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Altered Lower Limb Kinematics during Jumping among Athletes with Persistent Low Back Pain

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ABSTRACT

Background. The kinematics of a controlled functional task in female volleyball athletes may be an interesting area of study. Therefore, investigating if there are kinematic changes in a jump landing jump task among female athletes with low back pain (LBP) may help therapists and trainers better prevent and/or rehabilitate LBP in athletes. **Objectives.** The purpose of this study was to examine lumbopelvic and lower extremity kinematics in athletes with persistent LBP during a jumping task. **Methods**. A comparative cross sectional study conducted in a university research laboratory. Professional female volleyball players with (n = 20) and without (n = 18) LBP were recruited from the Iranian female volleyball league. To reduce heterogeneity, one particular subgroup of athletes with LBP were selected. Kinematic data including lumbar extension, hip flexion, rotation and adduction and knee flexion and abduction angles when the center of mass was at minimum height during a jump-landing-jump maneuver were collected using a Vicon motion analysis system and analysed using MATLAB software. Independent t-tests were used to compare mean values between the groups. **Results.** Athletes with LBP had significantly greater hip flexion (LBP: -73.62±11.06˚; Control: -62.88±7.03˚, p=0.016) and significantly less knee flexion (LBP: 77.06±7.27 ˚, Control: 81.62±4.70 ˚, p=0.029) at the lowest point of the jump than athletes without LBP. There were no other significant differences between the groups (p>0.05). **Conclusion.** A subgroup of female athletes with LBP display altered lower extremity kinematics during a jump task than athletes without LBP. This may have important implications for lower limb performance and injury.

KEY WORDS: ***Biomechanics, Low Back Pain, Knee, Hip.***

INTRODUCTION

Low back pain (LBP) is a common condition that affects 10-15% percent of athletes (1), including non-contact sports such as volleyball (2). There is little doubt that people with LBP move differently than pain-free individuals (3). These changes can vary from complete avoidance of a movement to the redistribution of activities between or within muscles (4). These changes may be observed as changes in recruitment pattern of motor units (5) and synergistic function of the muscles (6). Although these changes might arise as an attempt to prevent further injury/pain

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in the short-term, their long-term persistence may predispose people to persistent LBP due to changes in loading patterns (3). Previous studies suggest that these alterations remain even after remediation of symptoms (7). Since changes in lumbo-pelvic movement can affect the lower extremity (8), it is possible that alterations in lumbopelvic movement could negatively impact the lower extremity through changing loading patterns (9).

Several studies have shown that movement kinematics in athletes with LBP is different from those without LBP while performing athletic tasks (3). For example, specific subgroups of cyclists with persistent LBP ride their bicycle with more flexion in the lower lumbar spine (10), runners with LBP display more in-phase coordination in the frontal plane (11) and tennis players with LBP display altered kinematics while serving (12). On the other hand, several studies have reported that there are no kinematic changes in athletes with or without LBP (3), as there were no differences between the kinematics and kinetics of swing (13) as well as the crunch factor (14) in golfers with and without LBP. One explanation for these discrepancies in the present literature may be indicative of a need for classification of athletes with LBP (15), where more homogeneous subgroups of athletes with persistent LBP are studied to avoid results being affected by the 'wash-out' effect. Most studies that have investigated the kinematics of functional movements in persons with LBP do not involve athletic activities and therefore cannot be easily transferred to athletes. To our knowledge no study has investigated the kinematics of a specific task in volleyball athletes.

The jump landing jump is frequently performed in volleyball players and several injuries may happen while performing it. Previous studies demonstrated that female athletes land differently from males (16, 17) and the rate of LBP in female athletes is higher (18), such that investigating the kinematics of a controlled functional task in female volleyball athletes may be an interesting area of study. Therefore, investigating if there are kinematic changes in a jump landing jump task among female athletes with LBP may help therapists and trainers better prevent and/or rehabilitate LBP in athletes.

Purpose and Hypothesis. To compare lumbar and lower extremity kinematics during a jump-landing-jump maneuver in athletes with persistent LBP and pain-free athletes. We hypothesized that kinematics of the lumbar spine and lower extremity would be different between female volleyball athletes with and without persistent LBP.

