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Stabilizacja centralna w rehabilitacji dzieci – aspekt fizjoterapeutyczny

Core Stability in the Rehabilitation of Children – Physiotherapy Aspects

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Streszczenie
Wstęp. Termin „stabilizacja centralna" (ang. core stability) odnosi się do wydolności głębokich mięśni tułowia, których rolą jest kontrola centrum naszego ciała w statyce i dynamice. Praca przedstawia różne aspekty fizjoterapeutyczne dotyczące problemu stabilizacji centralnej w ewidencji naukowej potwierdzające skuteczność ćwiczeń.
Materiał i metody. W procesie wyszukiwania artykułów korzystano z baz artykułów MedLine i PubMed oraz PBL, uwzględniając następujące słowa kluczowe: stabilizacja centralna, stabilizacja lędźwiowa, stabilizacja dynamiczna, kontrola motoryczna, trening nerwowo-mięśniowy, stabilizacja tułowia, wzmacnianie centralne.
Wyniki. Liczne badania naukowe przedstawiają fakt, iż mięśniami, które odgrywają główną rolę w tym mechanizmie, są: mięsień poprzeczny brzucha, mięsień wielodzielny, mięsień skośny wewnętrzny brzucha, mięśnie dna miednicy oraz przepona. Prawidłowo funkcjonujące tworzą rodzaj cylindra, nadając odpowiednią stabilność dla okolicy dolnego tułowia (jest bazą dla mobilności na obwodzie).
Wnioski. U dzieci z dolegliwościami bólowymi okolicy dolnego kręgosłupa mięśnie głębokie są hamowane a ich timing jest zaburzony. Najpierw napinają się duże powierzchowne mięśnie odpowiadające za wykonanie ruchu, a następnie włączają się głębokie lokalne stabilizatory centrum. Zmiana ról między grupami mięśniowymi może być źródłem problemów przeciążeniowych, dlatego też ważnym jest aby zastosować odpowiednią rehabilitację wspomagającą stabilizację centralną.

Słowa kluczowe:
Stabilizacja centralna, rehabilitacja, fizjoterapia, kręgosłup, ćwiczenia wzmacniające

Abstract
Introduction. The term "core stability" refers to the efficiency of the deep torso muscles, which control the center of our body, both in statics and dynamics. This study presents the various physiotherapy related aspects regarding the core stability issue in the scientific materials, which confirm the effectiveness of physical exercises.
Materials and Methods. In the process of search for the topic related materials, we have used the article databases of MedLine, PubMed and PBL, applying the following keywords: core stability, lumbar stability, dynamic stability, motor control, neuromuscular training, trunk stability, core strengthening.
Results. Numerous scientific studies show, that the muscles playing the major role in this mechanism are: anterior scalene, multifidus muscle, internal oblique, pelvic floor muscles and sellar diaphragm. When properly functioning, the muscles form the kind of cylinder, providing sufficient stability for the lower trunk area (which is the basis for perimeter mobility).
Conclusions. In children with the pain sensation in the area of the lower spine, the deep muscles are being inhibited and their timing is being disrupted. First tighten the large surface muscles responsible for the execution of movement, and then the local center stabilizers get engaged. The role changing between the groups of muscles may be causing overload problems, thus it is important to provide the appropriate rehabilitation, which would support the core stability.

Key words:
Central stabilization, rehabilitation, physiotherapy, spine, strengthening exercises

Introduction

This article defines the core stability (CS) as the anatomical structures, which provide the stability, and it discusses the adverse effects of the impaired muscle tone distribution, from the physiotherapy point of view.

For this purpose, the CS must also be defined as the state characterized by the simultaneous, balanced satisfying of the needs for stability and mobility. The structures of the upper quadrant of the body, to which the concept of CS refers, include shoulder joint and scapulothoracic joint, while in the lower quadrant there should be included the hip joint and the lower part of the trunk.

