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Narrative review article

KINANTHROPOLOGICAL ANALYSIS OF THE CORE

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Abstract. *The aim of this research is to investigate existing research dealing with the topic of the structure, functional and morphological status of the muscles that make up the body's core, as well as how improving the core affects the advancement of sports technique and its efficiency. The term core most commonly refers to the trunk, or more precisely, to the lumbar region. Core muscles play a significant role in lower limb alignment and stability, associated with poor alignment and injuries. The development of the core strength to improve the efficiency of sports performance is a controversial issue that has yielded different results. The analysis of the scientific journal articles revealed that the specificity of the program for increasing lumbar stabilization with the appropriate sport or skill is of the utmost importance. Therefore, it is necessary to specialize training facilities so that they are suited to a specific sport branch or discipline.*

Key words: *Core Stability, Strength, Training, Sport Performance.*

INTRODUCTION

Optimal body stability is the basis of human movement, which applies equally to sports and everyday activities (Fitarelli, Ramos, Scudiero, Rabello, & Rodrigues, 2020). The musculature of the core acts as a link that functionally connects the upper and the lower body – the upper and lower extremities. This functional relationship between the core and the extremities is based on the kinetic chain theory (Pontillo et al., 2020). In biomechanical terms, this muscular whole provides dynamic and kinematic aspects of human locomotion, including maintaining the balance or stability of the body in its various positions. Certain research suggests that there is a connection between an increased likelihood of injury and core stability (Panjabi, 2003; Akuthota & Nadler, 2004; Peate, Bates, Lunda, Francis, & Bellamy, 2007;

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Akuthota, Ferreiro, Moore, & Fredericson, 2008; Smith, Nyland, Caudill, Brosky, & Caborn, 2008; Desai & Marshall, 2010; Sung, Yoon, & Lee, 2010). Topological positioning and functional incorporation are the reasons for labeling this muscle in its entirety with the term "core" (Fitzgerald, Ake, & Snyder-Mackler, 2000; Myklebust et al., 2003; Akuthota & Nadler, 2004; Myer, Ford, Brent, & Hewett, 2006; Akuthota et al., 2008; Kuszewski, Gnat, & Gogola, 2018; McGill, Grenier, Kavčić, & Cholewicki, 2003).

Most often, a stability function is added to the core muscles, which depends on the interaction of active, passive and neutral elements. Bliven and Anderson (2013) consider neural elements crucial for the optimal core stability in dynamic activities. In order to achieve a quality assessment of this body region, a multiple approach is necessary. According to Bliven and Anderson (2013), the functional elements of the core musculature are probably related to daily activities and sports training.

The significance of a stable core is most often associated with the improvement of the sports performance and as a prevention of injuries. However, reservations are necessary, due to modest precise evidence (Silfies, Ebaugh, Pontillo, & Butowicz, 2015). On the other hand, there are some indicators in favor of reducing injury rates when integrating core stabilization exercises into rehabilitation programs. There is still no consensus among experts on which exercises and programs contribute the most to improving core stabilization.

The promotion of knowledge about the musculature of the core, its contribution to the quality of motor competence and its contribution to the quality of human ontogenetic development is a hypothetical contribution to integrating activities aimed at the development and preservation of the function of this muscle region in the daily routine of the life of today (Fitzgerald et al., 2000; Santana, 2001; Cook, 2003; McGill et al., 2003; Boyle, 2004; Verstegen & Williams, 2004; Akuthota & Nadler, 2004; Willardson, 2007; Akuthota et al., 2008).

The aim of this research is to investigate existing research dealing with the topic of the structure, functional and morphological status of the muscles that make up the body's core, as well as how improving the core affects the advancement of sports technique and its efficiency.

Theoretical Considerations of the Problem

Morphological status

The nucleus consists of muscles located between the lower edge of the chest and the upper edge of the iliac bone (Akuthota et al., 2008; Cruz-Montecinos et al., 2019; Resende et al., 2019). The core musculature works like "a private strap" surrounding the lumbar region. The transverse abdominis muscle has a significant effect on the medial and posterior parts of the thoraco-dorsal fascia. In addition, the deep part is closely connected to the lumbar-spinal processes via the posterior layer. In fact, the thoracic-back fascia acts as a "corset" around the lumbar region (McGill, 2001), which provides, as previously mentioned, a kinetic link between the lower and upper extremities (Akuthota et al., 2008). The action of core muscles activates the proprioceptors in the dorsal fascia, which provides information about the position of the trunk (Akuthota & Nadler, 2004).

