International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.5, pp 330-340, 2017

A prospective study of core musculature endurance and the risk of lower extremity injuries among male football players

Nabil .A. Mohamed* and Maha. M. Mohamed

Physical Therapy for Musculoskeletal Disorders Department, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

Abstract : Core muscles endurance are important issues in lower extremity injury among football players. This study investigates the relation between core muscles' endurance and the occurrence of different lower extremity injuries during one season. Eighty-two male football players (mean age 20.69±3.85, weight 76.3±14and height 178±9.6) were tested. After being screened for a season. The prone-bridge, side-bridge, trunk flexion and horizontal back extension hold times were recorded for endurance assessment; in addition the numbers of different lower extremity injuries during the current season. The negative binominal regression method revealed that the maximum holding time for trunk flexor endurance only was significantly related to occurrence of lower extremity injuries ($p<0.05$). On the other hand the maximum holding time for plank, side plank and trunk extensor endurance were not significantly related to frequency of lower extremity injuries ($p\geq0.05$).Abdominal muscle endurance is related to the risk of lower extremity injuries more than plank, side plank and trunk extensor muscles endurance. Abdominal muscles endurance are more important issues in preventing different lower extremity injuries among male football players.

Introduction

Football (Soccer) is the most popular sport worldwide with around 265 million players [1]. It is a sport that uses walking, jogging, running, and sprinting. The most common injury locations in football players are the knee (7–32%), ankle (9–31%) and thigh (6–22%) [2,3,4,5,6].These injuries include traumatic anterior cruciate ligament (ACL) ruptures to overuse injuries such as patellofemoral pain syndrome, iliotibial band friction syndrome, and femoral, hamstring strain and ankle sprain[7,8].

Hamstring strain injury is one of the most common injuries in sports, and causes significant loss of training and significantly affects the quality of life of injured athletes. Hamstring muscle injury also has a high re-injury rate, which frustrates the injured athletes as well as the clinicians and increases cost of the treatment [9]. Anterior cruciate ligament (ACL) tear, is one of the most common knee injuries in sports [10], usually occurring in a multitude of sports such as basketball, soccer, handball and tennis [11,12]. Ankle inversion sprain are amongst the commonest injuries of lower extremities especially in athletes involved in high contact sports. A common complication after ankle sprain is the development of functional instability at the ankle joint and the tendency for the sprain to reoccur, thus resulting in chronic ankle instability [13].

Core stability is defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the peripheral segment in integrated athletic activities. Core muscle activity is best understood as the pre-programmed integration of local, single-joint muscles and multi-joint muscles to provide stability and produce motion. This results in proximal stability for distal mobility, a proximal to distal patterning of generation of force, and the creation of interactive moments that move and protect distal joints [14]**.**

The importance of core stability (CS) for injury prevention and performance enhancement has been increased during the recent period with minimal supporting evidence. Even though limited evidence exists, the integration of core stability exercises into injury prevention programs, particularly for lower extremity, is demonstrating decreased injury rates [15,16,17,18,19,20]**.**

Trunk and hip neuromuscular control measurements have been shown to predict the incidence of knee injury [21]**.** Control and stability of the lumbopelvic region is important in the transfer of forces between the lower limbs and spine. Inability to stabilize the lumbopelvic region during dynamic lower extremity movements could lead to excessive load on joints **(14).**Lumbopelvic motor control training in elite athletes was shown to increase targeted muscle size, reduce low back pain (LBP) and reduce occurrence and severity of lower limb injuries [22,23,24,25]**.**

There is only minimal voluntary isometric contractions of trunk musculature are necessary to stabilize the spine, so that muscular endurance along with sensory-motor control are of greater importance than strength when considering core stability[26]**.**Also,[27] stated that co-activation and coordination of the core muscles rather than strength, provide an ideal core**.**

In athletic tasks, muscle endurance appears to be more important than pure muscle strength[28]**.** Many studies have suggested that proper core stability is important for injury prevention, so poor core stability can be a predictor for injury. Poor core stability was reported as a predictor for anterior cruciate ligament injury, patellofemoral pain, iliotibial band syndrome, low back pain, and improper landing kinematics [29,30,31,32,33]**.** While other studies support the role of core training programs for injury prevention, they do not suggest that they will improve physical tasks or improving strength and sport-specific performance [30,34]**.**