MATERIALS AND METHODS

Subjects. This cross-sectional study included 18 to 25 year-old female athletes with or without nonspecific LBP on Tehran's volleyball teams. A total of 20 athletes with LBP and 18 athletes with no history of LBP were recruited. Inclusion for those with LBP was limited to those who met the criteria for membership of the active extension subgroup (AE-LBP). As part of this, participants underwent a standard evaluation according to the O`Sullivan classification model for patients with CLBP by two therapists who completed a three-day workshop on the O`Sullivan classification. The reliability of the O`Sullivan classification system has already been approved (19, 20). Overall inclusion criteria consisted of the following: at least three years of experience playing volleyball and at least three training sessions/week in volleyball, at least a three-month history of LBP, pain in the lumbar region increases with lumbar extension movements and decreases with lumbar flexion movements, lumbar range of motion was not being restricted due to pain or joint stiffness. People with the following conditions were excluded: history of Red Flags, Body Mass Index (BMI) ranges outside 18-25 kg/m^2, athletes with a high risk of chronicity based on the StartBack questionnaire (21), an Oswestry Disability Index score higher than 40%, a history of lumbo-pelvic surgery, spinal surgery or surgery of Anterior/Posterior Cruciate Ligaments (ACL/PCL) of the knee, any lower extremity or abdominal surgery in the last three months, pregnancy, menstruation, constant non-specific diffused pain, pain exacerbated while performing the jump-landing-jump maneuver and a pain intensity of above three on the Visual Analogue Scale (VAS) on the day of testing.

Preparation for Testing. After selecting subjects, the research methodology was introduced to subjects orally and in writing, informed consent form was obtained and demographic data were recorded. The study procedures and ethical considerations were approved by the research review board of University of Social Welfare and Rehabilitation Sciences. At the same session, participants were asked to warm up with 10 minutes of jogging and stretching exercises. Each athlete practiced the jump-landing-jump maneuver three times before the test and then the test was performed.

Tools. Pain intensity was measured using the VAS, which has established reliability and validity (22, 23). In order to evaluate disability, the Persian version of the Oswestry Disability Index questionnaire was used (24). To identify athletes at risk of chronicity, the Persian version of the STarT Back questionnaire was used (25). A Vicon 6 camera motion capture system (Vicon MX, Oxford Metrics, UK) was used to collect kinematic data.

Jump-Landing-Jump Maneuver. This test was chosen because of considerable similarities to jumping in volleyball. A 40cm high stool was placed at a distance of 15cm from the place that the athletes were asked to land there. In the jump-landing-jump maneuver, subjects were asked to stand on a stool with their legs 30cm apart so that their toes touched the edge of the stool in front, with their feet in full contact with the stool. The subjects were asked to be ready to jump and whenever they were ready, slightly jump upwards, landing on the ground. To control the pre-landing jump, a rope was adjusted to 10 percent of the subject's height above the stool plate, such that athletes were asked to jump so that their heels did not exceed this height. Once the subject landed she had to re-jump and try to touch the ceiling with her fingers (26). Subjects were asked to land after the implementation of the maneuver and not complete another jump. Each participant had a maximum of six jumps, with an interval of two minutes in between to have three proper efforts to be registered. A jump was admitted if the markers were all visible at the moment the center of mass was at the minimum height. In cases where more than 6 repetitions were needed, subjects were given a 15-minute break to avoid fatigue.

