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ORIGINAL

Biomechanical Analysis of Injury Factor According to the Change of Direction After Single-leg Landing

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Objective: The purpose of this study was to understand the injury mechanism and to provide quantitative data to use in prevention or posture correction training by conducting kinematic and kinetic analyses of risk factors of lower extremity joint injury depending on the change of direction at different angles after a landing motion.

Method: This study included 11 men in their twenties (age: 24.6 ± 1.7 years, height: 176.6 ± 4.4 cm, weight: 71.3 ± 8.0 kg) who were right-leg dominant. By using seven infrared cameras (Oqus 300, Qualisys, Sweden), one force platform (AMTI, USA), and an accelerometer (Noraxon, USA), single-leg drop landing was performed at a height of 30 cm. The joint range of motion (ROM) of the lower extremity, peak joint moment, peak joint power, peak vertical ground reaction force (GRF), and peak vertical acceleration were measured. For statistical analysis, one-way repeated-measures analysis of variance was conducted at a significance level of $\alpha < .05$.

Results: Ankle and knee joint ROM in the sagittal plane significantly differed, respectively (F = 3.145, p = .024; F = 14.183, p = .000), depending on the change of direction. However, no significant differences were observed in the ROM of ankle and knee joint in the transverse plane. Significant differences in peak joint moment were also observed but no statistically significant differences were found in negative joint power between the conditions. Peak vertical GRF was high in landing (LAD) and after landing, left 45° cutting (LLC), with a significant difference (F = 9.363, p = .000). The peak vertical acceleration was relatively high in LAD and LLC compared with other conditions, but the difference was not significant.

Conclusion: We conclude that moving in the left direction may expose athletes to greater injury risk in terms of joint kinetics than moving in the right direction. However, further investigation of joint injury mechanisms in sports would be required to confirm these findings.

Keywords: Single-leg landing, Change of direction, Lower extremity injury, Range of motion, Joint moment, Joint power

INTRODUCTION

Sports injuries occur frequently during various sports competitions, and many studies have been conducted to improve athletic performance and prevent injuries (Mcnitt-Gray, 1989). Lower extremity joint injuries occur in approximately 77% of cases, with knee (21%) and ankle (18%) joint injuries accounting for significant portions of such injuries (Tropp, Askling & Gillquist, 1985). With respect to injury type, approximately 50% and 13% of all knee injuries involved the anterior cruciate ligament (ACL) and medial collateral ligament (MCL), respectively (Majewski, Susanneet & Klaus, 2006). Among the injury types, ACL injuries account for approximately 70% of non-contact injuries during actual physical activities (Meyer & Haut, 2008). Ankle injuries occur at a frequency of 50% for sprains, 17% for spasms, 12% for bruises, and 5% for fractures (Hang, 2013). Among athletes who incurred ankle sprains, >70% experienced additional and repetitive symptoms of dysfunction and re-injury (Anandacoomarasamy & Barnsley, 2005). Knee ligament injuries and ankle sprains occur during sports competitions and trainings (Hootman, Dick & Agel, 2007).

Various reports have indicated that the causes of injuries include decreased range of motion (ROM) of the lower extremity joints and large impact force (Chae & Kang, 2009; Kim, Oh & Jeong, 2015; Yeow, Lee & Goh, 2011) and large valgus angle (Cho, Kim, Moon, Cho & Lee, 2010; Shin, Choi & Kim, 2015). Meanwhile, a study that compared between normal and perceived landing reported that the flexion angle of the knee was larger in perceived landing than in normal landing (Choi, 2015; Schmitz, Kulas, Perrin, Riemann & Shultz, 2007; Sigward, Pollard & Powers, 2012). Moreover, a study on landing that simulated actual sports motion reported that injuries may appear from the impact load in the lower extremity joints during landing from jumping (Kim & Cho, 2012). The cause of such injury was attributed to lower extremity joint injury from insufficient impact absorption during landing and increased amount of impact causing increase in musculoskeletal injury rate (Hewett, Myer & Ford, 2004; Yeow et al., 2011).

Moreover, during landing motion, lower extremity joint injuries occur more frequently in single-leg landing than in double-leg landing. As single-leg landing involves a motion that generates greater movement in the knee in a shorter time than double-leg landing, it represents a motion that exhibits a large amount of asymmetric movement (Taylor, Ford, Nguyen & Shultz, 2016). A review of studies on single-leg landing motion showed that during initial contact with the ground, injuries were caused as the front foot area touched down on the ground and that not only landing but also sudden change of direction often causes ankle sprains and jumper's knee injuries (Boden, Dean Feagin & Garrett, 2000; Gehring, Melnyk & Gollhofer, 2009). In studies on change-of-direction motions, the injury mechanism largely depended on whether the change of direction was anticipated or not (Houck, Duncan & Haven, 2006, 2007), and injury mechanism occurred largely according to differences in angles of directional changes (Lee, 1998; Kwon, Jung, Park, Kwon & Shin, 2007).