CS is defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the peripheral segment in integrated athletic activities. Core muscle activity is best understood as the pre-programmed integration of local, single-joint muscles and multi-joint muscles to provide stability and produce motion. This results in proximal stability for distal mobility, a proximal to distal patterning of generation of force, and the creation of interactive moments that move and protect distal joints [14]**.**Therapist and trainers have considered CS as an approach for improving sports performance [14]**,** preventing injury. However, these thoughts are not supported by clinical studies. Despite the strong believe in the positive effects of Core Stability Training (CST), there is limited scientific studies have shown direct relationship between stronger core muscles and better athletic performance and injury prevention [35,36]**.**

The relationship between core stability and injury prevention is also relevant. A study by [21] evaluated trunk displacement and stiffness in response to movement, as well as the ability to determine spatial position of the trunk. The findings were increased knee ligament and ACL injuries occurring in collegiate athletes which increase trunk displacement following a sudden force release and Lateral trunk displacement was illustrated to be the strongest predictor of knee ligament injury[21]**.**Over the past several years, the body of literature related to the relationship between core stability and injury prevention has significantly increased. However, this relationship has not been defined yet [37]**.**

Participants

Eighty two male football players (mean age 20.69± 3.85, weight 76.3± 14and height 178± 9.6) who volunteered to participate in the study. They were interviewed and screened based on the following inclusion and exclusion criteria:

Inclusion criteria:

The volunteered football players were included in the study if they had Body mass index (BMI) was less than 30 kg/m².Age ranging from 18-30 yearswith no previous history of sprain or strain or losing performance in training during the past participation season. 82 players met that criteria and were included in the study. Then we recorded the participants who experienced an injury to one of his lower extremity through the current season. Back and abdominal muscles' strengths of grade five as assessed by manual muscle test. Ankle dorsiflexors and evertotrs strength should of grade five as assessed by manual muscle test.

Exclusion criteria:

The volunteers were excluded if they had any history of traumatic fracture of femur, tibia, fibula, foot bones, or of traumatic patellar subluxation or dislocation, or Previous surgery in the knee and hip joints, orknee and hip joints osteoarthritis, or any conditions affect muscle strength: diabetes mellitus, rheumatoid arthritis, a history of any previous back and/or abdominal surgeries and/or diseases , any previously perceived episodes of low back pain one year before being involved in the study. Tightness of the lumbar flexors, lateral flexors or rotators.Tightness of the hip flexors.

Instrumentations:

1-Assessing the Core stability

Assessment of the core endurance was done using

1.1. The Prone Bridge
1.2. The Lateral Bridge
1.3. Torso Flexors Endurance

1.4TorsoExtensors Endurance

2- Data Collection Sheet

It includes the following items: participant's name, age, address, weight, height, body mass index and phone number.

3- Height and Weight Scale

A universal height and weight scale was used to determine the participant's height and weight.

Fig (1) height and weight scale

Procedures:

All volunteered players were informed by the purpose of the study and the testing procedure were fully explained and all relevant questions were answered. Then, if the individual agreed on participating in the current study, he signed on informed consent. A brief learning session about the nature of the study, the purpose of study and the tests to be done were provided to each participant.

1 Assessment of Core Stability:

1.1. Prone Bridge Test:

Fig.(2): prone bridge test

The prone bridge is done by supporting the body's weight between the forearms and toes and assesses primarily the anterior and posterior core muscles. It is essential that the athlete keep the pelvis in a neutral position and the body straight. Failure occurs when the athlete loses neutral pelvis and falls into a lordotic position with anterior rotation of the pelvis [38]**.** The total time the athlete was able to lift their pelvis from the table was recorded using a stopwatch.

1.2. Lateral Bridge Test:

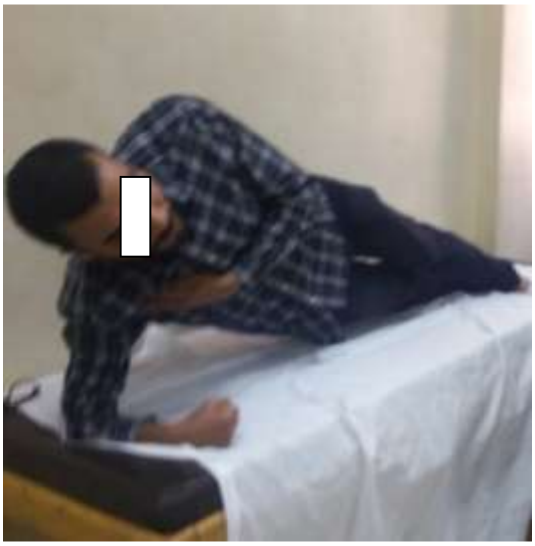

Fig.(3):Endurance testing of the lateral trunk using the side bridge test.