Data Recording. Before the run, according to the Plug-in-Gait marker set with minimal changes, 19 markers were attached on subjects' bony landmarks (27). Retroreflective markers were placed on bony landmarks over the skin. A sampling frequency of 200 Hz was used in this study. The data were collected using Vicon Workstation software version 4.6. The landmarks used were the 2nd metatarsal heads, lateral malleoli, calcanei lateral shanks, lateral femoral epicondyles, lateral thighs, anterior superior iliac spines, spinous processes of S2, L3, T12, C7 and the sternal notch. Motion analysis system was calibrated according to the manufacturer's instructions. Kinematic data were filtered with the help of a Butterworth fourth-order low-pass filter at a cut-off frequency of 10 Hz (28). After a test run, raw data were extracted into Excel files and then imported into a MATLAB program, where coding for data analysis was conducted by a biomechanist. The lumbar extension, hip flexion, rotation and adduction and knee flexion and abduction angles when the center of mass was at its minimum height were extracted from recorded data. The lowest height of the vertical trajectory of the S2 marker was considered as the lowest height of the center of mass. This timepoint was selected because it assumed that this is the time which these variables may be in maximum values. To calculate some anthropometric data, static data were recorded. Checking the marker trajectories were done for 'breaks' or missing information that can occur as a result of marker occlusion using Vicon Workstation software version 4.6. The breaks were infrequent and less than 20 frames in length. To interpolate these missing data, standard procedures were utilized.

Anthropometric Data. Anthropometric variables in this study included height, mass, thigh length, leg length, static lumbar posture (lordosis), hip width, lower extremity length and knee width. A stadiometer (Seca, model 213, Hamburg, Germany) was used to measure height. Mass was measured using a force plate (Kistler, Winterthur, Switzerland). In order to measure other variables, 10 added markers were attached to lower extremity bony landmarks. Thereafter, subjects were asked to stand up straight and data were recorded for 10 seconds. Additional markers were added for this purpose over the following locations: right and left medial malleoli, tibial tuberosities, mid patellas, greater trochanters and medial femoral epicondyles. These markers were removed from the skin before performing the jump-landing-jump maneuver. Static lumbar posture, leg length, pelvic width, femur length, shank length, knee width and ankle width were extracted from the static data and used as basic characteristics of subjects in analysis of the dynamic data.

Statistical Analysis. Characteristics such as age, height, mass and other variables were analyzed using both descriptive and inferential statistics in SPSS version 19. The Shapiro-Wilk test was used for evaluating the distribution of the data. Presence of LBP was considered as an independent variable, while the kinematics variables were considered the dependent variables for statistical analyzes. To compare the mean of each variable between the two groups, Independent t-tests were used. To explore reliability, Intraclass Correlation Coefficients (ICC) were used. Statistical significance was set at $\alpha<5\%$.

RESULTS

Table 1 shows the anthropometric characteristics of the subjects, with static lumbar posture being significantly more lordotic in the athletes with LBP (mean difference = 6.96º, p=0.033). All research variables had good to excellent reliability across three measurements in a single day (Table 2). Athletes with LBP displayed significantly less knee flexion (mean difference = 4.56º, p= 0.029) and significantly greater hip flexion (mean difference = 10.74º, p= 0.016) than the group without LBP at the lowest point of the jump-land-jump maneuver. There were no statistically significant differences between the other variables (Table 3).

Table 1. Demographic characteristics in LBP (20 females) and control groups (18 females)

Group	LBP	Control	p value
Variables	Mean±SD	Mean±SD	
Age (years)	21.45± 2.70	20.78± 2.42	0.426
Height (cm)	171.95±6.54	168.61±7.26	0.145
Mass (Kg)	61.80±7.78	61.86± 6.86	0.980
BMI (Kg/m^2)	21.00±2.19	21.59± 2.25	0.426
Playing history (years)	7.10±3.55	7.50±3.62	0.740
Static lumbar posture (º)	-10.51± 8.33	-3.55± 11.44	0.033*
Pain history (months)	15.28±8.85	-	-
VAS	1.42±0.79	-	-
Oswestry Disability Index	15.60±7.50	-	-
StartBack	2.67±1.72	-	-

*: **significant differences were observed.** LBP: **Low Back Pain,** SD: **Standard Deviation,** VAS: **Visual Analogue Scale,** BMI: **Body Mass Index**

Table 2. Reliability of the kinematic data (n=38)

Variables (Angles)	ICC (95%CI)	SEM	MDC
Hip Flexion	0.938(0.895-0.966)	2.25	6.24
Hip Adduction	0.910(0.846-0.950)	1.73	4.79
Hip Internal Rotation	0.888(0.808-0.938)	5.70	15.79
Knee flexion	0.836(0.719-0.909)	2.64	7.31
Knee abduction	0.949(0.912-0.972)	4.06	11.25
Lumbar Extension	0.811(0.676-0.895)	2.00	5.54

ICC: **Intra Class Correlation,** CI: **Confidence Interval,** SEM: **Standard error Measurement,** MDC: **Minimally Detectable Changes**

DISCUSSION

Lumbar posture in a static standing position was significantly more lordotic among athletes with AE-LBP. In addition, there was a significant increase in hip flexion and decrease in knee flexion at the lowest height of the jump-land-jump maneuver among athletes with AE-LBP.

