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Impact Differences among the Landing Phases of a Drop Vertical Jump in Soccer Players

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Abstract

The aim of this study was to examine the differences of landing phase biomechanics between the players who had anterior cruciate ligament (ACL) reconstruction and healthy participants during single leg drop vertical jump. In this study, 11 soccer players who had anterior cruciate ligament reconstruction (aged 23.0±3.6 years, height 177±5.0 cm, weight 83.8±11.7 kg) and 9 healthy soccer players(aged 22.2±2.4 years, height 178±3.0 cm, weight 74.3±6.1 kg) participated voluntarily. During the data collection phase three high speed cameras synchronized to each other and force plate were used. Visual analysis programme and MATLAB were used to calculate kinetic and kinematic variables. Landing techniques of the subjects' were examined by flexion angle of knee, ground reaction force and moment parameters. The statistical analyses of the measured results were performed by t-test and Pearson Correlation analysis. According to the results, it was determined that peak vertical ground reaction force exhibited significant phase differences (p=0.00, and p=0.00, respectively) between the groups. Obtained results can be explained with "quadriceps avoidance" motion pattern which is characterized by decreased quadriceps activity and lower external knee flexion moment in an effort to control anterior translation of the tibia in subjects with ACL reconstruction. A better understanding of the different phases during single-leg landings can shed a light on mechanism of non-contact anterior crucaite ligament injuries therefore future researches should assess how phase differences affect drop vertical jump performance.

Key words: *anterior cruciate ligament-ground reaction force-flexion angle-drop jump*

Introduction

In recent years, technological developments have allowed the easy and accurate assessment of knee motion during athletic (Bates, Myer, Shearn, & Hewett, 2015; Pujol, Blanchi, & Chambat, 2007; Peng, 2011; Robınson, Donnelly, Tsao, & Vanrenterghem, 2014; Weihmann, Karner, Full, & Blickhan, 2010). Many studies have been published that greatly improved our understanding of the aetiology, surgical reconstruction techniques and prevention of anterior cruciate ligament (ACL) injuries (Boden, Sheehan, Torg, & Hewett, 2010; Carcia, & Martin, 2007; Gao, Cordova, & Zheng, 2011; Myer, Ford, Brent, & Hewett, 2007; Pollard, Sigward, & Powers, 2007; Pujol, Blanchi, & Chambat, 2007; Reichl, Auzinger, Schmiedmayer, & Weinmüller, 2010; Shin, Chaudhari, & Andriacchi, 2009; Wang, 2011). Single- and double-leg drop jump techniques are frequently executed in many sports. Yu and Garret (2007) studied that the landing phase of stop-jump tasks presents a significant risk of injury to the lower extremities in general and to the ACL in particular.

A number of reports have shown that sports-related ACL injuries generally occur during non-contact situations that are characterized by landing, rapid deceleration, and sudden changes of direction and most of them occur during single-leg landings (Boden et al., 2010) which are common tasks performed from varying vertical heights and horizontal distances during sporting events such as volleyball, basketball and soccer (Pappas, Zampeli, Xergia, & Georgoulis, 2013). Soccer players sustain the greatest number of ACL injuries (53% of the total) with skiers and gymnasts also at high risk (Hewett, Myer, & Ford, 2005). Landing tasks have provided measures

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related to ACL injury risk factors, including vertical ground reaction force (VGRF), joint angles and moment contribute to knee instability and are a primary loading mechanism of the knee joint and ACL (Hewett et. al., 2005; Schroeder, Krishnan, & Dhaher, 2015; Siegmund, Huxel, & Swanik, 2009). Greater GRF upon landing increases the probability of ACL injury, prior to injury, participants who sustain ruptures exhibit 20% larger peak vGRFs during landing than participants who remain healthy. Moreover, the knee angle was significantly more extended in the injured athletes when the foot was completely flat at the initial foot contact kl So far many studies have been focused on initial contact phase of landing tasks (Čoh, Berić, & Bratić, 2013; Zahradnik, Uchytil, Farana, & Jandacka, 2014). But the other phases such as moment of jump and last contact with the ground can have an impact on biomechanical factors that present a risk for the occurrance of ACL injuries.

The purpose of this study was to determine how ground reaction forces, moments and knee flexion angles differ between healthy controls and reconstructed subjects during single leg landing phases. We suggested two hypotheses respectively: (1) the knee flexion angle correlated with the kinematics at the landing phases in both groups; and (2) force, moment and angle values will differ between each phase and also between the groups.