However, in addition to the change of direction mentioned in precedent studies, athletes face situations during actual sports competition that require various directional changes during landing, and the risk of lower extremity joint injury is believed to increase during landing. Moreover, such biomechanical studies presented knee and ankle injury mechanisms by calculating angles and moments of lower extremity joints. However, these analyses did not have diverse direction of movement, changed the height of the drop box, involved both legs, and analyzed change of direction after double leg landing, whereas studies that analyzed the motion of single-leg landing from a drop box are still lacking.

Accordingly, the present study used joint ROM, moment, and power, along with ground reaction force (GRF) and acceleration to analyze and identify lower extremity joint injury mechanisms during single-leg landing motion while perceiving the direction of movement after landing. Furthermore, insight into the risk factors associated with changing directions in various angles was gained for the objective of providing quantitative data on lower extremity joint injuries that can be used in rehabilitation and proper training.

METHODS

1. Participants

The study participants consisted of 11 right-leg-dominant male adults (age: 24.6 ± 1.7 years, height: 176.6 ± 4.4 cm, weight: 71.3 ± 8.0 kg) selected from among college students who were majoring in physical education-related courses at K University in Seoul.

The study was conducted with participants who understood the study objectives and consented to participate in the study. The participation was limited to those who did not have any history of musculoskeletal surgery or injury in the lower extremity in the past 6 months or any diseases in the lower extremity joints diagnosed at the time of the study. The study was conducted with the approval from the institutional review board (IRB) of the relevant institution (KNSU Industry-Academic Cooperation Foundation-1000, 20160805).

2. Measurements

With respect to motion analysis equipment, seven infrared cameras (Oqus 300, Qualisys, Sweden) were set up at a sampling rate of 200 Hz. One force platform (BP12001200, AMTI, USA) with a sampling rate of 2,000 Hz was used to measure ground impact, while an accelerometer (DTS accelerometer 400 g, Noraxon, USA) with a sampling rate set of 500 Hz, which would send signals by a wireless transmitter, was attached to the tibia for investigation of impact mechanism. The directions of the three-dimensional (3-D) spatial coordinates and GRF were established as left (-) and right (+) for the X axis, front (+) and back (-) for the Y axis, and vertical (+) for the Z axis (Figure 1). The Qualisys Track Manager (QTM) program (Qualisys, Sweden) were used to acquire the position data from the reflective markers attached to each joint point and ground reaction force (GRF), while Matlab R2014a (MathWorks, USA) and Visual3D (C-Motion, USA) were used for data analyses. To eliminate the noise generated while acquiring motion data, smoothing was performed by using a Butterworth second-order low-pass filter, cutoff frequencies for the 3-D coordinate and force platform were set to 12 Hz (Ford, Myer & Hewett, 2007) and 100 Hz (Sell et al., 2007), respectively.

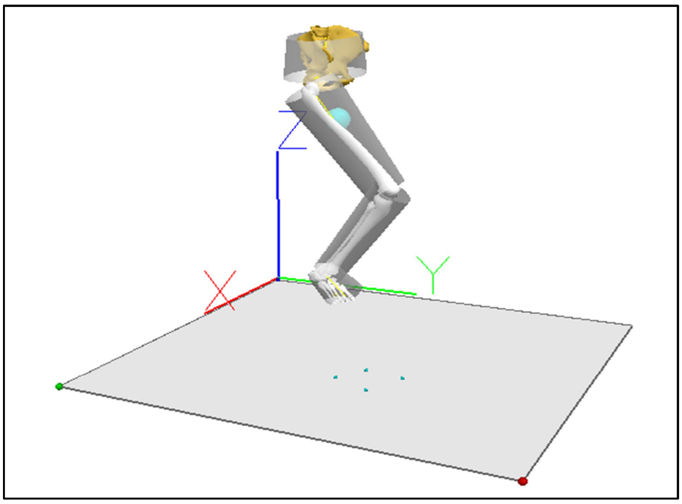

Figure 1. Coordinate system

3. Data processing

In the present study, none of the participants performed high-intensity physical activities that can cause fatigue prior to the start of the experiment. The experiment was conducted after receiving a written consent from participants who fully understood the objective and procedures of the study prior to the experiment.

First, the participants' physical characteristics (age, height, and weight) was collected, and the participants performed 10 min of warm-up exercise for safety during the experimental procedures. Then, the participants wore tights bottom and wore their own shoes. After which, 15 spherical reflective markers on the right lower extremity joints and two marker clusters, one marker each on the thigh and lower leg, were attached to the participants (Figure 2). In addition, an accelerometer was attached to the tibia for investigation of the impact mechanism.