Muscle fibers of slow contraction (SC) and fast contraction (FC) form the core. SC form the primary local musculature (internal musculature). The composition of the internal musculature is suitable for intersegmental control of the vertebrae - they respond to changes in body posture and external load. Major local muscles include the transverse abdominal muscle (TrA), multifidus, inner obliques, deep spinal muscles, and pelvic floor muscles. The multifidus has been found to atrophy in individuals with chronic lumbar pain (Akuthota & Nadler, 2004). The external musculature is predominantly composed of FC muscle fibers. Superficial muscles play a role in large overall movement. The main external muscles are: the levator scapulae, the outer obliques, rectus abdominis, and quadratus lumborum - considered by McGill et al. (2003) to be the main muscle stabilizers of the spine.

However, the abdominal muscles are vital components of the core. The transverse abdominal muscle stands out in particular by its stabilization of function because its fibers are arranged horizontally (except for the lowest positioned fibers, which follow the fibers of the inner oblique abdominal muscle), creating a band around the abdomen. By retracting the navel, it activates the TrA in isolation. Clinical research has shown that in healthy individuals, TrA and multifidus are activated 30ms before shoulder and upper extremity movement and 110 ms before leg movement - to stabilize the lower spine (Hicks, Fritz, Delitto, & Mishock, 2003). However, in patients with lower back pain, contraction of these two muscles is delayed before limb movement (Barnet & Gilleard, 2005). These patients have impaired standing postural control in static or dynamic balance postures (Foroughi, Sobhani, Yoosefinejad, & Motealleh, 2019). The increase in intraabdominal pressure occurs by activation of the inner obliques and the TrA – acting over the thoracic fascia, thus creating a pressure around the trunk, similar to the hoop. The benefit of this increase is spinal “fixation” (McGill, 2001). The external oblique abdominal muscle (superficially the largest abdominal muscle) controls the anterior pelvic tilt. The abdominal muscles and multifidus need to engage a very small percentage of their total muscle capacity to stabilize the spinal segments (Grenier & McGill, 2007; Akuthota et al., 2008).

The pelvic floor muscles are essential for the general functionality and stability of the hips and pelvis while walking (Akuthota et al., 2008). Poor endurance and delayed activation of the hip abductor/extensor muscle (m. gluteus medius) were first observed with people with lower back pain and other musculoskeletal conditions, such as, for example, ankle sprain (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). The iliopsoas muscle is the only blind flexor in the lumbar spine (Akuthota et al., 2008). However, it has the potential to exert strong pressure on the intervertebral discs. Maximum voluntary activation of the psoas muscle, such as in the exercise of full flexing of the trunk, can put a lot of pressure on the last disk, as much as 100 kg of weight (Akuthota et al., 2008). Shortening of the hip flexors (m. iliopsoas) can cause lower back pain by increasing pressure on the lumbar discs. Hold-relax stretching exercises of the iliopsoas muscle can be beneficial in reducing the intensity of pain with patients with lumbar hyperlordosis by improving the function of the transversus abdominis muscle (Bogdanović, Radenković, Kahrović, Murić, & Špirtović, 2020).

The diaphragm serves as a lid or a roof on the core muscle structure. The lower part consists of the pelvic floor muscles. Intra-abdominal pressure can also increase the activation of the diaphragm, contributing to spinal stability. The pelvic floor muscles co-activate together with transverse abdominal muscles (Hewett, Torg, & Boden, 2000). Patients with sacral and iliac pain show reduced activity of the pelvic muscles and the diaphragm (Akuthota et al, 2008). Based on this, it is possible that techniques that improve the work of the diaphragm and the muscles of the pelvic floor can become an integral part of the program for core stability.

Functional status

Core stability and the depending factors

In scientific and professional papers, there are many synonyms used for core stability (Akuthota & Nadler, 2004; Bliss & Teeple, 2005). Generally, core stability encompasses the lumbar-pelvic complex and its ability to maintain spinal vertebral balance within its physiological borders by reducing perturbations and maintaining the integrity of the spinal structure (Panjabi, 2003; Liemohn, Baumgartner, & Gagnon, 2005; Willson, Dougherty, Ireland, & Davis, 2005; Smith et al., 2008; Resende et al., 2019). Stability is the ability to maintain proper posture and/or control of segment movement and general movement. It is the ability to control force or a movement. In most cases, stability is a precursor to power (Cook, 2003). In order for stability to be optimal, it is necessary for any system to have the ability to maintain integrity (Willson et al., 2005). Clinically and practically, in these definitions there is a lack of practical applicability that would provide functional guidance in the development, application and assessment of current core stability (Bliven & Anderson, 2013). Several authors (Akuthota & Nadler, 2004; Kiesel, Plisky, & Butler, 2011; Colston, 2012; Bliven & Anderson, 2013) suggested a better definition in an attempt to write up the core. According to them, the core is the foundation of the kinetic chain in the transmission and distribution of kinetic energy between the cranial and caudal parts of the body, to solve various tasks in sports and everyday life.