Athletes performed the side bridge test as described by **McGill et al.,**[38] as a measure of lateral core muscle capacity, particularly the quadratuslumborum**.**

The athletes were positioned in right side lying with their top foot in front of their bottom foot and their hips in zero degrees of flexion. The athletes were asked to lift their hips off the treatment table, using only their feet and right elbow for support. The left arm was held across their chest with their hand placed on the right shoulder. The total time the athlete was able to lift their bottom hip from the table was recorded using a stopwatch. **McGillet al.,**[38] previously documented no significant difference between right and left side bridge endurance times. Therefore, the measure for the right lateral core muscles was used for data analysis. Failure occurs when the athlete loses them straight posture and the hip falls toward the table.

1.3. Torso Flexor Endurance Test:

Figure (4).Trunk flexors endurance test.

Torso flexors endurance assesses the endurance of trunk flexors muscles in a static manner while subject maintained 60 degrees of trunk flexion against gravity.Testing of the torso flexors were done by timing how long the athlete can hold a position of seated torso flexion. The torso should be flexed at 60° and the knees and hips flexed at 90°. The toes should be secured under toe straps or held by the examiner. Failure occurred when the athlete's torso falls below 60°.

1.4. Torso Extensors Endurance Test:

Figure (5).Trunk extensors endurance test.

Testing of the torso extensors can be done with the athlete in a prone position and the pelvis, hips, and knees secured on a table by the therapist**.**

The upper body was held out straight over the end of the table. Muscle capacity of the posterior core was measured using the modified Biering-Sorensen test **McGill** [38].The athlete was required to maintain the body in a horizontal position for as long as possible. The total time that the athlete was able to maintain the horizontal position until they touched down on the bench in front of them with their hands was recorded in seconds using a stopwatch. Failure occurred when the upper body falls from horizontal into a flexed position.

2 Data Collection

Preseason Data Collection.

The therapist obtained written informed consent from each player. Information on previous injuries (within the past 6 months and 1 year) and sports participation (within the past 6 months and 1 year) was collected. Past history, in addition to other medical history, were recorded from the athlete. The therapist completed measurements of height, weight, leg dominance, with all participating players. The leg preferred for kicking soccer ball determined leg dominance.

2 Injury Data Collection.

Any sports injury that resulted in the following: the inability to complete a full session, missing a subsequent session, or medical attention was recorded. The team therapist informed the researcher or the players informed the researcher directly by meeting him or calling him about his injury. If time loss from sports was associated with the injury assessed by the therapist and appropriate treatment was provided

Results

Eighty two male soccer players were participated in the current study without any missing of their injury profile during their playing season. The maximum holding time for plank, sideplank, trunk flexor endurance and trunk extensor endurance tests recorded as independent variables and numbers of injuries were recorded as a dependent variable during the current season. The holding time for each test was listed in **Table (1)**.

The recording of the frequency of lower extremity injuries (number of injury) is considered a count variable we should use passion regression analysis. In our study we used the negative binominal regression method during statistical analysis of our data due to over diversion of passion regression.

There was no significant relation between holding time of plank and number of injuries ($p = 0.860$). There was no significant relation between holding time of side plank and number of injuries ($p = 0.355$). There was a significant relation between holding time of trunk flexor endurance test and number of injuries ($p = 0.008$). Also, There was no significant relation between holding time of, trunk extensors endurance test and number of injuries ($p = 0.786$) as illustrated in a **table (2).**

Table (1) Holding Times or Endurance Tests

		N	Minimum	Maximum	Mean	Std. Deviation
Frequency of injuries	numberofinjury	82	0.00	6.00	1.15	1.62
Core endurance	TEET	82	2.00	325.00	84.57	49.23
	TFET	82	43.00	275.00	129.44	42.86
	LBT	82	6.50	173.30	89.99	32.29
	PBT	82	23.70	154.20	64.11	26.88

