The Effects of a Compression Garment on Lower Body Kinematics and Kinetics During a Drop Vertical Jump in Female Collegiate Athletes

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Background: The use of compression garments has spread rapidly among athletes, largely because of marketing and perceived benefits. Upon review, it is unclear whether compression garments have a significant effect on performance and recovery, although they have been found to enhance proprioception. Further, it is reported that compression of the knee joint improves both dynamic and static balance. However, there is currently a paucity of data demonstrating the effects of compression garments on the biomechanical risk factors of knee-related injuries in female athletes.

Purpose: To evaluate the ability of a directional compression garment to alter hip and knee kinematics and kinetics during a drop vertical jump (DVJ) in healthy college-aged female athletes.

Study Design: Controlled laboratory study.

Methods: A sample of 23 healthy female collegiate athletes (mean age, 19.6 ± 1.3 years) participating in jumping sports (volleyball, basketball, and soccer) was included in this analysis. Each athlete performed 2 sets of 3 DVJs with and without a directional compression garment. Three-dimensional hip and knee kinematics and kinetics were collected using a standard Helen-Hayes 29-marker set, which was removed and reapplied after the garment was fitted, as well as 8 visible-red cameras and 2 force platforms. Each participant was tested in a single session.

Results: Hip abduction range of motion was significantly reduced from 12.6° ± 5.5° to 10.2° ± 4.6° ($P = .002$) while performing DVJs without and with the compression garment, respectively. No statistically significant differences between conditions were found in peak hip abduction, knee valgus range of motion, peak valgus, peak hip abduction moment, and peak knee valgus moment.

Conclusion: The results of this study show that wearing compression garments does have minimal effects on lower body mechanics during landing from a DVJ, partially supporting the idea that compression garments could acutely alter movement patterns associated with the knee injury risk. However, further research should focus on muscle activation patterns and adaptations over time.

Clinical Relevance: The use of specifically designed compression garments could aid in the prevention of knee injuries by inducing changes in jumping mechanics.

Keywords: compression; kinetics; kinematics; knee; ACL; torque; force; valgus; tights; jump

Anterior cruciate ligament (ACL) injuries continue to be prevalent in collegiate athletes, particularly among female athletes, who are 3 to 6 times more likely to sustain an ACL injury than male athletes participating in such high-impact sports as soccer and basketball.[5,27] Nearly 60% of all ACL injuries occur by noncontact mechanisms.[2] Therefore, a large portion of knee injuries are related to intrinsic motor control issues and, as such, are potentially preventable through an increase in proprioception and proper movement biomechanics. The sports medicine community has been actively trying to change this trend, with new injury prevention strategies being actively and extensively studied.[4]

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Wearable modalities such as knee braces continue to improve in design and function and offer better fit and comfort. Most recently, orthotic manufacturers have released a series of functional knee braces that have been found to alter the mechanical and proprioceptive patterns that indicate structural alignment, shock absorption, and pain management.[9,12,13] Parallel to these efforts, other companies have begun developing sportswear aimed at preventing injuries. Between 2009 and 2012, the combined market for active sportswear and athletic footwear increased from US$142.13 billion to US$153.52 billion worldwide, with the United States accounting for 41% of the market.[24] Currently, both novice and professional-level athletes are using compression garments with the goals of improving athletic performance, increasing muscular endurance, and enhancing recovery. Most recently, Adidas (Powerweb), Opedix (Torque Reform Technology), Under Armour (Coreshorts), X-BIONIC, SKINS, and 2XU have produced lines of compression garments purported to increase strength, recovery, and stability, as well as to reduce chronic and overuse injuries. Despite these manufacturers' claims, the evidence in the literature to support the beneficial effects of compression garments on injury prevention remains equivocal.[10,11,14,20,23,28]

Based on findings reported in the current literature, compression garments appear to improve proprioception[16,31,33] and balance.[6,7,15,22,23,25] Given the improved proprioception, it is plausible that patients who have suffered knee injuries could benefit from wearing compression garments to maximize their rehabilitation process.[21] Furthermore, these compression garments may be of maximal benefit to patients at risk of injuries due to poor mechanics and dynamic instability. Compression-induced stimulation of the cutaneous receptors at the knee joint has been shown to increase kinesthesia.[8] This could be useful in re-creating the proper motor programs, resulting in improved movements.[4,15,16,18,24] Moreover, knowing the efficacy of these garments could aid in reducing the risk of injuries, making it important for fitness and health care professionals to fully understand the mechanisms by which the garments act.