Methods

Participants

The participant population consisted of two groups—ACL reconstructed group (n=11 patellar tendon autograft) and an uninjured control group (n=9). All participants were soccer players performing at amateur soccer clubs and matched for age, height, weight, sports age as shown in Table 1.

Table 1. The means and standard deviations of descriptive statistics of all subjects

	Age (year)	Height (m)	Weight (kg)	Sport Age (year)
Reconstructed	23.09±3.62	1.77±0.05	83.89±11.76	13.36±2.29
Uninjured	22.22±2.48	1.78±0.03	74.35±6.10	9.88±3.62

ACL-reconstructed palyers were included who had an isolated ACL rupture and a subsequent surgical reconstruction using either a hamstring tendon (HT) or patellar tendon (PT) autograft at least 6 months and up to 15 months prior to the study sessions and also only the subjects whose dominant leg were right to the study. Exclusion criterias were; history of significant knee pain prior to the injury and/or at time of testing, contralateral knee injury/ surgery, or prior injury/surgery to the reconstructed knee. The dominant leg was determined as the leg used by the participant to kick a ball. All experimental procedures were approved by The Ethic Comittee and complied with the principles of the Declaration of Helsinki. Informed consent was obtained from all subjects prior to participation in the research study.

Landing task

Players were instructed to warm up for 5min. and instructed to perform drop jump from a custom made takeoff platform from 20cm vertical height that were placed next to the edge of a force plate (Ali, Robertson, & Rouhi, 2014). The command of 'ready' was given to the participants before the start of each landing task. For each landing task all participants began with a standard take-off position by standing on a take-off platform with hands placed on the hips, legs shoulder width apart, and the toes of both feet aligned with the edge of the take-off platform. Participants were then instructed to stand on their dominant leg, drop off, and land as naturally as possible with their dominant foot only centered on the force plate and jump vertically as soon as possible. The participants were asked to keep their hands on their hips when landing to reduce any variability from swinging arms. Each subject was asked to perform three successful trials, and the best result was used for further analysis.

All participants wore their own sports shoes throughout data collection. Motion analysis was performed on all subjects using a-camera motion capture (SIMI Reality Motion Systems GmbH, GER) system with three cameras (Basler A602f-HDR GmbH, GER) which were set at 100 frames per second as shown in Figure 1. For digitization, 7 retroreflective markers attached to right side of the body; trochanter major, spina iliaca anterior superior, patella, condylus lateralis, tuberositas tibia, condylus lateralis tibialis, malleollus lateralis.

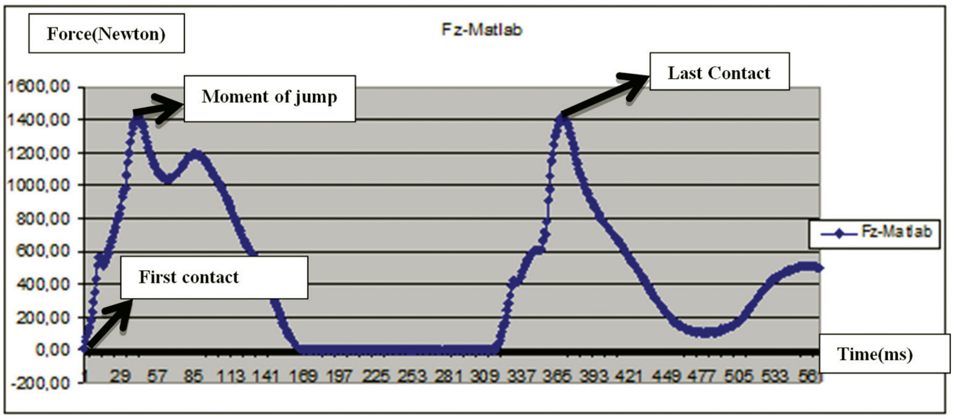

Figure 1. One participant' s jump performance force data

Cameras were placed at different angles in the plane of motion and the force plate as shown in Picture 1.The plane of motion was calibrated vertically and horizontally by using a rigid pole visible markings.Three-dimensional marker position coordinates of all markers were computed using the direct linear transformation(DLT) method(Abdel-Aziz, YI& Karara

Picture 1. Location points of the cameras in the experimantal setups

HM; 1971) by means of motion analysis software.

A force plate (FP4060-10, BERTEC, USA) measured ground reaction forces (GRFs) at a sampling rate of 1000 Hz. Videographic and force plate data were time synchronized. The vertical ground reaction force (VGRF) was defined as the reaction to the force the body exerts on the ground in the vertical direction.