TEET : Trunk Extensor Endurance Test
TFET : Trunk Flexor Endurance Test
LBT : Lateral Bridge Test
PBT : Prone Bridge Test

Table (2) Negative Binominal Regression showed The Relation Between Variables

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	**.77**	**.71**	**-.62**	**2.17**	**1.18**	**1**	**.28**	**2.17**
TEET	-.001	.0040	-.009	.007	.074	1	.786	.98
TFET	.013	.0049	.003	.023	7.135	1	.008	1.01
LBT	-.005	.0054	-.016	.006	.857	1	.355	.96
PBT	.001	.0059	-.011	.013	.031	1	.860	1.001

TEET : Trunk Extensor Endurance Test
TFET : Trunk Flexor Endurance Test
LBT : Lateral Bridge Test
PBT : Prone Bridge Test

The purpose of this study was to examine the relationship between core muscles endurance measures and risk of different lower extremity injuries among male football players. It was a trial to identify one or a combination of core endurance measures that could be used to identify those individuals who are at increased risk for lower extremity injury. In the current study there was no significant relation between the endurance measures (holding time) for plank, side plank, trunk extensor endurance and the frequency of lower extremity injuries. While there was a significant relation between the endurance measures (holding time) for trunk flexor (abdominal) endurance and lower extremity injuries among male players (P = 0.008) with 95% confidence interval (0.003:0.023).We suggest that trunk muscles weakness reduces the ability of the athletes to stabilize the trunk against the large external forces experienced by these segments during athletic maneuvers especially the anterior abdominal muscles.Our finding agree with previous studies that clarified that CS has been considered an important issue for maintaining dynamic joint stability throughout the kinetic chain that extends from the foot to the lumbar spine [39,40]**.**Alteration of neuromuscular activation patterns in the core and the lower extremity have been documented in patients with joint injuries that are distant from the affected musculature [41,42]. The injury-related neural effect on muscle activation can occur in either a distal-to-proximal or proximal-to-distal direction. Lower extremity dysfunction increases susceptibility to low back injury [29]and susceptibility to lower extremity injury appears to be increased by low back dysfunction[21,41,43]**.**

Suboptimal endurance of the core muscles has been associated with impaired neuromuscular control of the body’s center of mass, inhibition of lower extremity muscles, and elevated risk for lower extremity injury[21,32,41,42,43,44]**.** Early fatigue in core muscles also may be a cause in predisposing athletes to injury, as fatigue of the abdominal muscles has been found to be a contributor to hamstring injuries [45]**.** There also may be gender differences in whether CS plays a role in risk of injury, as suggested by [21] who found that increased trunk displacement and decreased proprioception on testing predicted knee ligament injury for women, although these findings were not predictive in men.

The current study found that core endurance measures of abdominal muscles are predictors of injury status over the course of one athletic season for football male players. However, the trunk flexors are only some of elements of core stability, and other elements of core stability not included in this study that may add to the predictive value of the regression equation. Core stability is dependent on motor control and muscular capacity of the lumbo-pelvic-hip complex.Decreased perception of rapid body core displacements during sport-specific tasks may interfere with the ability to generate adequate corrective responses of the core muscles, which requires lower extremity joints to displace to a greater extent to maintain postural stability[40]**.**Any delay in activating muscles that span the displaced joints is likely to increase injury susceptibility.The time an individual can sustain a static body position that involves loading of the core musculature may be valuable for quantifying the risk for injury to either the core or the lower extremity [46]**.**

Greater rectus abdominis, external oblique, and internal oblique activity occurs in the side bridge compared with the crunch exercise [47]**.** No significant difference in rectus abdominis activity were found during prone and side bridge, but significantly greater external oblique and lumbar paraspinal activity was seen in the side bridge compared with the prone bridge [48]**.** The crunch and side bridge are effective in activating the internal oblique and transversusabdominis[49]while the side bridge is effective in recruiting the quadratuslumborum [50]**.**

Side bridge on toes and knees demonstrated significantly less upper and lower rectus abdominis, internal oblique, and latissimusdorsi activity as well as rectus femoris activity but significantly greater lumbar paraspinal activity compared with supine and prone position exercises [51]**.**

Our results did not come with agreement with both Zazulak et al.,[21] who reported that lateral trunk control was a predictor of knee injury risk, and Hewett et al.,[52] who used observations of noncontact ACL injury events to conclude that lateral trunk position may be an important factor in the ACL injury mechanism. Leetun et al**.,**[32] found that the performance in the side bridge test was not a risk factor for low back and LL injuries during a season in basketball and track and field athletes which support our results as we limited our sample to male football players only.