Individual speed is supposedly an inborn trait and cannot be changed through training. It appears, however, that the impaired muscle tone, restricted joint mobility and pain, can become barriers which prevent a child from achieving the individual maximum range of the trait. The task of the physiotherapist in charge of rehabilitation is to diagnose the irregularities affecting the CS and to design the exercise program, which shall lead to the increased strength, power and endurance of the particular, dysfunctional joints or muscles. The specifics of the rehabilitation program shall help to cope with the shortcomings in the musculoskeletal system and to exploit to maximum the child's potential within the range of the particular motor skills. To achieve this, it is necessary to properly develop the strength, power and endurance of the muscles providing the CS [1].

The lower parts of the system ensuring the CS consist of the muscles, ligaments and fascia responsible for the simultaneous movement and stability of the trunk, hip joints and the lower extremities. On the one hand, the movement of a lower extremity begins with the activation of muscles directly adjacent to the bone - stabilizing muscles (deep), and on the other hand - the muscles which launch movement in the joint - motion muscles (surface). Preserving the CS depends on the balanced tension of the both above mentioned muscle systems. If the postural muscles insufficiently stabilize a joint, the surface muscles performance will be impaired. These disorders, due to the close interaction between the postural and surface muscles, may lead to injuries and imbalances in the muscle tone distribution [2].

There are 35 muscles directly attached to the sacrum and the hip bone. The purpose of this chapter is not to accurately describe the anatomy of each of the muscles, but rather to draw attention to the particular groups of muscles and their specific importance for both, mobility and stability. The chapter shows, why the muscle groups providing the CS for trunk and hips, to such a significant extent help to prevent injuries. The lower trunk CS system include abdomen muscles, muscles supporting the thoracic-lumbar and lumbar spine sections and the muscles located on the side of the thoracic-lumbar section. The hip joints core stability system includes: flexors, extensors, adductors, abductors and external rotators of this joint [1].

Materials and methods

In the scientific literature on the subject, there can be found arguments in favor of the different, particular types of the

physical exercises for the core stability. What draws special attention, is the variable activity of the individual muscles during the exercises. An assessment of the muscle work in comparison to the research on patients with the chronic disorders suggests, that many of the proposed exercises increase the endurance but do not improve the performance of the spine muscles.
In the process of search for the topic related materials, we have used the article databases of MedLine, PubMed and PBL. To perform the search, we have applied the following keywords: core stability, lumbar stability, dynamic stability, motor control, neuromuscular training, trunk stability, core strengthening.
Moreover, some of the cited articles, which had been published in previous years, constitute the basis for the core stability research development and have been cited numerous times by different authors, still we have made the attempt to choose the original works.

Results

In recent years the concept of core stability has undergone significant changes, which have affected the way of the physiotherapy treatment of patients. We have decided to use the term of "core stability", although in the subject literature there are also being used other terms describing this phenomenon, such as: lumbar/lumbar-hip complex stability, dynamic stability, motor (movement) control, neuromuscular training, spine control (stabilization) in the natural position, spine stabilization (immobilization) through the natural muscle tension, trunk stabilization, core strengthening.
The authors of all the above formulas have had in mind the muscle control, which is necessary to maintain the functional stability of the hip-lumbosacral area. Considerable attention is being paid to the concept of the "core of stabilization", since it functions as the muscular corset, which is essential to stabilize the body and spine, both during the movement of the extremities, and when the extremities remain motionless. In short, the "core of stabilization" constitutes something like the basic component, a kind of driving element, power plant or engine, necessary for the movement of extremities. All movements begin from the core and then they are being transferred to the extremities.

Core stability of trunk and hip joint

The lower torso CS system includes muscles supporting the thoracic-lumbar spine section (thoracic part of the longissimus thoracis muscle, iliocostalis cervicis), the lumbar spinal section (multifidus muscle, lumbar part of the iliocostalis cervicis and the longissimus thoracis muscle, transversal, spinalis capitis muscles and rotators), the muscles located on the side of the thoracic-lumbar section, quadratus lumborum and the abdomen muscles (transversus abdominis, rectus abdominis, and internal and external obliques). Although the thoracic-lumbar fascia is not a contractile structure, it does contribute to the CS of the lower trunk. This is possible, because it is the place where several important muscles are attached.
The CS system of the hip joint includes muscles: psoas, iliacus, gluteus maximus, gluteus medius (its anterior and poste-

rior fibers), rectus femoris and ischio-tibial muscles. External and internal rotators of the hip joint are a large group of muscles. The group is important for mobility and stability of the hip joints and the trunk, and its strength limitations may be a cause of injuries..