Data reduction and Analysis:

One trial was selected from the best of three trials for data analysis. The best trial was determined as the one in which the participant did not remove their hands from the hip during landing, did not allow their non-dominant leg to impact the force plate during landing, or did not lose a marker during impact with the ground. Joint kinematics and kinetics were determined for the dominant leg. Joint kinematic data were calculated using a SIMI Motion Analysis System and analog data was imported into MATLAB (Version 5.3 , The Mathworks Inc., Natick, MA). Maximum vertical ground reaction force was calculated after initial contact with the force plate during the task which was divided into three phases. *Initial contact* (IC) phase was defined as the instant where the force plate reported values greater than 20 N VGRF, *Moment of Jump phase* (MoJ) phase defined as peak VGRF and *last contact* (LC) phase was defined as the greatest force value after moment of jump. According to Ford, Myer and Hewett (2014) study, marker trajectories were filtered using a low-pass 2nd-order Butterworth filter with a cut-off frequency of 12Hz, chosen after conducting a residual analysis. Ground reaction forces were normalized to each subject's body weight and moments normalized by the product of body mass and body height. The knee flexion angle was defined as the angle between the thigh and leg segment. Kinetic raw data was collected at 1000Hz and kinematic raw data was collected at 100Hz. Therefore sampling frequency of both data equated at 250Hz. Kinematic data were low-pass filtered using a second-order Butterworth filter at 100Hz and analog data were filtered at 25Hz.

Statistical analysis

Groups were tested for normal distribution by means of the Kolmogorov–Smirnov test. Homogeneity of the variances was ascertained by Levene's F test. The Independent Samples t-test and Pearson correlation analysis were used for variables depending on the normality of distribution. The level of significance was set at $p<0.05$.

Results

The overall means and standard deviations of the vertical

Table 2. The means and standard deviations of each dependent variable among all subjects, t-test coefficients of peak VGRF with knee flexion angle

		Groups	x̄±Sd	t	p
IC	VGRF (N/kg)	Reconstructed	3.98±0.19	-13.11	0.00*
		Uninjured	5.11±0.18		
	KA(deg)	Reconstructed	15.18±13.4	-0.21	0.83
		Uninjured	13.62±17.8		
MoJ	VGRF (N/kg)	Reconstructed	14.29±2.79	-4.20	0.00*
		Uninjured	19.24±2.35		
	KA(deg)	Reconstructed	23.9±9.44	0.11	0.91
		Uninjured	14.62±18.21		
LC	VGRF (N/kg)	Reconstructed	6.93±0.35	0.44	0.66
		Uninjured	6.69±0.98		
	KA(deg)	Reconstructed	19.9±15.40	1.71	0.10
		Uninjured	35.5±24.23		

Legend: IC: Initial Contact; LC: Last Contact; VGRF: Vertical Ground Reaction Force; MoJ: Moment of Jump; KA: Knee Flexion Angle; *Significant difference ($p<0.05$)between the groups.

ground reaction force and knee flexion angle for the vertical height test among all subjects and t-test coefficients of peak VGRF with knee flexion angle and moments are provided in Table 2. The findings from the t-test conducted, revealed for the single landing test that VGRF was significantly higher in uninjured group at the initial contact (p=0.00) and at the moment of jump (p=0.00) but there was no significant difference at the moment of last contact between the groups.

Table 3. Pearson correlation coefficients of peak VGRF with knee flexion angle and moment values at the moment of jump

				My	**Knee Flexion Angle(degree)**
IC	reconstructed	VGRF(N/kg)	r	0.571	-0.569
			p	0.009*	0.009*
		My(N/kg .m)	r		-0.181
			p		0.444
	uninjured	VGRF(N/kg)	r	0.761	-0.594
			p	0.17	0.092
		My(N/kg .m)	r		-0.198
			p		0.61
MoJ	reconstructed	VGRF(N/kg)	r	0.132	0.35
			p	0.58	0.13
		My(N/kg.m)	r		0.372
			p		0.106
	uninjured	VGRF(N/kg)	r	0.384	0.56
			p	0.308	0.117
		My(N/kg .m)	r		0.573
			p		0.107
LC	reconstructed group	VGRF(N/kg)	r	0.011	-0.175
			p	0.965	0.461
		My(N/kg .m)	r		-0.14
			p		0.556
	uninjured	VGRF(N/kg)	r	0.42	-0.488
			p	0.261	0.182
		My(N/kg .m)	r		-0.171
			p		0.66

Legend: *Significant relationship (p<0.05) between the variables of the groups.