Current published research has focused on performance and recovery,[22] with minimal inquiry into reduction of the injury risk, particularly through the alteration of biomechanical patterns of sport-specific tasks such as jumping or cutting. Chae and Kang[6] investigated compression garments and muscle activation patterns and found support for the theory that these garments are able to increase muscle activation because of an increase in cutaneous stimulation. However, they did not address changes in either joint kinematics or kinetics. Furthermore, it is unclear if compression garments have any effect on the biomechanical risk factors of an ACL injury in those predisposed to higher injury risk, such as female athletes.[18]

Therefore, the purpose of this study was to explore the effects of compression garments on lower body 3-dimensional (3D) motion, specifically investigating both kinematic and kinetic changes at the knee and hip joints during a drop vertical jump (DVJ) in female collegiate athletes. It was hypothesized that the use of compression garments would induce kinematic and kinetic changes in hip and knee motion in this particular sample when landing from a jump. We hope that the findings of this study will provide the basis for future evaluations of compression garments as tools in ACL injury prevention and rehabilitation.

METHODS

Participants

A sample of 23 National Collegiate Athletic Association (NCAA) Division II female athletes, aged 18 to 23 years (mean, 19.6 ± 1.3 years) and recruited directly from a pool of 50 competitive athletes at Point Loma Nazarene University, participated in this study. Each athlete was an active member of either the women's volleyball, basketball, or soccer team to ensure participation in sports requiring jumping, landing, and cutting tasks. The athletes were tested during their respective off-seasons to increase ease of participation. All athletes signed an informed consent form before participating in this study, which was approved by the university's institutional review board. No compensation was provided to the athletes in accordance with the eligibility requirements of the NCAA. The inclusion criteria were as follows: age ≥18 years, no current lower extremity injuries that prevented training and competing in her respective sport at the time of the study, and no risk of aggravating a current injury as assessed by the athletic training staff. Exclusion was based on an inability to complete trials, body measurements outside of the recommended range for each garment size, and injuries during any of the trials.

Compression Garments

A single model of compression garments (KNEE-Tec; Opedix) was used for this study, and the manufacturer provided all garments of various sizes to accommodate the various somatotypes of the participants (Figure 1). The compression garments featured an 18-panel construction with a lighter weight base fabric woven through the Torque Reform Technology (Opedix) designed by the manufacturer to improve dynamic knee stability.

Experimental Procedures

Participants were instructed to wear spandex shorts and a sports bra or tank top. Waist circumference measurements were taken upon arrival to select the correct garment size according to the manufacturer's specifications. Leg length was prioritized to maintain correct alignment of the knee with the garment's supporting structure. Before recording, participants were instructed on the testing procedure, and 3 to 5 jumps were performed to ensure proper performance of the testing protocol. A set of 29 passive, reflective markers (9-mm diameter) was placed on the skin surface overlying specific anatomic landmarks to estimate joint

Figure 1. The KNEE-Tec (Opedix) compression garment showing different textile materials around the knee.

locations and adjacent bone segments, following the Helen-Hayes model (Figure 2).[3]

The markers were positioned by a certified athletic trainer (J.Z.) and a senior athletic training student under the supervision of the athletic trainer. Both were trained in marker placement, and each trainer applied the markers on the same respective participant for each condition to minimize discrepancies between applications. Such locations are defined to estimate joint kinematics and kinetics based on previously reported model specifications.[3,18] During each movement, 3D global locations of the markers were captured using 8 visible-red cameras (Kestrel; Motion Analysis) at a sampling rate of 200 Hz. The motion analysis system was calibrated to reconstruct the 3D locations of marker centroids to within a 3D residual of 0.5 mm.[3] Two force platforms (AMTI) recorded ground-reaction force data at a sampling rate of 1200 Hz, integrated with Cortex software (version 6; Motion Analysis).