Among the external rotators of the hip joint, there are: piriformis muscle, gemellus muscles inferior and superior, obturator internus and externus, quadriceps femoris, gluteus maximus (2/3 of which is attached to the tensor of fascia lata), iliopsoas, sartorius and biceps femoris [2].

The internal rotators include the paracentral part of the ischio-tibial muscles, front section of the gluteus medius muscle, tensor of the thigh fascia lata, iliotibial tract, gluteus minimus, pectineus and gracilis.

Global and local muscles

As already mentioned, the above listed muscles may be classified either as stabilizing or mobilizing. Richardson et al. have formulated the most accurate definition and description of the hip-lumbar trunk complex stability [3, 4]. The stabilizing function of muscles is a dynamic process, based on the control of static positions and functional movements. In practice, this means that the transition of the spine from the bent position to the upright position should be a controlled sequence of the intervertebral rotations and the translation movements [4]. Bergmark describes the local stabilizing system as a group of muscles attached directly to the vertebrae of the lumbar spine section. These muscles have the ability to modulate the degree of rigidity of this part of the spine. An example of the local muscle, responsible for the rigidity of the lumbar spine section, is characterized by the segmented system of muscle attachments - the multifidus muscle [5].

Another part of the local system constitute the attached to the thoracic-lumbar fascia, the rear fibers of the internal oblique muscles and the transversus abdominis muscle, as well as the paracentral fibers of the quadratus lumborum muscle, the lumbar part of the iliocostalis lumborum and longissimus thoracis muscles.

The global muscular system includes large, surface muscle groups of the trunk, which are not directly attached to the vertebrae. These muscles are used as the torque generators during the spine movements and perform the function similar to the ropes of a tent, which means, that they are "controlling the position of the whole spine, balance and compensate the external trunk loads and transfer the loads from the chest to the pelvis" [6]. The global muscles include: internal and external oblique muscles, lateral fibers of the quadratus lumborum muscle, thoracic part of the longissimus thoracis muscle and thoracic part of the iliocostalis lumborum muscle.

Core stability of hip joint

Gluteus maximus and gluteus medius are generally regarded as the most important stabilizers of the lumbar spine section and the pelvis. The initial attachment of the gluteus maximus muscle is located on the thoracic-lumbar fascia, while 80% of its fibers are attached distally to the iliotibial tract. The gluteus maximus belongs to a group of surface muscles and is responsible for the straightening and external rotation in the hip

joints. In addition, the upper part of the muscle performs abduction, and the bottom part - adduction [7].
Too low strength of the gluteus maximus muscle causes lower efficiency of other muscle groups in the rear part of the hip joint, such as the rear fibers of the gluteus medius, gluteus minimus and external rotators, and impairs the control of movement of the femur in its acetabulum. Front fibers of the gluteus medius muscle abduct, rotate to the inside and support flexion of the hip joint.
Many studies have confirmed the ability of the lumbar spine muscles to increase the rigidity of its segments. Kaigle et al. have demonstrated that the simultaneous activation of the paraspinal muscles (multifidus muscle, lumbar part of the erector spinae, quadratus lumborum, psoas) restricts the segmental movement the damaged part of the spine [8]. Goel et al. have assessed the effects of work of the interspinal and the intertransverse muscles, the multifidus and the quadratus lumborum muscles. Activation of these muscles supported the ligament stabilization and resulted in the increase of the loads operating on the surfaces of the facet joints [9]. Panjabi et al. have found, that the segmented layout of the multifidus muscle deep fibers attachments significantly improves the stability of the individual intervertebral connections of the lumbar section [10, 11]. Wilke et al. have in turn demonstrated, that the multifidus muscle is responsible for the limiting ranges of all movements of the lumbar spine section, except the rotation [12].
To sum it up, it can be stated that the efficient CS of the trunk and the hips constitutes the basis, on which any motor activity is being built. The joint work of the abdominal muscles, erector spinae and the side part of the quadratus lumborum muscle, provides the trunk stability, which allows the hip joints muscles to develop their explosive power. Through the action of agonists and antagonists, isometric, concentric and eccentric contractions, the CS system muscles control both, the movement and the stability of the body [2].