Mean lordosis angle while standing in the group with AE-LBP was significantly higher than in those without LBP. It is noted that people with

LBP who are in the subgroup of AE-LBP tend to hold their spine closer to end range extension. Some studies show that there is no significant difference between the lordosis angle of patients with and without LBP (29, 30). This finding could be due to the lack of classification of the patients with LBP in these studies. Our results are consistent with Dankaerts et al. (2006) (31) who showed that when patients with LBP are generally compared with painfree subjects, significant difference are not observed between lumbar spine posture in sitting position. However, they demonstrated that when patients were classified according to the O`Sullivan approach, patients with AE-LBP demonstrated higher lumbar lordosis in the lower lumbar region (31).

Table 3. Kinematic differences between female athletes with (n=20) and without (n=18) LBP when the center of mass was at its minimal height

Variables (angle)	LBP Group Mean±SD	Control group Mean±SD	Mean differences	t	Sig	Power
Hip flexion	-73.62±11.06˚	-62.88±7.03 ˚	-10.74	-2.52	0.016*	0.690
Hip adduction	-0.82±4.90 ˚	1.83±6.43 ˚	-2.65	-1.43	0.159	0.288
Hip internal rotation	10.40±17.99 ˚	12.34±16.54 ˚	-1.94	-0.345	0.732	0.063
Knee flexion	77.06±7.27 ˚	81.62±4.70 ˚	-4.56	-2.27	0.029*	0.598
Knee abduction	6.32±19.47 ˚	7.28±16.62 ˚	-0.96	-0.159	0.874	0.053
Lumbar extension	-3.48±4.49 ˚	-4.34±4.82 ˚	0.86	0.567	0.574	0.086

***: statistically significant differences were observed**

Mean hip flexion angle in athletes with AE-LBP was significantly different to the control group, as was the mean angle of knee flexion. The between-group in lumbar lordosis and hip flexion exceed the MDC values, suggesting the difference is greater than mere measurement error. These observed differences are also consistent with other studies that demonstrate significant differences in lumbar posture between patients with and without LBP (31, 32). In contrast, the between-group difference for knee flexion angle was less than the relevant MDC, such that the clinical significance of this needs to be interpreted more cautiously.

Potential mechanism for the kinematic alterations observed. Increased angle of hip flexion and reduced angle of knee flexion can be explained by considering the interaction of these joints in the closed kinetic chain. Since the trunk, head and neck and upper extremity include more than 60% of body weight (33), their position relative to other joints can change ground reaction forces, energy absorption and the forces acting on the joints (34). In patients with AE-LBP, lordosis angle in standing and sitting positions is increased, the spinal extensor muscles are stiffened and this is accompanied by anterior pelvic tilt (35). These changes in athletes with AE-LBP may affect the function of lower extremity in dynamic tasks by increasing hip flexion angle through an increase in anterior pelvic tilt.

The decreased knee flexion may be explained by the fact that the AE-LBP subgroup primarily use their spine for force generation rather than their legs. This is relevant since research has shown that reducing knee flexion angle on landing and jumping can increase the shear forces on the ACL and increases the probability of ACL injuries (36). In athletes where landing and jumping involve shallow knee flexion, it seems that the loads exerted on the knee are absorbed for a shorter period of time and the risk of ACL injury may be increased (37). Therefore, notwithstanding the cross-sectional nature of this study, the current results suggest that athletes with LBP may be placing their knees under greater strain during landing and jumping tasks, which has potentially important implications for their risk of knee injury.