The stability of the core can be static or dynamic (Bliss & Teeple, 2005; Cook, 2003). Static stability can be demonstrated during e.g. standing on one leg (Lee & Sun, 2018) or during the flexed arm hang test (Bubanj, Šekeljić, Marković, & Mazić, 2017), while dynamic activities are those that cause disturbances in the center of gravity in response to muscle activity (Bliss & Teeple, 2005). Maintaining the stability of the system through all three planes of motion during changes in the center of gravity means dynamic stability (Bliss & Teeple, 2005).

According to a group of authors (Akuthota et al., 2008), the system for maintaining spinal stability consists of passive, active and neural elements.

In order for stability to be optimal, all three elements must contribute and complement each other. The role of passive elements is very small. It includes the interrelationships of bone and ligament structures (Wilson et al., 2005). The contribution to the stability of the active muscle elements is significantly higher. For example, the in vivo lumbar part of the spinal column can withstand pressure >6000 N during daily work tasks with excellent stability (Wilson et al., 2005). But, if active support is lacking, the bone-ligamentous structure (spine) becomes unstable under a compressive load of only 90 N, a load much smaller than the weight of the upper body (Wilson et al., 2005; Kibler, Press, & Sciascia, 2006; Akuthota et al., 2008). There are three ways in which the active component contributes to core stability: pressure inside the abdomen, force compression, and tenseness of the core muscles (Wilson et al., 2005). The contraction of the abdominal muscles leads to an increase in intra-abdominal pressure. Also, the activity of the muscles of the diaphragm and pelvic floor contributes to an increase in general stiffness and intra-abdominal pressure (Wilson et al., 2005). Therefore, the significance of the active component for global rigidity is very important.

However, spine stability depends not only on muscle strength, but also on an adequate nerve impulse that gives feedback to the central nervous system (CNS) about the position (or relationship) of the trunk in space, thus enabling an adequate response (Akuthota et al., 2008; Pogetti, Nakagawa, Conteçote, & Camargo, 2018). Many causes that lead to reduced efficiency of movement or performance, as well as increased chances of injury, can be directly related to inadequate coordination in the core muscles. (Akuthota & Nadler, 2004; Akuthota et al., 2008). Therefore, motor learning can be just as significant as strengthening the core muscles. The neutral spine is crucial for optimal stabilization of the core (Bliss & Teeple, 2005), but also the ability to control and maintain such an ability. This spine position is usually, but erroneously, synonymous with a straight back position. A neutral spine is not a single flat position. Instead, it is an intermediate position common to all movements and is usually located between flexion and extension. It is dictated by the musculoskeletal flexibility and structural anatomy of the individual (Bliss & Teeple, 2005). The immediate response of the CNS to a change in the position of the body or its extremities, or a change in the position of the center of gravity, is needed in order to adequately activate the muscular systems and maintain or establish adequate core stability. (Akuthota & Nadler, 2004; Willson et al., 2005; Kibler et al., 2006; Smith et al., 2008; Escamilla et al., 2010; Bliven & Anderson, 2013).