To control the height, a drop box (50 × 40 × 30 cm) was set up 30 cm in an anterior direction from the force platform. Prior to data collection the participants were given prior information on the direction of movement to allow them to perceive the direction of movement in advance, with the direction of movement selected randomly.

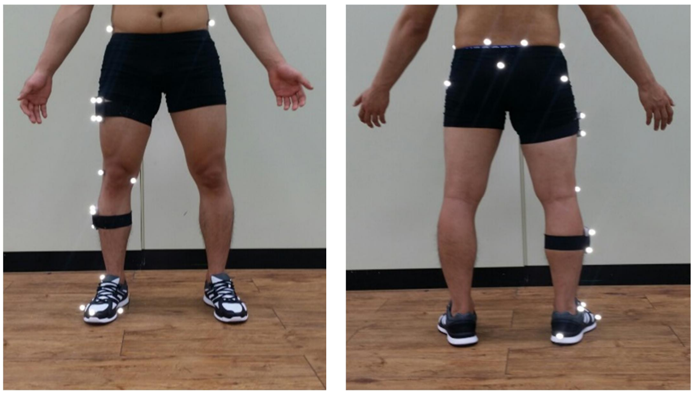

Figure 2. Maker set and accelerometer location

To prevent any impact force from being applied during landing, the participants were instructed to perform a single-leg landing by shifting the center of gravity with the left leg extended, only moving the right leg forward. To enable the participants to perform the motion without any difficulties, they were allowed to practice enough trials before performing the experimental motion. The motion was performed with both arms crossed and both hands placed under the armpits. Any of the following cases during the experimental motion was considered a failed motion: the foot touched down outside the force platform during landing; mid- or rear-foot landing occurred; the arms moved; and the participant fell from not being able to maintain balance during landing. To analyze the most natural motion, motion was performed 10 trials in each direction (Figure 3).

The directions of movement after single-leg landing were defined according to 5 types as follows: landing in place (landing [LAD]), moving the left leg in the right-hand direction by 45° (after landing, right 45° cutting [LRC]), moving the right leg in the right-hand direction by 45° (after landing, right 45° direct [LRD]), moving forward after landing (after landing, forward step [LFS]), and moving the right leg in the left-hand direction by 45° (after landing, left 45° cutting [LLC]). These motions were executed as a continuous motion (Figure 4). For event analysis intervals, events 1, 2, and 3 were set to the moment of touching down on the ground, the moment of peak vertical GRF, and the maximum right-knee flexion angle, respectively.

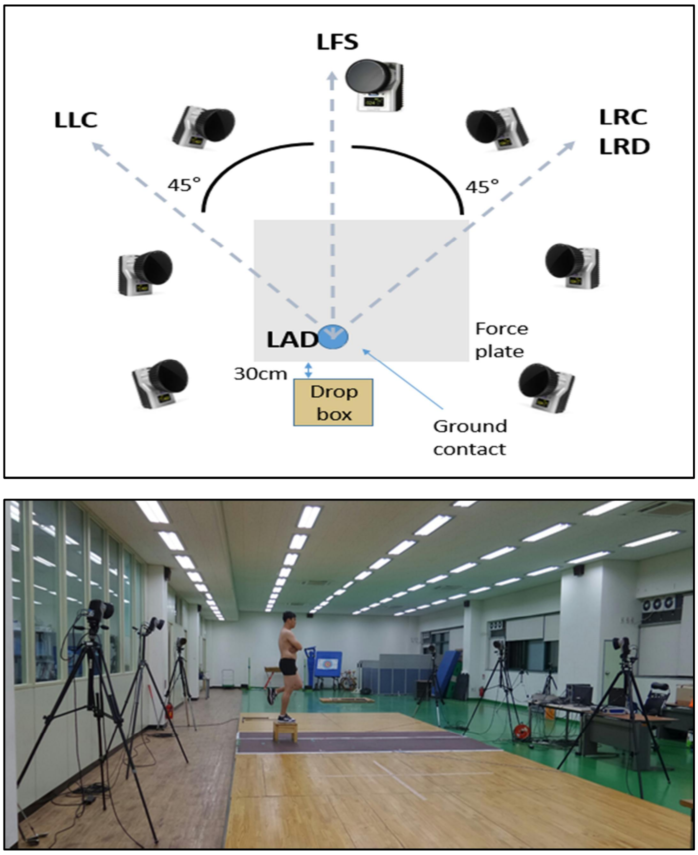

Figure 3. Experimental setup

4. Statistical analysis

For the statistical analysis in the present study, one-way repeated-measures analysis of variance was performed on each variable by using SPSS 21.0 (IBM, USA), with the significance level set at α = .05. If significant effect differences appeared, a post hoc test was performed using Bonferroni corrections.