Campbell et al previously observed significant differences in lower extremity kinematics between people with and without LBP during a tennis serve. They showed that players with LBP had earlier peak right knee extension velocity during the drive phase of the tennis serves (12). Our findings, along with those of Campbell et al, indicate that motor control changes in the lumbo-pelvic region associated with LBP may be associated with motor control changes in the lower extremities.

Considering that the subjects with LBP in this study were selected from the subgroup of AE-LBP, it seems reasonable that the kinematic alterations of the lumbar spine and trunk would be most evident in activities which requires greater range of extension in spine, especially in high load activities. On the other hand, most studies showing significant differences between lumbo-pelvic kinematics in subjects with and without LBP have evaluated subjects in low load functional activities (3, 31, 38). Since the jump-landing-jump was analyzed at a moment that the lumbar spine may be in flexion, it was possible that any alterations in kinematics would not be evident. However, a key characteristic of the AE-LBP group is an inability to relax during forward bending activities. Therefore, even though there is considerable flexion mobility available, the AE-LBP athletes tend to hold themselves in a more extended posture. This finding is consistent with Dankaerts et al (2009) who showed that lumbar flexion mobility is not significantly different between subjects with AE-LBP and healthy controls during forward bending, even though the AE-LBP group reach their maximum flexion much later while bending (32). In other words, it is not that the AE-LBP group cannot flex their lumbar spine, but that they choose not to unless they are required to assume very flexed postures e.g. slump sitting, deep squatting.

Kinematics in the frontal and transverse planes were not significantly different between the two groups. According to the results of previous studies, it can be inferred that trunk motor control changes can affect lower extremity function in the frontal and transverse planes if activities require lateral or rotational movement of the trunk (39, 40). Therefore, it seems reasonable that the impairments of these planes are more evident in these movements rather than the jump-landing-jump maneuver which is a symmetrical task with loading on both extremities.

Reliability of data show that all variables have excellent to good reliability. The findings of a review article suggest that reliability of walking kinematic data for the angles of the hip flexion, knee flexion and hip adduction is good to excellent (41). The results of this study are consistent in this regard with these studies. The higher reliability of our data for knee abduction angles and hip rotation may be due to the calculation of lower extremity length, thigh length, leg length, knee width, ankle width and hip width from the static data, whereas these data are calculated in most studies only as an estimation of the ratio of body height (41).

Limitations. In this study, athletes without LBP were only compared with athletes with AE-LBP, and further comparison with other LBP populations is required. Given that various studies show that kinematics of jump-landing is different in men and women (16, 17), these results cannot be generalized to men. The analysis was limited to a single task, and a single timepoint during that task, such that how these findings relate to other tasks and other timepoints is unclear. The cross-sectional nature of the study prevents interpretation regarding any causal relationship between these findings and future injury, such that prospective studies are needed to clarify the issue. Furthermore, we acknowledge that we cannot be sure whether these changes are maladaptive, although there is some evidence to support this being the case (4, 15), such that they might need to be addressed in planning rehabilitation programs. The severity of pain and disability in subjects with AE-LBP was low, suggesting differences might be even more pronounced in more disabled populations. In future studies, using electromyographic analysis of muscle activity may enhance understanding of the mechanisms involved in the control of movement. The good to excellent reliability of kinematic variables enhance the rigor and trustworthiness of the findings.

CONCLUSION

The results of this study showed that athletes with AE-LBP perform a jump-landing-jump maneuver differently to matched pain-free athletes. In particular, the athletes with AE-LBP showed lower knee flexion angles and higher hip flexion angles during the task. Therefore, modifications to jump-landing-jump technique in rehabilitation programs may be worth considering for these athletes. However, further studies of other athletic tasks in larger samples of different groups of athletes with LBP are required to build on this initial study.

APPLICABLE REMARKS

- Mean hip flexion angle in athletes with AE-LBP was significantly different to the control group, as was the mean angle of knee flexion so it is recommended to flex knees more while jump-landing in the training sessions.
- Mean lordosis angle while standing in the group with AE-LBP was significantly higher than in those without LBP, so we recommend cognitive functional exercise therapy to realign the spine in more dynamic positions.

