., 1993; McGill et al., 1999). Isometric endurance tests include the Biering-Sørensen test of lumbar extension (Biering-Sørensen, 1984) and the flexor and side bridge endurance tests (McGill, 2001). Isoinertial tests, such as the field test of trunk flexor endurance, have also been promoted (Baechle et al., 2008). New field tests of core stability that correlate with traditional measures have been proposed, like the front abdominal power test of Cowley and Swensen (2008). This test, along with selected anthropometric data, can be used to estimate isokinetic trunk strength (Cowley et al., 2009). Still, characterizing core stability using a single test is unlikely to capture the pivotal role these muscles play during physical task. Thus, there is a need for new robust tests that assess multiple aspects of core function and correlate well to physical tasks.

This is especially true during lifting tasks. For many years, isometric strength measurements were recommended as a standard for lifting tasks. This was based on evidence that lower-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 the trunk muscles (and thus the internal loading of the spine) are significantly different under isometric and dynamic conditions. In addition to this, manual material-handling tasks require a coordinated multilink activity. Evaluations of performance during such complex lifting tasks would require a test that best simulates the individual's spinal loading preconditions.

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. However, there are currently no global measures taking into account arm, shoulder, trunk, and leg strength as well as the individual's lifting technique and overall fitness. Therefore, we have attempted to develop a test evaluating performance during lifting tasks and a related methodology quantifying data variability under different conditions (equipment used, weight lifted, etc.). 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.

We estimated the reliability of data obtained from deadlift to high pull on the Smith machine and with free weights (Zemková et al., 2016b). 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 be used for data analysis. Furthermore, during the diagnostic set, the power increases from lower weights, reaches a maximum, and then decreases again at higher weights. 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, these 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. There are also 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 during deadlift to high pull and upright row on the Smith machine as well as with free weights. This fact has to be taken into account when functional performance during lifting tasks is evaluated.

This study demonstrated that the deadlift to high pull with free weights may be applied for evaluation of power performance during lifting tasks. The movement pattern during this exercise is most likely closer to task-lifting requirements of daily life as 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. It has been shown that deadlift to high pull with free weights 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. Since this task involves working major muscle groups in the upper body and lower body, it may be applied in 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.

Assessment of maximal voluntary isometric strength

Before testing begin, subjects warm up by doing 3–5 submaximal isometric trials for a minimum of three seconds using a FiTRO Back Dynamometer (FiTRONiC, Slovakia) so as to become accustomed to the testing procedure. The test is performed according to standardized procedures. One has to take into account that maximal isometric force is significantly higher when the test is performed with slightly flexed than straight knees (Poór et al., 2015). Once subjects are placed in position (knee and hip angles are measured with goniometry), they perform three maximal isometric contractions for a minimum of three seconds (Figure 3). They are provided with two minutes of passive recovery between each maximal effort. They are carefully instructed to contract "as quickly and as forcefully as possible". The assistant provides verbal encouragement to promote maximal effort. On-line visual feedback of the instantaneous force is provided to the subject on a computer screen. Peak force and rate of force development are analyzed.

Figure 3 Assessment of maximal voluntary isometric strength using the FiTRO Back Dynamometer

Assessment of muscle power during a lifting task

Subjects perform two repetitions of deadlift to high pull on the Smith machine or with free weights from lower weight (20 kg) increasing stepwise (10 kg at lower and 5 kg at higher weights) up to a one repetition maximum. Emphasis is placed on the proper technique for the exercises while using maximal effort in the lifting phase. Subjects assume a hip-width stance with the knees slightly flexed and the toes pointed straight ahead (Figure 4). The grip is approximately shoulder width. Then they lift the bar as high as possible off the floor, to about chin level. During the upward movement phase, they have to keep their knees slightly flexed and the torso in a flat-back position. When these exercises are performed with free weights, two laboratory assistants should stand behind the participant to impede possible falls.

Basic biomechanical parameters involved in the lifting exercises are monitored using the FiTRO Dyne Premium system (FiTRONiC, Slovakia). The system consists of a sensor unit based on a precise encoder mechanically coupled to a reel. While pulling the tether (connected by means of a small hook to the barbell axis) out, the reel rotates and measures velocity. The rewinding of the reel is secured by a string producing a force of about 2 N. Signals from the sensor unit are conveyed to the computer. The instantaneous force of moving a barbell of a specific mass in a vertical direction is calculated as the sum of the gravitational force (mass multiplied by the gravitational constant) and the acceleration force (mass multiplied by acceleration). The acceleration of the vertical motion (positive or negative) is obtained by derivation of vertical velocity, measured by a highly precise device mechanically coupled to the barbell. The power is calculated as the product of force and velocity, and the actual position by the integration of velocity. The device was placed on the floor and anchored by a nylon tether to a bar. Subjects perform the exercises while pulling on the nylon tether on the device. Both peak and mean values of power during lifting are analyzed.

Figure 4 Assessment of muscle power during a lifting task using the FiTRO Dyne Premium system

Recently, we evaluated the effect of three months of resistance and aerobic training programs on power produced during a lifting task in the form of a deadlift high pull in the overweight and obese (Zemková et al., 2017). The resistance training enhanced power outputs during a lifting task with weights from 30 to 50 kg (~40–60% of 1RM) in these individuals. 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. The test was sensitive to changes in power outputs during a modified lifting task following the training. It should be implemented in the functional diagnostics for overweight and obese individuals and also complement existing testing methods.

In conclusion, the present study provided an overview of tests designed for the assessment of core stability and strength. As an example were introduced instrumented torsional tests, load release balance test complemented with measurement of trunk motion, tests of maximal isometric strength of back muscles and muscle power during a lifting task. Given the importance of core stability and strength in the activities of daily living, their assessment should be considered an integral part of functional diagnostics. We believe that above described tests and methods using portable diagnostic systems may be considered to be a suitable and practical alternative of laboratory and/or field testing.

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