All the tests were performed under the supervision of the university athletic training staff. A static capture was recorded immediately after application of the markers and was used as the base template. This was followed by a walking trial in which participants were asked to walk at a normal pace for 5 m, which served to extend the marker identification template. Each participant performed a DVJ with and without the compression garment. The trial order was randomized to reduce bias. The DVJ was performed from the top of a 27 cm–tall box with the feet shoulder width

Figure 2. Helen-Hayes marker placement and starting position.

apart. Movement was initiated by stepping forward with the dominant leg and landing with each foot on a separate force plate, followed by an immediate vertical jump with maximum effort. The dominant leg was identified by asking each participant which leg she would use to kick a soccer ball. Participants were given sport-specific verbal cues such as "jump for a rebound" or "block a shot." It was assumed that the tests performed were well within the athletic abilities of the participants and that they performed them without a conscious effort to maintain perfect knee alignment and with the same effort and strength that they would use in a competition or game.

Between the control and intervention conditions, the markers below the pelvis had to be removed and repositioned. New static and walking captures were recorded to ensure the accuracy of 3D modeling with the new marker placement. The marker positions captured by the motion analysis system were digitally smoothed using a second-order Butterworth filter at a cutoff frequency of 12 Hz to reduce any kinematic errors potentially introduced by surface motion artifacts. It was determined that during the data reduction process, the marker noise bandwidth encompassed artifacts from both the control and intervention trials. Therefore, the level of systematic errors in marker data in the compression garment condition was

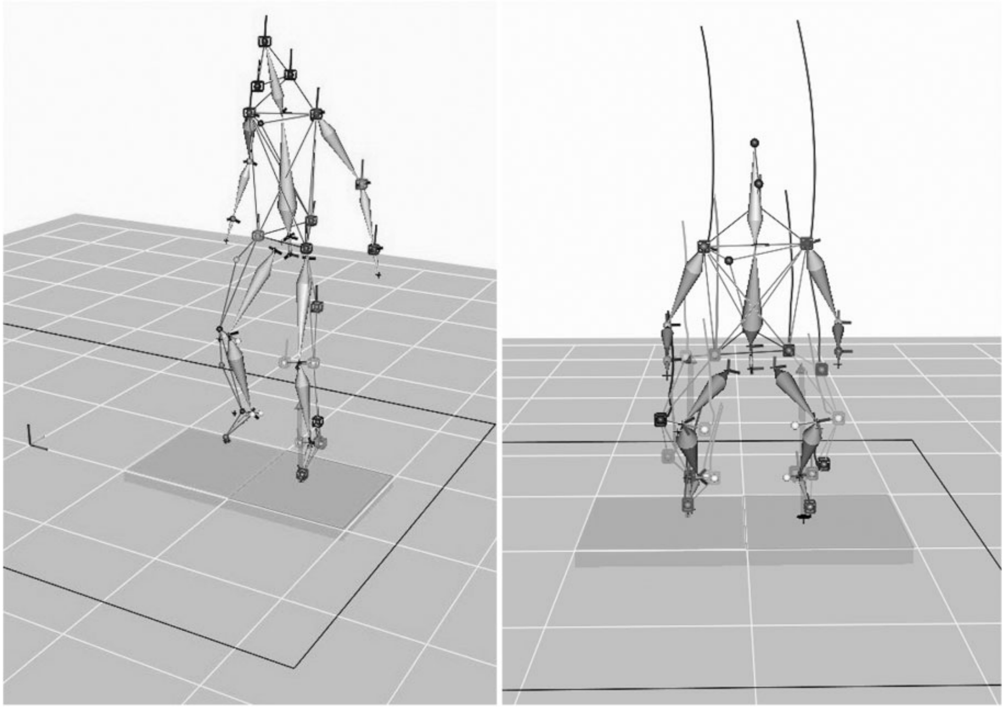

Figure 3. Screenshots displaying tracking marker motion and the ground-reaction force vector during a representative drop vertical jump, processed using Cortex software.

no more than that of the control condition. Time-series marker data of all DVJs were processed using Cortex software (Figure 3).

Statistical Analysis

Selected kinematic and kinetic parameters of hip and knee motion were estimated using standard Euler-based kinematic and inverse dynamic methods[3] built in Cortex software and extracted as dependent variables to test the hypothesis that compression garments would have an effect on them during a DVJ. These parameters were previously found to have a significant relationship with the risk of an ACL injury in female soccer players[17] and therefore were selected as the outcome measures for this study. They were extracted as the range-of-motion and peak values during the landing phase of the DVJ (Table 1).