Core stability and sports performance

The relationship between core stability and sport performance is a controversial issue. The musculature positioning of the core enables the maintenance of a neutral position of the spine and pelvis, functioning in such a way as to protect against injuries to these parts of the body (Stanton, Reaburn, & Humphries, 2004). However, some researchers have found different relationships between core stability (Abt et al., 2007; Nesser, Huxel, Tincher, & Okada, 2008; Nesser & Lee, 2009) and programs related to the development of core stability (Stanton et al., 2004; Tse, McManus, & Masters, 2005; Myer et al., 2006; Thompson, Cobb, & Blackwell, 2007). The core muscles are thought to play a significant role in the transfer of kinetic energy across the trunk to the extremities (Abt et al., 2007; Tse et al., 2005). Sports performance can be significantly reduced if the extremity muscles are allowed to be much stronger than the core muscles (Tse et al, 2005; Nesser et al., 2008; Nesser & Lee, 2009). Some research has examined the link between core stability in different sports. The aim was to assess the role of the core in sports performance (Abt et al., 2007; Nesser et al., 2008; Nesser & Lee, 2009). Some other research has considered the economy/performance ratio (Stanton et al., 2004), the speed of movement of the rod head in golfers (Thompson et al., 2007), swimming (Nikolenko, Brown, Coburn, Spiering, & Tran, 2011), rowing (Tse et al., 2005) and balance (Myer et al., 2006). Despite this research, clear and precise information is still lacking. The focus of a large number of studies is on assessing the stability and endurance of core muscles and their influence on performance (Stanton, et al., 2004; Tse, et al., 2005; Meyer et al., 2006; Abt et al., 2007; Nesser et al., 2008; Nesser & Lee, 2009; Sato & Mokha, 2009; Nikolienko et al., 2011). Measures used to evaluate the core musculature may not evaluate its role in energy transfer during sports performance (Tse et al., 2005; Cowley & Swensen, 2008; Nesser et al., 2008; Cowley, Fitzgerald, Sottung, & Swensen, 2009; Nesser & Lee, 2009) due to the lack of test specificity.

At this point, there is limited research on the relationship between core muscle strength and athletic performance (Myer, et al., 2006; McGill, Karpowicz, & Fenwick, 2009) using tests specifically targeting the core. There is a possibility that the stability of the core does not play as big a role as it was thought in improving performance.

In one study, a group of researchers (Nikolenko et al., 2011) investigated the relationship between dynamic power tests and some performance parameters. The research involved 20 men with at least 6 months of training experience. Respondents were tested over three days.

On the first day they were provided with theoretical background pertaining to all the tests (where their height and body weight were also measured). On the second day the 40-yard sprint test was implemente (Nesser et al., 2008; Nesser & Lee, 2009), the shuttle run (Nesser et al., 2008; Nesser & Lee, 2009), the vertical jump and the back squat-1RM (Baechle & Earle, 2008). On the third day, a core test was performed with two standard medicine ball tests (Cowley & Swensen, 2008; Cowley et al., 2009).

Variables related to sports performance generally proved to be insignificant compared to the two core tests (Nikolienko et al., 2011), except the 1RM back squat test, that was found to have a moderate correlation with the test of throwing a medicine ball from a supine position. This may be because this test intentionally activates similar muscle groups as the back squat test (Nikolienko et al., 2011). So, in this case, the increased 1RM of the back squat and the test of throwing the medicine from a supine position can be attributed to the greater strength of the hip flexor muscles. The aim of this research was to verify the relationship between two dynamic core tests and sports performance tests. Apart from a moderate correlation between the back squat test and core tests, no other significance was found. So, according to this research, core power will not improve performance. One reason for this may be because it was measured by core-specific tests that are not adequate for the sports performance measures included in this study. It is possible that the mode of muscle work is not similar in the core tests and performance tests, but that does not mean that the trunk muscles were not active in the sports performance tests (Nikolienko et al., 2011).

Nesser and Lee (2009) conducted research concerning the relationship between core stability, endurance and different performance parameters. No significant correlation was found between core stability tests and performance parameters. The obtained results can be attributed to the specificity of training and testing procedures aimed to determine the role and the involvement of core muscles in sports performance. Also, research conducted by Nikolenko et al. (2011) shows a significant lack of core contribution to sports performance, and is similar to that conducted by Tse et al. (2005). The topic of the research was to explore the impact of the basic program on the endurance of some of the measures of sports performance. Both studies found no significant inter- or intra-group differences from the initial to the final status, after a core strengthening training program and any performance variable. This may be because the core training protocols were either not long enough or did not adequately engage the core muscles.

First of all, a very good evaluation of sports skills and adjustment of the tests to measure the strength and stability of the core is needed, and then an investigation of their conditional connection (Tse et al., 2005). Thompson et al. (2007) dealt with the impact of an eight-week training program on a specific task (stick head speed in golf). The findings showed a difference between the experimental and control groups. In the experimental group, the speed increased by 4.9%, while in the control, there was a slight decrease in the speed of the golf club head.