RESULTS

1. Peak GRF and Acceleration

The analysis of peak vertical GRF and peak vertical acceleration of the lower extremity joints according to the direction of movement showed that the highest peak vertical GRF values (4.17 ± 0.99 and 4.10 ± 0.53 %BW, respectively) were found in movements in the LAD and LLC directions (F = 9.363, p = .000). Moreover, the highest peak vertical acceleration values (26.93 ± 9.34 and 26.35 ± 8.27 g, respectively) were found in movements in the LAD and LLC directions. Although significant differences were found in peak vertical GRF (F = 9.363 p = .000), significant differences in peak vertical acceleration were not found (Table 1).

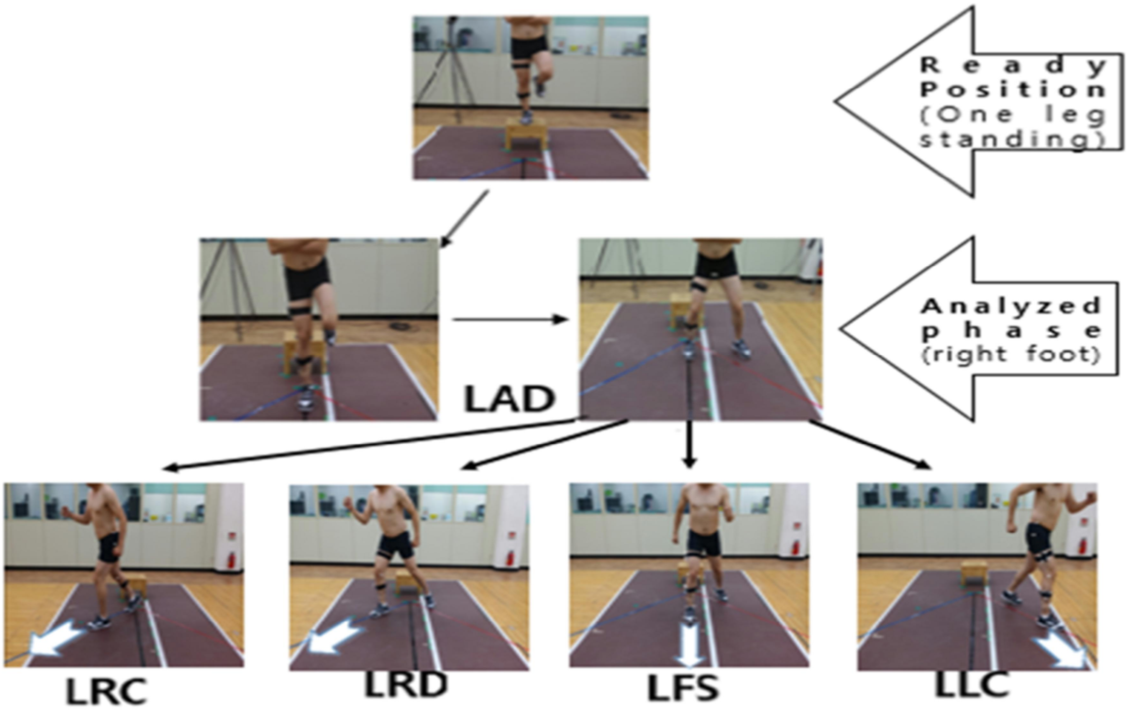

Figure 4. **LAD** - Landing, **LRC** - after landing, right 45° cutting, **LRD** - after landing, right 45° direction, **LFS** - after landing, forward step, **LLC** - after landing, left 45° cutting

Table 1. Results for GRF and acceleration variables

	LAD Mean (SD)	LRC Mean (SD)	LRD Mean (SD)	LFS Mean (SD)	LLC Mean (SD)	*F* (*p*)	Post hoc	ES (η^2)	Power
GRF peak (%BW)									
Peak vertical	4.17 (0.99)	3.35 (1.11)	3.37 (0.99)	3.98 (0.61)	4.10 (0.53)	9.363 **(.000)***	LRD < LAD LRD < LLC	.48	.99
Acceleration (g)									
Peak vertical	26.93 (9.34)	23.29 (9.82)	24.16 (10.31)	23.75 (8.19)	26.35 (8.27)	2.113 (.143)		.17	.40

LAD - landing, **LRC** - after landing, right 45° cutting, **LRD** - after landing, right 45° direction, **LFS** - after landing, forward step, **LLC** - after landing, left 45° cutting. *$p < .05$

2. Peak joint power

The analysis of peak joint power of the lower extremity joints according to the direction of movement showed that in the ankle joint, the lowest and highest minimum values (-34.83 ± 11.69 and 23.02 ± 10.39 W/kg, respectively) were found in movements in the LLC and LFS directions (F = 1.179, p = .335). In the knee joint, the lowest and highest minimum values (-18.39 ± 14.39 and -6.97 ± 16.93 W/kg, respectively) were found in movements in the LAD and LFS directions (F = 1.373, p = .261). In both joints, significant differences were not found (Table 2).