For each participant, the kinematic and kinetic parameters were calculated per trial, consisting of 3 jumps per condition, and were averaged for analysis. Only those trial averages with less than a 10% coefficient of variation were included in subsequent analysis. The sample means and standard deviations of each parameter were calculated for each condition, and paired-sample *t* tests were used to compare the parameters with and without compression garments to determine statistical significance at a corrected alpha level of .008. All statistical analyses were performed using SPSS Statistics for Windows (version 22.0; IBM). An a priori power analysis revealed that a sample size of 34 athletes was needed to detect a significant treatment effect size of 0.5 at 80% power.

TABLE 1
Selected Kinematic and Kinetic Parameters Used as Outcome Measures to Analyze the Effect of Compression Garments During a Drop Vertical Jump

Kinematic Parameters, deg	Kinetic Parameters, N·m/kg
Hip frontal-plane range of motion	Peak hip abduction moment
Knee frontal-plane range of motion	Peak knee valgus moment
Peak hip abduction	
Peak knee valgus	

RESULTS

Table 2 lists the 6 biomechanical variables measured from the DVJ trials and compared between the control and compression garment conditions. There were no significant differences between conditions, with the exception of hip frontal-plane (adduction-abduction) range of motion, which was significantly less with the compression garment (10.2° ± 4.6°) than without (12.6° ± 5.5°) ($P = .002$). The change in peak hip abduction moment was not significantly different, with a mean of 0.51 ± 0.22 N·m/kg and 0.46 ± 0.18 N·m/kg with and without the compression garment, respectively ($P = .931$). Likewise, peak knee valgus moment was 0.60 ± 0.18 N·m/kg and 0.57 ± 0.22 N·m/kg with and without the compression garment, respectively, but this mean difference was not statistically significant ($P = .406$).

TABLE 2
Kinematic and Kinetic Parameters for a Drop Vertical Jump With and Without a Compression Garment[a]

Biomechanical Parameter	Control	Compression Garment	P
Hip frontal-plane range of motion, deg	12.6 ± 5.5	10.2 ± 4.6	.002[b]
Knee frontal-plane range of motion, deg	5.6 ± 2.1	6.9 ± 3.0	.072
Peak hip abduction, deg	3.0 ± 5.1	2.7 ± 4.4	.671
Peak knee valgus, deg	2.9 ± 2.1	2.2 ± 2.5	.320
Peak hip abduction moment, N·m/kg	0.46 ± 0.18	0.51 ± 0.22	.931
Peak knee valgus moment, N·m/kg	0.57 ± 0.22	0.60 ± 0.18	.406

[a]Values are shown as mean ± SD.
[b]Statistically significant difference ($P < .008$).

DISCUSSION

The purpose of this study was to evaluate the effects of directional compression garments on dynamic hip and knee motion with female collegiate athletes performing DVJs. It was hypothesized that specifically designed compression garments would be able to alter the biomechanical patterns known to be significantly related to a higher risk of knee injuries.[4,18] Historically, functional knee bracing has been used prophylactically to reduce or control knee joint motion.[1,13,26,31] However, the evidence reviewed in the current literature suggests that the mechanical restraints of these braces cannot effectively prevent ACL injuries because of their inability to reduce anterior tibial translation beyond the magnitude and rate of joint loading most associated with a higher risk of ACL injuries.[30] Thus, any preventive effect of functional braces and similar wearable modalities could reasonably be the result of neuromuscular responses to simply wearing the modality.

Similarly, the compression garments tested in this study exhibited no effect on external moments acting on the tibiofemoral joint. They were designed using a combination of fabrics with different elasticity and tensile strength properties in an effort to increase support at the knee joint. There are no solid parts, and therefore, they cannot physically match the stiffness of a hinged knee brace.[12] Consequently, it is believed that compression garments lack the mechanical properties to prevent acute knee injuries.