Vleeming and colleagues [53]noted that the gluteus maximus and contralateral latissimusdorsi provide a perpendicular force to stabilize the Sacroiliac (SI) joint. The SI joint activates the gluteus maximus, quadratuslumborum, and multifidus[54]**.**So, the SI joint provides lumbopelvic stabilization for locomotion and posture. Changes in the loading of the SI joint may alter the activation of stabilizing muscles. Contraction of the TransversusAbdominis (TrA) has been shown to increase SI joint stability [55]**.**Preactivation of the multifidus and internal oblique muscles contributes to compression of the SI joint necessary for lumbopelvic stabilization during load transfer from double- to single-leg stance[56]**.**

The cause of groin injury may not be the groin area itself but rather the supporting areas of the abdominal core and hip. Athletes with chronic groin pain demonstrate delayed activation of the TrA compared with controls [57]**.**Holmich et al. [58]utilized a successful gradual strengthening and conditioning program for weak abdominal muscles and hip adductors in athletes with chronic groin pain. A recent study reported that a progressive agility training program with trunk stabilization exercises is more effective than an isolated hamstring stretching and strengthening rehabilitation program [59]**.**

Conclusion

Abdominal muscle endurance is related to the risk of lower extremity injuries more than plank, side plank and trunk extensor muscles endurance. Abdominal muscles endurance are more important issues in preventing different lower extremity injuries among male football players.

Limitations and recommendations

The primary limitation of this study was the relatively small number of injuries sustained by the football players during a surveillance period that was limited to a single season.Also a limitation of this study was the operational definition of an injury as any core or lower extremity sprain or strain.The results of this study made many questions for further studies. For example, future studies may use measures that assess core muscles function during closed chain activities. Further, these tests may not reflect the degree to which the muscles are recruited by the athletes during athletic participation. Future studies also should add a dynamic test of lower extremity alignment during a closed kinetic chain activity such as the single leg step down test.

References

1. Federation International of Football Association (FIFA). FIFA Big Count 2006: 270 Million People Active in Football; FIFA Communications Division Information Services: Zurich, Switzerland, 2007.
2. Lohmander LS, Östenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. Arthritis Rheum 2004; 50:3145-52.
3. Söderman K, Adolphson J, Lorentzon R, Alfredson H. Injuries in adolescent female players in European football: a prospective study over one outdoor soccer season. Scand J Med Sci Sports 2001;11:299-304.
4. A Junge, K Cheung, T Edwards, J Dvorak Injuries in youth amateur soccer and rugby players—comparison of incidence and characteristics Br J Sports Med 2004;38:168–172.
5. Faude O, Junge A, Kindermann W, Dvorak J. Injuries in female soccerplayers: a prospective study in theGerman national league. Am J SportsMed 2005: 33: 1694–1700.