REFERENCES

1. Petering RC, Webb C. Treatment options for low back pain in athletes. Sports Health. 2011;3(6):550-5.
2. Briner WW, Jr., Benjamin HJ. Volleyball injuries: managing acute and overuse disorders. Phys Sportsmed. 1999;27(3):48-60.
3. Sheikhhoseini R, O'Sullivan K, Alizadeh MH, Sadeghisani M. Altered Motor Control in Athletes with Low Back Pain: a Literature Review. Annals of Applied Sport Science. 2016;4(4):43-50.
4. Hodges PW, Smeets RJ. Interaction Between Pain, Movement and Physical Activity: Short-term Benefits, Long-term Consequences, and Targets for Treatment. Clin J Pain. 2014.
5. Tucker K, Butler J, Graven-Nielsen T, Riek S, Hodges P. Motor unit recruitment strategies are altered during deep-tissue pain. J Neurosci. 2009;29(35):10820-6.
6. Hodges PW, Cholewicki J, Van Dieën JH. Spinal control : the rehabilitation of back pain : state of the art and science. Edinburgh: Elsevier; 2013. p. p.
7. Lomond KV, Henry SM, Hitt JR, DeSarno MJ, Bunn JY. Altered postural responses persist following physical therapy of general versus specific trunk exercises in people with low back pain. Man Ther. 2014.
8. Mendiguchia J, Ford KR, Quatman CE, Alentorn-Geli E, Hewett TE. Sex differences in proximal control of the knee joint. Sports Med. 2011;41(7):541-57.
9. Chuter VH, Janse de Jonge XA. Proximal and distal contributions to lower extremity injury: a review of the literature. Gait Posture. 2012;36(1):7-15.
10. Van Hoof W, Volkaerts K, O'Sullivan K, Verschueren S, Dankaerts W. Comparing lower lumbar kinematics in cyclists with low back pain (flexion pattern) versus asymptomatic controls--field study using a wireless posture monitoring system. Man Ther. 2012;17(4):312-7.
11. Seay JF, Van Emmerik RE, Hamill J. Low back pain status affects pelvis-trunk coordination and variability during walking and running. Clin Biomech (Bristol, Avon). 2011;26(6):572-8.
12. Campbell A, O'Sullivan P, Straker L, Elliott B, Reid M. Back pain in tennis players: a link with lumbar serve kinematics and range of motion. Med Sci Sports Exerc. 2014;46(2):351-7.
13. Tsai YS, Sell TC, Smoliga JM, Myers JB, Learman KE, Lephart SM. A comparison of physical characteristics and swing mechanics between golfers with and without a history of low back pain. J Orthop Sports Phys Ther. 2010;40(7):430-8.
14. Cole MH, Grimshaw PN. The crunch factor's role in golf-related low back pain. Spine J. 2014;14(5):799-807.
15. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. Man Ther. 2005;10(4):242-55.
16. Ali N, Rouhi G, Robertson G. Gender, Vertical Height and Horizontal Distance Effects on Single-Leg Landing Kinematics: Implications for Risk of non-contact ACL Injury. Journal of human kinetics. 2013;37:27-38.
17. Bruton MR, O'Dwyer N, Adams R. Sex differences in the kinematics and neuromuscular control of landing: biological, environmental and sociocultural factors. Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology. 2013;23(4):747-58.
18. Noll M, de Avelar IS, Lehnen GC, Vieira MF. Back Pain Prevalence and Its Associated Factors in Brazilian Athletes from Public High Schools: A Cross-Sectional Study. PLoS One. 2016;11(3):e0150542.
19. Dankaerts W, O'Sullivan P. The validity of O'Sullivan's classification system (CS) for a sub-group of NS-CLBP with motor control impairment (MCI): overview of a series of studies and review of the literature. Man Ther. 2011;16(1):9-14.
20. Dankaerts W, O'Sullivan PB, Straker LM, Burnett AF, Skouen JS. The inter-examiner reliability of a classification method for non-specific chronic low back pain patients with motor control impairment. Man Ther. 2006;11(1):28-39.