However, the reduction in hip abduction during a DVJ in the current study suggests that the possible injury prevention effect of compression garments is functional, rather than mechanical. This is consistent with the findings of Hanzlikova et al[15] and Schween et al[29] on knee bracing and elastic knee sleeves. Such kinematic changes could potentially indicate a change in the motor control strategy induced by compression garments, or at least suggest that the reported benefits of compression garments result from other physiological mechanisms, as previously shown in single-leg hopping.[14] In the female athletes tested in the current study, the hip joint showed 19% less frontal-plane motion during landing from a DVJ while wearing the compression garment when compared with no such garment. It is plausible that these changes may be the result of increased proprioceptive stimulation of the hip musculature, leading to improved movement mechanics.[19] However, whether this statistically significant change in frontal-plane hip kinematics is clinically meaningful is unclear, as previous reports on the relationships of secondary variables with the risk of ACL injuries in female athletes do not list hip abduction-adduction as a significant risk factor.[18,32]

Limitations

The combined rosters of the 3 teams amounted to over 50 female athletes, but because of injuries and the voluntary nature of the study, a sample of 23 athletes was ultimately included in this study. Therefore, the results of this study should be interpreted with caution, as the sample size was inadequate to detect a significant effect with at least 80% statistical power at the a priori significance level. In addition, only 1 specific model of compression garments was tested, and therefore, the results are limited to that particular item and are not necessarily applicable to other brands and/or models. A 3D motion analysis based on skin markers is typically adjusted through standard filtering methods to compensate for skin gliding over bony landmarks, increasing the accuracy and reliability of the biomechanical data. However, when markers are placed over a garment, it is possible to have different accessory motions over the bony landmarks. With that being said, the compression garment was fitted to the participant so that a tight fit would optimize garment function and minimize motion artifacts from the garment-attached markers, the data of which were also smoothed.

CONCLUSION

The results of this study showed a significant reduction in frontal-plane hip motion as a result of wearing compression garments in female collegiate athletes performing a DVJ. Considering the popularity of compression garments among athletes of all levels and the paucity of data to support the prophylactic claims made by garment designers, this study's findings support, in part, the idea that compression garments may aid in injury prevention and rehabilitation. However, it is not possible to clearly identify the mechanisms by which they occur. Future research on the effects of compression garments on lower body biomechanics should focus on 2 main areas: muscle activation patterns and adaptations over time. Electromyography recordings have shown an increase in muscle activation when compression is applied to a body segment,[6] and they may help identify the relationship between compression, proprioception, and movement patterns, potentially clarifying the extent of these effects. The use of electromyography has been a staple in gait analysis and is generally considered to be a reliable measure of muscle activation.[34] Furthermore, research focusing on long-term intervention, similar to studies on neuromuscular training in ACL injury prevention programs, could help clarify if compression garments have any lasting effects or if they only elicit momentary responses.