6. Giza E, Mithofer K, Farrell L, Zarins B, Gill T. Injuries in women's professionalsoccer. Br J Sports Med 2005: 39: 212–216.
7. Gemmell, I. M. M. Injuries among female army recruits: a conflictof legislation. *J. R. Soc. Med.* 2002; l95:23–27,.
8. Taunton J, Ryan M, Clement D, McKenzie D, Lloyd-Smith D, Zumbo B.A retrospective case-control analysis of 2002 running injuries. Br J Sports Med 2002;36:95-101
9. Liu.H, Garrett.W ,Moorman.C, Yu.B Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: A review of the literature Journal of Sport and Health Science 1 (2012) 92-101.
10. Yu B, Queen RM, Abbey AN et al. Hamstring muscle kinematics and activation during overground sprinting. J Biomech 2008; 41(15):3121–3126.
11. Bahr R, Holme I. Risk factors for sports injuries- a methodological approach. Br J Sports Med 2003;37:384–92.
12. Jeffrey Paszkewicz [1], Tristen Webb , Brian Waters , Cailee Welch McCarty , Bonnie Van Lunen The Effectiveness of Injury-Prevention Programs in Reducing the Incidence of Anterior Cruciate Ligament Sprains in Adolescent Athletes.J Sport Rehabil2012 ;21 (4), 371-377.
13. Kirkendall DT, Garrett WJ.The anterior cruciate ligament enigma.Injury mechanisms and prevention.ClinOrthopRelat Res. 2000(372):64– 8. [PubMed: 10738415].
14. 14.Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Med (Auckland, NZ) 2006; 36(3):189–198.
15. Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball: a prospective intervention study. Scand J Med Sci Sports. 1999;9:41-47
16. Knapik JJ, Bullock SH, Canada S, et al. Influence of an injury reduction program on injury and fitness outcomes among soldiers. Inj Prev. 2004;10(1):37-42.
17. Hubscher M, Zech A, Pfeifer K, Hansel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. Med Sci Sports Exerc. 2010;42:413-421.
18. Kiani A, Hellquist E, Ahlqvist K, Gedeborg R, Michaelsson K, Byberg L. Prevention of soccer-related knee injuries in teenaged girls. Arch Intern Med. 2010;170(1):43-49.
19. Sadoghi P, von Keudell A, Vavken P. Effectiveness of anterior cruciate ligament injury prevention training programs. J Bone Joint Surg Am. 2012; 94:769-776.
20. Walden M, Atroshi I, Magnusson H, Wagner P, Hagglund M. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. BMJ. 2012;344:e3042.
21. Zazulak BT, Hewett TE, Reeves NP et al. Deficits in neuromuscular control of the trunk predict knee injury risk – a prospective biomechanical-epidemiologic study. Am J Sports Med 2007; 35(7):1123–1130.
22. Hides J, Stanton W. Can motor control training lower the risk of injury for professional football players? Med Sci Sports Exerc 2014; 46(4):9. 7.
23. Hides JA, Stanton WR, Mendis MD et al. Effect of motor control training on muscle size and football games missed from injury. Med Sci Sports Exerc 2012; 44(6):1141–1149
24. Hides J, StantonW, McMahon S et al. Effect of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain. J Orthop Sports PhysTher 2008; 38(3):101–108.
25. Hides JA, Stanton WR, Wilson SJ et al.Retraining motor control of abdominal muscles among elite cricketers with low back pain. Scand J Med Sci Sports 2010; 20(6):834–842.
26. Borghuis J, Hof AL, Lemmink KAPM. The importance of sensory-motor control in providing core stability. Sports Med. 2008; 38:893-916.
27. Key J. 'The core': understanding it, and retraining its dysfunction. J Bodyw Move Ther. 2013;17:541-559.
28. Taimela S, Kankaanpaa M, Luoto S. The effect of lumbar fatigue on the ability to sense a change in lumbar position.A controlled study. Spine 1999;24:1322-7.
29. Nadler SF, Wu KD, Galski T, Feinberg JH. Low back pain in college athletes: a prospective study correlating lower extremity overuse or acquired ligamentous laxity with low back pain. Spine 1998; 23:828–833.
30. Nadler, S.F., Malanga, G.A., Bartoli, L.A., Feinberg, J.H., Prybicien, M., and Deprince, M. 2002. Hip muscle imbalance and low back pain in athletes: influence of core strengthening. Med. Sci. Sports Exerc. 34(1): 9–16.