Disorders of the core stability
The lower kinematic chain is the system of connections, which includes a number of joints, such as the ankle, knee, hip and the trunk joints. This allows the transfer of forces in the direction of the hips and the trunk when jogging, jumping, kicking and throwing. Dysfunction of one of the joints belonging to the lower kinematic chain may cause a disorder in another spot. Kinematic chain damages tend to be the result of an unbalanced muscle tension, movement restrictions in the joints or improperly applied rehabilitation. Beckman and Buchanan, studying the patients with the chronic ankle joint sprains, have observed the delayed activation of the gluteus medius muscle, when compared to the healthy persons [13]. Devita et al. have demonstrated the change of the stimulation speed of the proximal muscles in the hips area, in patients with the anterior cruciate ligament insufficiency [14]. Jaramillo et al. have identified significant loss of strength in the gluteus medius muscle on the side of the knee, which had undergone a surgery [15]. In turn, Yamamoto has noted the increased frequency of injuries in persons, who had shown weakness of the ischio-tibial muscle group and the lowered

strength ratio of the rear thigh muscles in relation to the strength of the quadriceps femoris muscle [16].

Treatment of the injuries associated with the muscle overload must encompass the assessment of the CS disorders and the adequate rehabilitation. Mascal et al. have written, that the strengthening of the hip joints, pelvis and the trunk muscles, contributes to the reduction of pain in the patellofemoral joint, improvement the lower extremities kinematics, and also increases the chances of the patient's recovery to the initial level of efficiency. The muscles strengthened first have been the abductors, extensors and the internal/external rotators of the hip joint [17].

The concept of exercises: from the core stability to the distal parts of extremities

The exercises within the closed kinetic chain encompass the body weight with the shear forces, which occur due to the eccentric muscular activity [18]. The functional training exercises merge a series of the body reactions, including the stabilization, synergistic, neutralizing and antagonistic structures, all harmoniously collaborating, so that the body can speed up, slow down and maintain its stability in the three planes [19]. Strength, in the functional terms, means the ability of the neuromuscular system to take on the concentric, eccentric or the isokinetic body stabilization, in response to the force of gravity, momentum or to the the ground reaction force [20].

Stabilization of the pelvis is crucial for the whole of the body. During any activity, the closer the center of gravity is to the support plane, the greater the stability is [21]. Low located center of gravity allows an athlete to efficiently perform the appropriate action, whenever required. The lower extremities generate the strength, and thanks to the stability of the pelvis and the trunk, it is being transferred towards the upper extremities. It is possible to quadruple the strength in the pushing movement with the use of the legs and the whole of the body, in comparison to the situation when only the upper extremities are being used [22].

Lunge exercises performed in many planes, activating the different muscle motor patterns, allow the development of dynamic, functional stability. For example, when your foot hits the ground the ischio-tibial muscles activity, which works eccentrically, inhibits the internal tibia rotation, the internal thigh rotation and the hip flexion. These muscles stabilize the knee joint, work in synergy with the gluteus maximus and the piriformis muscles [23]. While performing the lunge exercises, it is possible to recreate the functional motor patterns of these muscle groups.