An adequate assessment of the core stability and the impact on improving sports performance depends mostly on the specifics of the sport and tests (Kubo, Ohta, Takahashi, Kukidome, & Funato, 2007). Magnetic Resonance Imaging taken from a wrestler's trunk muscles has shown that increasing the cross-section of the torso flexor muscles increases efficiency of the wrestling technique. The research of Kubo et al. (2007) suggests that there is a link among muscle cross-section and performance. However, it does not state how the core contributes to performance. Two basic field tests used in the research by Nikolenko et al. (2011) emphasized the core strength component. The main reason why there is no significant correlation between core stability tests and different measures of sports performance seems to be the absence of a specific core test for a specific sport. In recent years, fitness experts and researchers have increasingly emphasized the significance of exercise and training programs to increase core stability. Also, a large number of researchers and clinicians suggest that increased lumbar stabilization is significant in the prevention of sports injury (Wang et al., 2012). Therapy that includes exercises to stabilize the body's core is an effective treatment in pain relief and in an improvement of the functional status in patients with chronic lumbar pain in most clinical practices (Hayden, Tulder, Malmivaara, & Koes, 2005). In addition to fitness, training for improving core stability is increasingly used in sports rehabilitation programs (Akuthota et al., 2008). Research has shown that lumbar stabilization exercises are a significant component of rehabilitation (Desai & Marshall, 2010; Sung et al., 2010). Usually, fitness exercisers and athletes generally follow core training programs the most (Willardson, 2007). The intertwining of different disciplines, therapy through personal trainers and fitness trainers, is becoming more pronounced. For example, the use of similar props, the performance of exercises, review of catalogs for sports equipment, etc. indicate a growing interest in the development of stability and core strength (Willardson, 2007). Seminars and workshops offered at national conferences have expanded the information on the proper use of such training programs and have suggested the benefits of such training. Some authors (Cook, 2003; Santana, 2001; Willardson, 2007) specifically highlight and promote special equipment for enhancing lumbar stabilization. Scientific papers from rehabilitation have shown the effectiveness of exercises and training programs to develop core stability in reducing the likelihood and prevention of sports injuries - mostly in the lower back and lower extremities (Fitzgerald et al., 2000; McGill et al., 2003; Myklebust et al., 2003; Myer et al., 2004). However, relatively few studies have directly examined the benefits for healthy athletes (Stanton et al., 2004; Willardson, 2007).

Experts interpret the concept of the core differently, and thus exercises and programs to increase core stability. Also, there is no consensus among them on whether and to what extent core stability affects performance improvement (Willardson, 2007). Also, there is no clear boundary that would separate core exercises from traditional exercises.

CONCLUSION

In this paper, the structure, functional and morphological status of the muscles that make up the body's core are presented, as well as how improving the core affects the advancement of sports technique and its efficiency. Most research shows that core stability improvement programs are very effective in an untrained population, as well as in athletes who are in the process of the rehabilitation. These studies suggest that it is necessary to incorporate a program to increase the lumbar stabilization at the beginning of basic sports programs. Also, as strength, endurance, coordination and skills are improved, it is necessary to continually improve lumbar stabilization programs. Recommended core stability exercises typically include isometric muscle activity, low exercise, and long periods of tension. This approach does not mean a certain improvement in core stability. Also, it is not certain that increased core stability will lead to a better sports performance.

Basically, clear consent is the first thing that needs to happen among sports experts; agreement on what the core is and which exercises are most effective for its development. Perhaps research should focus on traditional forms of exercise (e.g. the deadlift, different types of squats, cleans, different types of thrusts and jerks) and examine how much they affect core stability and how much the development of stability affects their performance. To date, no battery of tests has been established that accurately assesses core stability in healthy athletes. The focus of future research should be on finding the appropriate core stability tests incorporating dynamic muscular activity while maintaining relatively high posture loads, consistent with the core stability requirements in sports performance.

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KINANTROPOLOŠKA ANALIZA TRUPA

Cilj ovog istraživanja je da se sprovede pretraga postojećih istraživanja koja se bave temom strukture, funkcionalnog i morfološkog statusa mišića trupa, kao i kako trup utiče na unapređenje sportske tehnike i efikasnosti. Termin "core" najčešće se odnosi na trup, tačnije na lumbalni region. Mišići trupa igraju značajnu ulogu u poravnanju i stabilnosti donjih ekstremiteta, povezanih sa povredama. Razvoj snage trupa u poboljšanju efikasnosti sportskih performansi je kontroverzno pitanje koje sa različitim rezultatima. Analizom članaka u naučnim časopisima utvrđeno je da je od posebne važnosti specifičnost programa za povećanje lumbalne stabilizacije odgovarajućim sportom ili veštinom. Zbog toga je neophodno sprovesti specijalizaciju trenažnih uslova na način da odgovaraju određenoj sportskoj grani ili disciplini.

Ključne reči: *stabilnost trupa, snaga, trening, sportske performanse*