31. Ireland ML, Willson JD, Ballantyne BT, McClay Davis I. Hip strength in females with and without patellofemoral pain. J Orthop Sports PhysTher 2003; 33(11):671–6.
32. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc.*2004; 36:926-934.
33. Jacobs CA, Uhl TL, Mattacola CG, Shapiro R, Rayens WS. Hip abductor function and lower extremity landing kinematics: sex differences. J Athl Train. 2007;42:76-83.
34. Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA. Hip abductor weakness in distance runners with iliotibial band syndrome. Clin J Sport Med 2000;10(3):169–75.
35. Cosio-Lima, LM, Reynolds, KL, Winter, C, Paolone, V, and Jones MT. Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women. J Strength Cond Res2003; 17: 721–725.
36. Stanton R, Reaburn PG, Humphries B. The effect of short-term Swiss ball training on core stability and running economy. J Strength Cond Res. 2004;18:522–8.
37. Sharrock C, Cropper J, Mostad J, et al. A pilot study of core stability and athletic performance: is there a relationship? Int. J. Sports Phys. Ther. 2011; 6:63Y74.
38. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. Arch Phys Med Rehabil. 1999; 80(8):941–944.
39. Akuthota V, Nadler SF. Core strengthening. Arch Phys Med Rehabil 2004;85(Suppl. 1):86–92.
40. Zazulak B, Cholewicki J, Reeves NP. Neuromuscular control of trunk stability: clinical implications for sports injury prevention. J Am AcadOrthop Surg. 2008;16(9):497–505.
41. Suter E, Lindsay D. Back muscle fatigability is associated with knee extensor inhibition in subjects with low back pain. Spine (Phila Pa 1976). 2001;26(16):E361–E366.
42. Nadler, S.F., Malanga, G.A., DePrince, M., Stitik, T.P., and Feinberg, J.H. 2000.The relationship between lower extremity injury, low back pain, and hip muscle strength in male and female collegiate athletes.Clin. J. Sport Med. 10(2): 89–97.
43. Hart JM, Kerrigan DC, Fritz JM, Saliba EN, Gansneder B, Ingersoll CD. Contribution of hamstring fatigue to quadriceps inhibition following lumbar extension exercise.J Sports Sci Med. 2006; 5:70-79.
44. Hammill RR, Beazell JR, Hart JM. Neuromuscular consequences of low back pain and core dysfunction. Clin Sports Med. 2008; 27:449-462.
45. Devlin L. Recurrent posterior thigh symptoms detrimental to performance in rugby union: predisposing factors. Sports Med. 2000; 29:273-287.
46. Wilkerson GB, Giles J, Seibel D. Prediction of core and lower extremity strains and sprains in college football players: a preliminary study. J Athl Train. 2012;47(3):264–272.
47. Kavcic N, Grenier S, McGill SM. Determining the stabilizing role of individual torso muscles during rehabilitation exercises. Spine. 2004;29:1254-1265.
48. Ekstrom RA, Osborn RW, Hauer PL. Surface electromyographic analysis of the low back muscles during rehabilitation exercises. J Orthop Sports PhysTher. 2008;38:736-745.
49. Teyhen DS, Rieger JL, Westrick RB, Miller AC, Molloy JM, Childs JD. Changes in deep abdominal muscle thickness during common trunk-strengthening exercises using ultrasound imaging.J Orthop Sports PhysTher. 2008;38:596-605.
50. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implication for injury and chronic low back pain. ClinBiomech. 1996;11(1):1-15.
51. Rafael F Escamilla and James R Andrews .Muscle Activation Among Supine, Prone, and Side Position Exercises With and Without a Swiss Ball Article in Sports Health A Multidisciplinary Approach · June 2016 DOI: 10.1177/1941738116653931.
52. Hewett TE, Torg JS, Boden BP. Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. Br J Sports Med. 2009; 43:417-422.
53. Vleeming A, Pool-Goudzwaard AL, Stoeckart R, van Wingerden JP, Snijders CJ. The posterior layer of the thoracolumbar fascia.Its function in load transfer from spine to legs. Spine 1995;2: 753-8.
54. Holm, S., Indahl, A., and Solomonow, M..Sensorimotor control of the spine. J. Electromyogr. Kinesiol.2002 ;12(3): 219–234.
55. Richardson CA, Snijders CJ, Hides JA, Damen L, Pas MS, Storm J. The relation between the transversusabdominis muscles, sacroiliac joint mechanics, and low back pain. Spine (Phila Pa 1976). 2002; 27(4):399–405.

56. Hungerford B, Gilleard W, Hodges P. Evidence of altered lumbopelvic muscle recruitment in the presence of sacroiliac joint pain. Spine (Phila Pa 1976). 2003;28:1593-1600.
57. Cowan SM, Schache AG, Brukner P, Bennell KL, Hodges PW, Coburn P et al. Delayed onset of transversusabdominus in longstanding groin pain. Med Sci Sports Exerc 2004; 36:2040-2045.
58. Holmich P, Uhrskou P, Ulnits L et al. Effectiveness of active physical training as treatment for long-standing adductor-related groin pain in athletes: randomised trial. Lancet.1999; 353:439-443.
59. Sherry M A, Best T M, 2004 A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. Journal of Orthopaedic and Sports Physical Therapy 34(3):116-12.

*****