3. Peak joint moment

The analysis of peak joint moment in the lower extremity joints according to the direction of movement showed that the largest and smallest ankle inversion moments during landing (1.47 ± .64 and 0.99 ± 0.64 Nm/kg, respectively) were found in movements in the LLC and LFS directions (F = 4.298, p = .006). With respect to knee valgus moment, movements in the LAD and LLC directions showed the highest and lowest values of -2.05 ± 1.02 and -1.61 ± 1.05 Nm/kg, respectively (F = 5.700, p = .006). Moreover, with respect to ankle abduction moment, movements in the LLC and LRC directions showed the highest and lowest values of -0.80 ± 0.27 and -0.58 ± 0.30 Nm/kg, respectively (F = .600, p = .665). For knee external rotation moment, movements in the LLC and LRC directions showed the highest and

Table 2. Results for the joint power variables (unit: W/kg)

Peak joint power	LAD Mean (SD)	LRC Mean (SD)	LRD Mean (SD)	LFS Mean (SD)	LLC Mean (SD)	*F* (*p*)	Post hoc	ES (η^2)	Power
[Sagittal plane]									
Ankle	-32.03 (10.68)	-26.01 (10.00)	-23.33 (10.78)	-23.02 (10.39)	-34.83 (11.69)	1.179 (.335)		.10	.34
Knee	-18.39 (14.30)	-10.27 (14.48)	-9.17 (15.19)	-6.97 (16.93)	-15.59 (17.39)	1.373 (.261)		.29	.39

LAD - landing, **LRC** - after landing, right 45° cutting, **LRD** - after landing, right 45° direction, **LFS** - after landing, forward step, **LLC** - after landing, left 45° cutting. *p < .05

Table 3. Results for the joint moment variables (unit: Nm/kg)

Peak moment	LAD Mean (SD)	LRC Mean (SD)	LRD Mean (SD)	LFS Mean (SD)	LLC Mean (SD)	*F* (*p*)	Post hoc	ES (η^2)	Power
[Frontal plane]									
Ankle (inversion)	1.23 (0.61)	1.15 (0.60)	1.19 (0.55)	.99 (0.64)	1.47 (0.64)	4.298 **(.006)***	LRC < LLC LRD < LLC LFS < LLC	.30	.88
Knee (valgus)	-2.05 (1.02)	-1.96 (1.04)	-1.82 (1.03)	-1.79 (1.15)	-1.61 (1.05)	5.700 **(.006)***	LLC < LAD LLC < LRC LLC < LFS	.36	.88
[Transverse plane]									
Ankle (abduction)	-0.66 (.28)	-0.58 (0.30)	-0.66 (.33)	-0.70 (0.34)	-0.80 (0.27)	.600 (.665)	LRC < LFS	.06	.18
Knee (external rotation)	-0.68 (0.28)	-.59 (0.30)	-0.67 (0.33)	-.69 (0.37)	-0.71 (0.27)	4.980 **(.014)***	LRC < LFS.	.33	.781

LAD - landing, **LRC** - after landing, right 45° cutting, **LRD** - after landing, right 45° direction, **LFS** - after landing, forward step, **LLC** - after landing, left 45° cutting. *p < .05

lowest values of 0.71 ± 0.27 and -0.59 ± 0.30 Nm/kg, respectively (F = 4.980, p = .014). In the transverse plane, significant differences were found in all the variables, except the ankle joint (Table 3).

4. Joint ROM

The analysis of ROM of the lower extremity joints according to the direction of movement showed that in the ankle ROM in the sagittal plane during landing, the highest and lowest ROM (56.59° ± 6.75° and 49.77° ± 7.16°, respectively) were found in movements in the LFS and LAD directions (F = 3.145, p = .024). In the knee joint, the highest and lowest flexion-extension ROM (75.63° ± 18.74° and 50.36° ± 5.67°, respectively) were found in movements in the LRD and LLC directions (F = 14.183, p = .000). In the transverse plane, the highest and lowest ankle ROM (22.06° ± 10.82° and 14.31° ± 5.95°, respectively) were found in movements in the LRC and LLC directions (F = 6.276, p = .068). The highest and lowest knee ROM (25.07° ± 3.00° and 21.87° ± 3.82°, respectively) were found in movements in the LRC direction (F = 1.675, p = .175). In the transverse plane, no significant differences were found in all the variables, except the knee joint (Table 4).