REFERENCES

1. AAOS. *Position Statement: The Use of Knee Braces*. Rosemont, Illinois: American Academy of Orthopaedic Surgeons; 1997.
2. Agel J, Rockwood T, Klossner D. Collegiate ACL injury rates across 15 sports: National Collegiate Athletic Association Injury Surveillance System data update (2004-2005 through 2012-2013). *Clin J Sport Med*. 2016;26(6):518-523.
3. Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *J Appl Biomech*. 2007;23(1):42-51.
4. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players, part 2: a review of prevention programs aimed to modify risk factors and to reduce injury rates. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(8):859-879.
5. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. *Am J Sports Med*. 1995;23(6):694-701.
6. Chae W-S, Kang N-J. Effects of wearing spandex pants on impact forces and muscle activities during drop landing. *Korean J Sport Biomech*. 2009;19(3):603-610.
7. Chuang SH, Huang MH, Chen TW, Weng MC, Liu CW, Chen CH. Effect of knee sleeve on static and dynamic balance in patients with knee osteoarthritis. *Kaohsiung J Med Sci*. 2007;23(8):405-411.
8. Collins DF, Refshauge KM, Todd G, Gandevia SC. Cutaneous receptors contribute to kinesthesia at the index finger, elbow, and knee. *J Neurophysiol*. 2005;94(3):1699-1706.
9. DJO Global. *The TriFit Web Knee Brace Fit to Remarkable Function*. Vista, California: DJO Global; 2017.
10. Doan BK, Kwon YH, Newton RU, et al. Evaluation of a lower-body compression garment. *J Sports Sci*. 2003;21(8):601-610.
11. Duffield R, Cannon J, King M. The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. *J Sci Med Sport*. 2010;13(1):136-140.
12. Ewing KA, Begg RK, Galea MP, Lee PV. Effects of prophylactic knee bracing on lower limb kinematics, kinetics, and energetics during double-leg drop landing at 2 heights. *Am J Sports Med*. 2016;44(7):1753-1761.
13. Giotis D, Zampeli F, Pappas E, Mitsionis G, Papadopoulos P, Georgoulis AD. The effect of knee braces on tibial rotation in anterior cruciate ligament-deficient knees during high-demand athletic activities. *Clin J Sport Med*. 2013;23(4):287-292.
14. Gupta A, Bryers JJ, Clothier PJ. The effect of leg compression garments on the mechanical characteristics and performance of single-leg hopping in healthy male volunteers. *BMC Sports Sci Med Rehabil*. 2015;7(1):10.
15. Hanzlikova I, Richards J, Tomsa M, et al. The effect of proprioceptive knee bracing on knee stability during three different sport related movement tasks in healthy subjects and the implications to the management of anterior cruciate ligament (ACL) injuries. *Gait Posture*. 2016;48:165-170.
16. Hassan BS, Mockett S, Doherty M. Influence of elastic bandage on knee pain, proprioception, and postural sway in subjects with knee osteoarthritis. *Ann Rheum Dis*. 2002;61(1):24-28.
17. Herrington L, Simmonds C, Hatcher J. The effect of a neoprene sleeve on knee joint position sense. *Res Sports Med*. 2005;13(1):37-46.
18. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33(4):492-501.
19. Hooper DR, Dulkis LL, Secola PJ, et al. Roles of an upper-body compression garment on athletic performances. *J Strength Cond Res*. 2015;29(9):2655-2660.
20. Kraemer WJ, Bush JA, Bauer JA, et al. Influence of compression garments on vertical jump performance in NCAA Division I volleyball players. *J Strength Cond Res*. 1996;10(3):180-183.
21. Kuster MS, Grob K, Kuster M, Wood GA, Gachter A. The benefits of wearing a compression sleeve after ACL reconstruction. *Med Sci Sports Exerc*. 1999;31(3):368-371.
22. MacRae BA, Cotter JD, Laing RM. Compression garments and exercise: garment considerations, physiology and performance. *Sports Med*. 2011;41(10):815-843.
23. MacRae BA, Laing RM, Niven BE, Cotter JD. Pressure and coverage effects of sporting compression garments on cardiovascular function, thermoregulatory function, and exercise performance. *Eur J Appl Physiol*. 2012;112(5):1783-1795.
24. Özdil N, Anand S. Recent developments in textile materials and products used for activewear and sportswear. *Electronic Journal of Vehicle Technologies*. 2014;8(3):68-83.
25. Perlau R, Frank C, Fick G. The effect of elastic bandages on human knee proprioception in the uninjured population. *Am J Sports Med*. 1995;23(2):251-255.
26. Pietrosimone BG, Grindstaff TL, Linens SW, Uczekaj E, Hertel J. A systematic review of prophylactic braces in the prevention of knee ligament injuries in collegiate football players. *J Athl Train*. 2008;43(4):409-415.
27. Prodromos CC, Han Y, Rogowski J, Joyce B, Shi K. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. *Arthroscopy*. 2007;23(12):1320-1325.e6.
28. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. *Sports Med*. 2004;34(7):465-485.
29. Schween R, Gehring D, Gollhofer A. Immediate effects of an elastic knee sleeve on frontal plane gait biomechanics in knee osteoarthritis. *PLoS One*. 2015;10(1):e0115782.
30. Smith SD, Laprade RF, Jansson KS, Aroen A, Wijdicks CA. Functional bracing of ACL injuries: current state and future directions. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(5):1131-1141.
31. Sugimoto D, LeBlanc JC, Wooley SE, Micheli LJ, Kramer DE. The effectiveness of a functional knee brace on joint-position sense in anterior cruciate ligament-reconstructed individuals. *J Sport Rehabil*. 2016;25(2):190-194.
32. Thompson JA, Tran AA, Gatewood CT, et al. Biomechanical effects of an injury prevention program in preadolescent female soccer athletes. *Am J Sports Med*. 2017;45(2):294-301.
33. Tiggelen DV, Coorevits P, Witvrouw E. The effects of a neoprene knee sleeve on subjects with a poor versus good joint position sense subjected to an isokinetic fatigue protocol. *Clin J Sport Med*. 2008;18(3):259-265.
34. Turker H, Sze H. Surface electromyography in sports and exercise. In: Turker H, ed. *Electrodiagnosis in New Frontiers of Clinical Research*. Rijeka, Croatia: Intech; 2013:175-189.