21. Hill JC, Dunn KM, Lewis M, Mullis R, Main CJ, Foster NE, et al. A primary care back pain screening tool: identifying patient subgroups for initial treatment. Arthritis Rheum. 2008;59(5):632-41.
22. Gaston-Johansson F. Measurement of pain: the psychometric properties of the Pain-O-Meter, a simple, inexpensive pain assessment tool that could change health care practices. J Pain Symptom Manage. 1996;12(3):172-81.
23. Bijur PE, Silver W, Gallagher EJ. Reliability of the visual analog scale for measurement of acute pain. Acad Emerg Med. 2001;8(12):1153-7.
24. Mousavi SJ, Parnianpour M, Mehdian H, Montazeri A, Mobini B. The Oswestry Disability Index, the Roland-Morris Disability Questionnaire, and the Quebec Back Pain Disability Scale: translation and validation studies of the Iranian versions. Spine (Phila Pa 1976). 2006;31(14):E454-9.
25. Abedi M, Manshadi FD, Khalkhali M, Mousavi SJ, Baghban AA, Montazeri A, et al. Translation and validation of the Persian version of the STarT Back Screening Tool in patients with nonspecific low back pain. Man Ther. 2015;20(6):850-4.
26. Ortiz A, Micheo W. Biomechanical evaluation of the athlete's knee: from basic science to clinical application. PM R. 2011;3(4):365-71.
27. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. Journal of orthopaedic research : official publication of the Orthopaedic Research Society. 1990;8(3):383-92.
28. Shultz SJ, Nguyen AD, Leonard MD, Schmitz RJ. Thigh strength and activation as predictors of knee biomechanics during a drop jump task. Med Sci Sports Exerc. 2009;41(4):857-66.
29. Nourbakhsh MR, Arab AM. Relationship between mechanical factors and incidence of low back pain. J Orthop Sports Phys Ther. 2002;32(9):447-60.
30. Nourbakhsh MR, Moussavi SJ, Salavati M. Effects of lifestyle and work-related physical activity on the degree of lumbar lordosis and chronic low back pain in a Middle East population. Journal of spinal disorders. 2001;14(4):283-92.
31. Dankaerts W, O'Sullivan P, Burnett A, Straker L. Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified. Spine (Phila Pa 1976). 2006;31(6):698-704.
32. Dankaerts W, O'Sullivan P, Burnett A, Straker L, Davey P, Gupta R. Discriminating healthy controls and two clinical subgroups of nonspecific chronic low back pain patients using trunk muscle activation and lumbosacral kinematics of postures and movements: a statistical classification model. Spine (Phila Pa 1976). 2009;34(15):1610-8.
33. de Leva P. Joint center longitudinal positions computed from a selected subset of Chandler's data. J Biomech. 1996;29(9):1231-3.
34. Devita P, Skelly WA. Effect of landing stiffness on joint kinetics and energetics in the lower extremity. Med Sci Sports Exerc. 1992;24(1):108-15.
35. Boyling JD, G J. Grieve's modern manual therapy : the vertebral column. 3rd ed. Edinburgh ; New York: Churchill Livingstone; 2005. xviii, 870 p. p.
36. Hewett TE, Myer GD, Ford KR. Prevention of anterior cruciate ligament injuries. Current women's health reports. 2001;1(3):218-24.
37. Manske RC. Postsurgical orthopedic sports rehabilitation : knee & shoulder. St. Louis, Mo.: Mosby; 2006. xviii, 714 p. p.
38. Dankaerts W, O'Sullivan P, Burnett A, Straker L. Altered patterns of superficial trunk muscle activation during sitting in nonspecific chronic low back pain patients: importance of subclassification. Spine (Phila Pa 1976). 2006;31(17):2017-23.
39. Hollman JH, Hohl JM, Kraft JL, Strauss JD, Traver KJ. Effects of hip extensor fatigue on lower extremity kinematics during a jump-landing task in women: a controlled laboratory study. Clin Biomech (Bristol, Avon). 2012;27(9):903-9.
40. 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(1):76-83.
41. McGinley JL, Baker R, Wolfe R, Morris ME. The reliability of three-dimensional kinematic gait measurements: a systematic review. Gait Posture. 2009;29(3):360-9.