DISCUSSION

The present study analyzed the kinematic characteristics related to injury factors in the lower extremity joints by using peak vertical GRF, peak vertical acceleration, peak joint power, peak joint moment, and ROM of the lower extremity joints to investigate the injury factors in the lower extremity joints according to the change in direction after single-leg landing.

First, with respect to the impact power at the point of the foot touching the ground, investigation of the peak vertical GRF value for each change in direction during single-leg drop revealed that LAD and LLC directions showed the highest values, with 4.17 ± 0.99 and 4.10 ± 0.53 %BW, respectively, with LAD and LLC showing significant differences. In a study by Cowley, Ford, Myer, Kernozek, and Hewett (2006), these peak GRF values were similar during unexpected cutting motion by basketball and soccer players. Moreover, a study by Kellis and Kouvelioti (2009) showed a peak GRF value during single-leg landing

Table 4. Results for joint ROM variables (unit: degrees)

Joint ROM	LAD Mean (SD)	LRC Mean (SD)	LRD Mean (SD)	LFS Mean (SD)	LLC Mean (SD)	*F* (*p*)	Post hoc	ES (η^2)	Power
[Sagittal plane]									
Ankle (dorsiflexion)	49.77 (7.16)	50.12 (14.13)	56.51 (6.74)	56.59 (6.75)	51.13 (6.38)	3.145 **(.024)***	LAD < LRC, LAD < LRD LRD < LFS, LAD< LFS LLC < LFS	.24	.77
Knee (flexion)	62.05 (11.84)	71.59 (15.49)	75.63 (18.74)	59.76 (16.49)	50.36 (5.67)	14.183 **(.000)***	LAD < LRD, LLC < LAD LLC < LRC, LFS < LRD	.59	1.00
[Transverse plane]									
Ankle (adduction)	18.29 (8.79)	22.06 (10.82)	20.45 (12.36)	19.63 (8.45)	14.31 (5.95)	6.276 (.068)		.39	.98
Knee (internal rotation)	23.08 (5.12)	25.07 (3.00)	23.47 (4.46)	22.47 (5.85)	21.87 (3.82)	1.675 (.175)	LLC < LRC	.14	.47

LAD - landing, **LRC** - after landing, right 45° cutting, **LRD** - after landing, right 45° direct, **LFS** - after landing, forward step, **LLC** - after landing, left 45° cutting. $^*p < .05$

of 4.19 ± 0.40 %BW, which was similar to those in movements in the LAD and LLC directions in the present study. Meanwhile, peak vertical acceleration values were higher in movements in the LAD (26.93 ± 9.34 g) and LLC directions (26.35 ± 8.27 g) than in other directions, which were similar to the peak GRF and peak acceleration values during landing in a study by Tran, Netto, Aisbett and Gastin (2010). Yeh et al. (2013) reported that large impact during landing increased the risk of ankle sprain or knee ACL injury. Thus, large impact being delivered to the lower extremities during landing was found in LAD and LLC, which may cause ligament and joint injuries by transfer to the body.

Investigation of peak joint power in the lower extremity joints based on change in direction after landing showed values of -32.03 ± 10.68 and -18.39 ± 14.30 W/kg for the ankle and knee in LAD, respectively. Moreover, in LLC, the values were -34.83 ± 11.69 and -15.59 ± 17.39 W/kg for the ankle and knee, respectively. In both the ankle and knee joints, significant differences were not found. A study by Kim and Cho (2012) on impact absorption by body segments according to changes in height during drop landing showed similar results, while reporting that increased negative joint power can be viewed as impact absorption capability (Kwon, 2012; Zhang, Bates & Dufek, 2000). Increased negative joint power in the present study predicted the magnitude of impact force in the ankle and knee joints. Impact load is transferred from the ankles to the knees, and increased negative knee joint power is believed to act as a protective mechanism for lowering the risk of ACL injury by absorbing the energy from impact to the knees through eccentric contraction.

With respect to peak moment in the lower extremity joints, ankle inversion moment in LLC showed the highest value of 1.47 ± 0.64 Nm/kg and knee valgus moment showed the lowest value of -1.61 ± 1.05 Nm/kg. Moreover, knee valgus moment showed the highest value in LAD, which was similar to the knee valgus moment reported in a study on injuries during single leg drop conducted by Shimokochi, Ambegaonkar, Meyer, Lee and Shultz (2013). Relatively higher values were seen in the ankle abduction moment (-0.80 ± 0.27 Nm/kg) and knee external rotation moment (-0.71 ± 0.27 Nm/kg) in LLC than in the other conditions. Furthermore, more-significant differences in joint moments were found in the knee joint than in the ankle joint. With respect to knee moments, internal rotation moment has been reported to possibly act as a cause of injury (Meyer & Haut, 2008), but the combined load of exerting external rotation while valgus moment is in effect may also increase the risk of injury (Shimokochi & Shultz, 2008; Shin, Chaudhari & Andriacchi, 2011). Moreover, Kirkendall and Garrett (2000) reported that injuries can be prevented by understanding the role of the inversion moment in the ankles and valgus, and the internal moment and internal rotation in the knee. In the present study, ankle inversion and knee external rotation moments in LLC movement showed a higher risk of anterior talofibular ligament (ATFL) injury than movement in other directions. As LAD had the highest valgus moment, it represented the biggest risk of knee ACL injury.