The balance exercises, with swings of the load free extremity in different planes, thus with the extended pelvis, is associated with the extensive gluteus medius muscle activity. The group of muscles located in the area known as groin, includes the hip muscles and flexors. When performing the test of balance with the legs' swings and their rotation in the posterior-paracentral direction and to the sides, the individual muscles - i.e. gluteus medius, gluteus maximus, piriformis, abdominal muscles and the erector spinae - collaborate in harmony with the muscles of the front part of the body, that is with the adductors and the abductors of the hip joint [24].

The squats, on both or on one leg, allow for the isolated activity of the gluteal muscles, quadriceps femoris and the ischiotibial muscles, depending on how deep the squats are and in what plane they are being performed. These exercises require very good stability of the pelvis, due to the eccentric action of the double joint knee flexors, with the simultaneous contraction of the quadriceps, abdominal and spinal muscles, in order to control the upright trunk posture [25] . The isolated action of the quadriceps occurs when squats are being performed in the upright position, as opposed to the squats performed with the trunk positioned more horizontally, in the case of which more engaged become the gluteal muscles.

Stabilizing exercises and the effectiveness of the strengthening exercises for the core stability

Stability exercises for the lower back may be of different difficulty levels. To date, in the subject literature, there have been published many stabilization exercises, but the main principles for their application remain the same.. At the first stage, the exercising person needs to master the ability to activate the transversus abdominis and the multifidus muscles, with the understanding, that with time the contraction of these muscles must become an automatic function, without the necessity to engage the consciousness while performing the functional activities. Rehabilitation of these muscles may be divided into three distinct stages [26]:

- learning and developing a motor skill,
- application of the acquired skills in performing the functional activities,
- the use of the acquired skills.

Most therapists agree, that teaching of movements, especially the techniques to activate the deep muscles, which are responsible for the stability (transversus abdominis and multifidus), constitutes the first stage of the program of stabilization exercises. Richardson et al. have recommend, that during the

exercises it should be attempted to achieve the simultaneous contraction of the transversus abdominis and the multifidus muscles, and they have emphasized the need to get the co-contraction of the pelvic floor muscles and the transversus abdominis. The exercise, during which these muscles work most effectively, is the exercise of "abdominal retraction" [4].
The objective, which the patient should reach, is the use (activation) of the appropriate muscles in response to a therapist command of: "Retract your abdomen, but do not move neither your spine nor pelvis, and maintain this position for 10 seconds, while breathing in a normal and calm way". Kneeling supported on hands is the starting position, which most effectively helps to learn this exercise. Ask the patient to inhale and exhale in a calm manner, then command him to retract his abdomen (upwards), in the direction of the spine, suspending breath for a moment. Contraction of the muscles should be done slowly and in a controlled manner. At the same time the patient tightens the pelvic floor muscles and slightly rotates the pelvis forward, in order to cause the contraction in the multifidus muscles. Evaluation of the quality of this exercise is made by palpation or one of the feedback methods can be used, such as ultrasound. Upon achieving the contraction, the patient should begin to breathe slowly and in a controlled manner, while maintaining the muscle contraction for 10 seconds.
The ability to perform this exercise should then be confirmed by a test, with the patient lying on the belly and using a pressure instrument to verify the feedback. The patient lies on his belly, his arms on the sides, and under his belly a pressure cushion is placed (belly button is located in the middle of the further edge of the cushion, on par with the line connecting the right and the left anterior superior iliac spine). The cushion is filled with the pressure of 70 mmHg, after which - allowing the time needed to stabilize the pressure in the cushion - the patient receives a command to inhale and exhale, and then to hold his breath (after exhaling) and slowly retract his abdomen, so that it comes up from the cushion, without changing the position of the spine. After tightening the muscles, the patient again begins to breathe in a normal and calm manner. The muscles contraction is being maintained for 10 seconds, and the whole exercise should be repeated 10 times.
Having mastered the skill to stabilize the lumbar-pelvic area with the use of the above described isometric exercises, which will make it possible to get the functional muscle corset, the patient may begin the dynamic stability exercises. McGill has recommended an early inclusion, to the rehabilitation program, the below described, very important exercises [27]:
• Lifting the head, neck and shoulders causing tightening of the rectus abdominis muscle. The rectus abdominis muscle works most significantly during the first stage of lifting the head, neck and shoulders. The lumbar spine section should remain in the neutral position. The level of the exercise difficulty can be raised, by commanding the patient to raise his elbows by a few centimeters.
• Raising of the trunk on the elbows, in the position of lying on the side, the tightening of the abdominal oblique muscles, quadratus lumborum and the transversus abdominis. Tightening of all the muscles around the lower section of the spine is also recommended. The level of the exercise difficulty can be raised,