In the comparison of changes in direction during landing, ankle flexion extension ROM showed the lowest value of 49.77° ± 7.16° in LAD (F = 3.145, p = .024), which was similar to the ankle ROM found in landing with weighted load in a study conducted by Nordin and Dufek (2016) and to 46.56° ± 6.08° found in a study by Kim and Cho (2012) on ankle ROM during single-leg landing according to cutting directions. Moreover, a study by Myer et al. (2015) that compared between single- and double-leg landings also showed a similar pattern of ROM during single-leg landing. Among ankle ROM in executing various movements, all other movements showed higher ankle ROM than LAD, which was because LAD motion involved standing in place without changing directions after landing while perceiving the direction of movement. Thus, impact from GRF, one of the injury mechanisms in the lower extremities, may have been absorbed by ankle flexion extension. In knee flexion extension ROM, the highest and lowest values were found in LRD (75.63° ± 18.74°) and LLC directions (50.36° ± 5.67°), respectively. According to McNair, Marshall and Matheson

(1990), ACL injuries occur more often when the knee is extended by about 20° than when it is fully extended. Yeow, Lee and Goh (2009) reported that a large flexion motion is made in the knees to absorb the impact in each joint. In the present study, the highest value was seen in LRD, representing a large impact absorption, which may have appeared so high for absorbing impact delivered to the body. Therefore, ROM showed a high value to reflect rapid transition to the perceived direction.

With respect to the injury mechanism in the lower extremity joints, ATFL injuries occurred frequently from repeated landing under the condition of ankle plantar flexion and inversion (Safran, Benedettl, Bartolozzi & Mandelbaum, 1999). In the knees, ACL injuries often occurred from hyperextension and valgus of the knees while the feet were firmly planted on the ground, and posterior translational motion and axial rotation of the femur while the tibia was fixed (Neumann, 2010).

In the present study, the peak GRF and peak vertical accelerometer values during landing appeared in LAD and LLC, respectively, which is expected to receive the most impact. Owing to peak joint power, LAD and LLC absorbed more of the impact load on the ankle and knee during landing than LRC and LRD. In the comparison of ROM, LLC showed a lower value than LRC, while LLC showed a lower peak joint moment, which was similar to a study that reported that with respect to peak moment, decrease in knee flexion angle also decreased knee valgus (Lepers, Hausswirth, Mailetti, Briswalter & Hoecke, 2000). Therefore, when changing direction during landing after perceiving the direction of movement, moving to the left is more prone to injury risk than moving to the right. Moreover, LAD movement, which involves no movement after landing while perceiving the direction of movement, poses greater injury risk than other movements.

CONCLUSION

The present study analyzed biomechanical characteristics of lower extremity joints according to changes in direction during single-leg landing in 11 male participants in their twenties. The study also investigated injury mechanism with peak vertical GRF value, peak vertical accelerometer value, peak joint power, joint moment, and ROM.

The highest peak vertical GRF and peak vertical acceleration values were found in LAD. In joint power, the results showed that impact absorption was highest in LAD and LLC, but the differences were not statistically significant. Ankle joint inversion moment was high in LAD and LLC, while knee valgus moment was high in LLC. The biggest difference in ROM was found between LRD and LLC. It is suspected that moving to the left after landing on the right leg is more prone to injury than moving to the right. Moreover, LAD also receives a significant amount of impact, making it prone to injury risk.

Future studies on muscle movement according to the direction of movement during single-leg landing should use the analysis of electromyography (EMG) and muscle strength in order to understand contribution by lower extremity muscles on impact absorption, and studies on non-dominant leg are also warranted.

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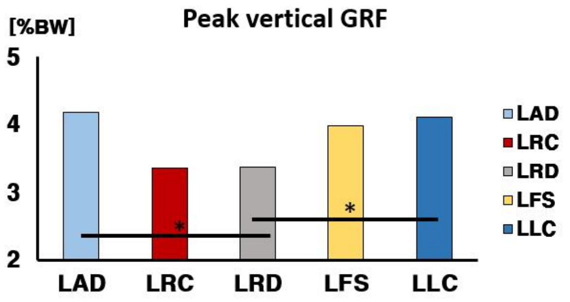
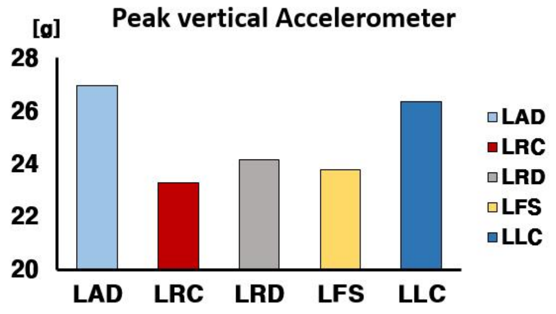
Appendix

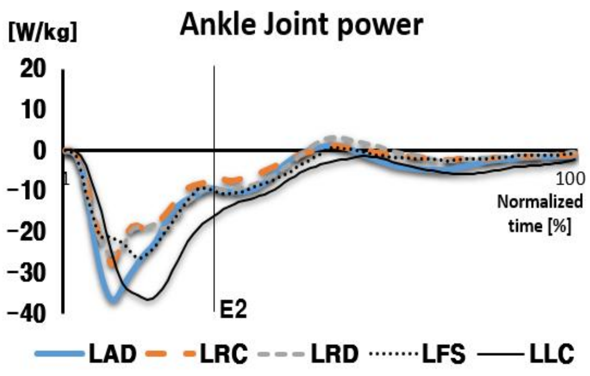
Ankle	Knee

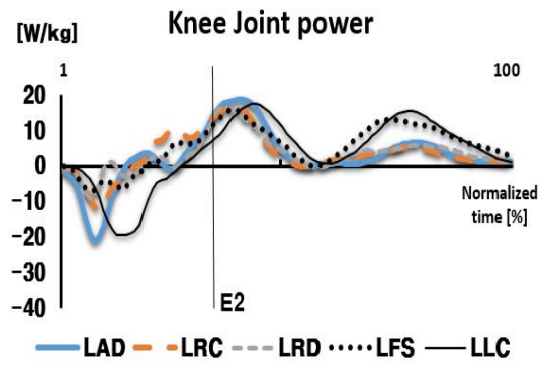




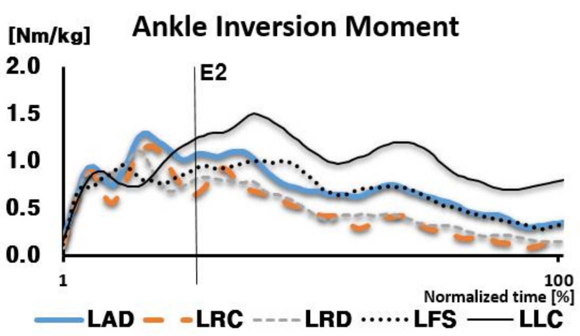
GRF Peak Vertical

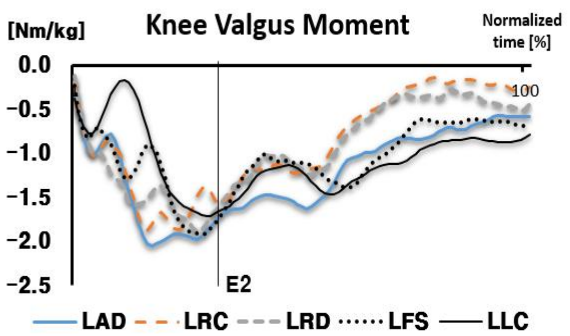
Accelermeter Peak Vertical



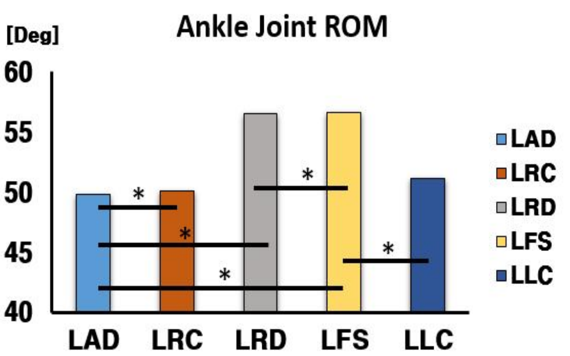


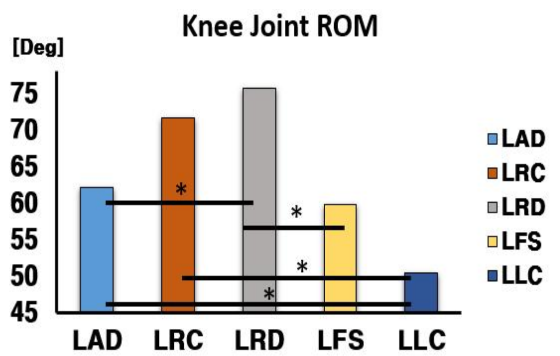
Joint Power [sagittal plane]





Joint Moment [frontal plane]





Joint ROM [sagittal plane]