by commanding the patient to place the opposite arm along her trunk, and then asking her to straighten the lower extremities.
Many therapists applying the stabilization exercises, take as the basis the research published by Saal and Saal, who have studied the issues of the dynamic stabilization programs efficiency [28]. Also Sahrmann has described the entire series of the strengthening exercises, for the lower abdominal muscles, with the increasing difficulty levels [29].
The first research program assessing the core stability exercise program, has been the prospective study "dynamic stabilization of the lumbar spine section" with the participation of the of patients with the lumbar spine intervertebral hernia accompanied by radioculopathy [2]. The actual impact of the therapeutic exercises alone has proven difficult to assess in this research, since the patients during the therapy have undergone other non invasive methods of treatment, such as pharmacotherapy, epidural injections of steroids and have participated in the "back school" program. The exercise program suggested to the patients has been clearly defined and included the exercises to improve the joints mobility, mobilization of the hip joints and the joints of the thoracic-lumbar section of the spine, stabilization and strengthening exercises program for the abdominal muscles, also the gym exercises program and the aerobic fitness type exercises. The program has ended with the successful results in 50 out of 52 (96%) participating patients. The described dynamic stabilization exercises program for the lumbar spine section resembles the currently recommended exercise programs for the core stability, with the exception of the specialist core stability exercises. Since the above mentioned research has been performed, numerous other authors have presented their stabilization exercise programs [17, 24].

Discussion

Strengthening exercises for the core stability improvement in children have not been so far the subject of many scientific studies. This state of affairs can be ascribed to the absence of a clear definition of the strengthening exercises, carried out for the purpose of the core stability training. For example, in some publications this type of exercises is being presented as the medical treatment procedure leading to the neuromuscular reeducation, in others they are closely related to training process for a particular sport discipline, and still in others they may be a kind of education for some functional activities.
Insofar, there have not been any randomized clinical trials performed, regarding the effectiveness of the strengthening exercises applied in the core stability training. Majority of the published research results concerns the prospective observations and individual cases.

Conclusions

The concept of the core stability has its theoretical background in the treatment and prevention of various disorders and dysfunctions of the musculoskeletal system. It should be noted, however, that the studies carried out so far concerned only the application of this concept in the lower spine pain therapy. Taking into account progress which has taken place in the recent years, in the areas of anatomy and in development of theories dealing with the teaching of movement, it can be assumed, that the core stability exercises programs may become the topic of new, innovative research programs.

The upper parties include rotators of shoulder joints and shoulder blade muscles, the lower parties - trunk and hip joints muscles. In both cases the CS is a process. in which simultaneously occur movement and stability. Electromyographic analysis and strengthening programs focusing on the CS of the upper and the lower body parts indicate, that the result depends on the condition of the providing it muscles, which move and stabilize the shoulder and hip joints, and the trunk.

The CS impairment may be causing injuries of shoulder and elbow joints, lower back and lower extremities.

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Piśmiennictwo/ References

1. Akuthota V, Nadlet S. Core strengthening. Arch Phys Med Rehabil 2004; 85: 86-92.
2. Bliss LS, Teeple P. Core stability: the centerpiece of any training program. Curr Sports Med Rep 2005; 4: 179-83.
3. Richardson C, Hodges P, Hides J: Therapeutic exercise for lum- bopelvic stabilization. A motor control approach for the treatment and prevention of low back pain, Philadelphia, Elsevier, 2004.
4. Richardson C, Juli G, Hodges P, et al. Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain. Edinburgh: Churchill Livingstone, 1999.
5. Bergmark A: Stability of the lumbar spine. A study in mechanical engineering, Acta Orthopaedica Scand, 1989; 230:20-24.
6. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine 1996; 21(22): 2640-50.
7. McGill S. Low Back Disorders: Evidence-Based Prevention and Rehabilitation. Champaign, IL: Human Kinetics, 2002.
8. Kaigle AM, Holm SH, Hansson TH: Experimental instability in the lumbar spine, Radiology, 1995; 55:145-149.
9. Goel K Gilbertson L: A combined "nite element and optimization of lumbar spine mechanics with and without muscles, Spine 1993; 18:1531-1541.
10. Panjabi M, Abumi K, Duranceau J, et al: Spinal stability and intersegmental muscle forces. A biomechanical model, Spine, 1989; 14:194-200.
11. Panjabi MM. Clinical spinal instability and low back pain. J Electromyogr Kinesiol 2003; 13(4): 371-9.
12. Wilke HJ, Wolf S, Claes LE, et al: Stability increase of the lumbar spine with different muscles groups. A biomechanical in vitro study, Spine, 1995; 20:192-198.
13. Beckman SM, Buchanan TS. Ankle inversion injury and hypermobility: effect on hip and ankle muscle electromyography onset latency. Arch Phys Med Rehabil 1995; 76(12): 1138-43.
14. Devita P, Hunter PB, Skelly WA. Effects of a functional knee brace on the biomechanics of running. Med Sei Sports Exerc 1992; 24(7): 797-806.
15. Jaramillo J, Worrell TW, Ingersoll CD: Hip isometric strength following knee surgery, J Orthop Sport Phys Ther, 1994; 20:160-165.
16. Yammamoto T: Relationship between hamstring strains and leg muscle strength. A follow up study of collegiate track and "eld athletes, J Sport Med Phys Fitness, 1993; 33:194-199.
17. Mascal C, Landel R, Powers C: Management of patellofemoral pain targeting hip, pelvis, and trunk muscles function: 2 case reports, J Ortho Sports Phys Ther, 2003; 33(ll):647-660.
18. Adams MA, Dolan P, Hutton WC. Diurnal variations in the stresses on the lumbar spine. Spine 1987; 12(2): 130-7
19. Bogduk N, Pearcy M, Had'eld G: Anatomy and biomechanics of the psoas major, Clin Biomechanics, 1992; 7:109-119.
20. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of hamstring strains. / Orthop Sports Phys Ther 2004; 34 (3): 116-25.
21. Nadler SF, Malanga GA, Fienberg JH, et at Functional performance de'cits in athletes with previous lower extremity injury, Clin Sport Med, 2002; 12(2):73-78.
22. Kollmitzer J, Ebenbichler GR, Sabo A, Kerschan K, Bochdansky T. Effects of back extensor strength training versus balance training on postural control. Med Sei Sports Exerc 2000; 32(10): 1770-6.
23. Hides JA, Richardson CA, Juli GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine 1996; 21 (23): 2763-9
24. Marfan HF, Cossette JW, Robertson GH, et al. The effects of torsion on the lumbar intervertebral joints: the role of torsion in the production of disc degeneration. / Bone Joint Surg Am 1970; 52(3): 468-97.
25. Sapsford RR, Hodges PW, Richardson CA, et al. Co-activation of the abdominal and pelvic floor muscles during voluntary exercises. Neurol LJrodyn 2001; 20(1): 31-42.
26. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of hamstring strains. / Orthop Sports Phys Ther 2004; 34 (3): 116-25
27. McGill SM: A myoelectrically based dynamic 3-D model to predict loads on lumbar spine tissues during lateral bending, J Biomechanics, 1992; 25(4):395-399.
28. Saal JA. Dynamic muscular stabilization in the nonoperative treatment of lumbar pain syndromes. Orthop Rev 1990; 19(8): 691-700.
29. Sahrmann S. Diagnosis and Treatment of Movement Impairment Syndromes. St Louis: Mosby, 2002.