As Shown in Table 3, peak VGRF was significantly and negatively correlated knee flexion angle (r=−0,569 p=0.009) in reconstructed group at the moment of initial contact. It is also worth noting from Table 3 that peak VGRF was unsignificantly and negatively correlated to knee flexion at the last contact in both groups, too. But VGRF was unsignificantly and positively correlated to knee flexion angle at the moment of jump. There was no significant correlation amongst VGRF, knee flexion angle and y component of moment.

Discussion

The purpose of this study was to investigate how VGRF, moments and knee flexion angles differ between healthy controls and reconstructed subjects during single leg landing phases. It was found that though knee flexion angles and moment values are equivalent between the groups, differences in VGRF indicate that each phase has its own biomechanical mechanisms.

Previous research has suggested that a relationship exist between demographics which supported by Robinson et al. (2014) stated that females to exhibit greater hip internal rotation and hip adduction moment than males (Abdel-Aziz, & Karara, 1971; Pollard et. al., 2007; Ford et al., 2014). Additionally, stronger support for the "quadriceps dominance" theory as a potential mechanism for the sex disparity in ACL epidemiology is provided by studies that found females to demonstrate preferential quadriceps activation compared to males (Ford et al., 2014). Therefore, only male subjects were included in our study (Table 1).

Our results showed that there is a significant difference in VGRFs at IC and MoJ phases but there is no significant difference in VGFR at LC between the groups (Table 2). This can be explained with "quadriceps avoidance" motion pattern.

Early biomechanical researches that investigated kinetic and kinematic differences between healty subjects and reconstructed subjects indicated that many of the subjects perform the tasks with a "quadriceps avoidance" which is characterized by decreased quadriceps activity and lower external knee flexion moment in an effort to control anterior translation of the tibia (Ali et al., 2014). We found no significant difference neither in knee flexion angle nor in moment values between the groups (Table 2). Podraza and White (2010) found similar results; given that ground reaction forces are more likely to be greatest and knee extensor moments smallest when landing in an extended knee position; it is possible that ACL strain from noncontact deceleration may be related to rapid translational joint forces that propagate up the kinetic chain rather than resulting from quadriceps overload induced anterior tibial translation. Boden et al. (2010) also proposed that a lack of absorption of ground reaction forces who were injured, landed with a mean knee flexion angle of 17.6° compared to uninjured controls that landed with a more plantar flexed ankle and had a knee flexion angle of 39.3°.Previous studies indicated that the impact on the lower extremities increases as the peak vertical ground reaction force increases (Ali et al., 2013; Pappas et al., 2013; Podraza et. al., 2010; Wang, 2011). Pappas et al. (2013) compared the ground reaction force between single-leg drop landings and double-leg drop landings. Pappas et al. (2013) found that single-leg drop landings from a height of 0.4 m produced a higher peak vertical ground reaction force than stop jump. The results from the work of Boden et al. (2010) suggested that the propagation of reaction forces when landing with the knee near full extension could be an important component of non-contact ACL injuries. Support moment is the net summation of ankle plantar flexion, knee extension and hip extension moment. Hewett et al. (2005) measured landing biomechanics at baseline for female athletes participating in high school basketball and soccer and followed them for one to two seasons. They found that high knee valgus angle and moment and high side-to-side differences in knee valgus angle and moment during landing from a jump were strong predictors of future ACL injury. Since landing from a rebound is the task most commonly associated with ACL rupture in basketball (Sugimoto et al., 2015),it is possible that the first drop landing task does not sufficiently simulate all the biomechanical mechanisms enacted when landing from a maximal jump. Greater fall heights prior to landing incrementally increase perturbations and, consequently, vGRFs on the lower extremity (Peng, 2011; Abdel-Aziz, & Karara, 1971).

Within the findings and limitations of this study, we observed that VGRF s and knee angles differ among the phases. Additionally, other potential limitation to the current study includes that all participants performed single leg drop vertical jump, future researches may include double leg drop vertical jump task and add different heights to their studies. A better understanding of the different phases during single-leg landings can shed a light on mechanism of non-contact ACL injuries.

As a conclusion, there are differences between the landing phase kinetics and kinematics of single leg drop veritical jumps. We suggest that a higher risk of ACL injury could result from the fact that the single-leg drop jumps exhibites greater peak forces and moments during the landing than the moment of jump and initial contact phases. This indicates that non-contact injuries occur during landing phase of jump tasks.

Future research is necessary to evaluate the injury-specific influences of landing phases. Researchers should attempt to extrapolate these findings to more dynamic and challenging tasks that are more representative of scenarios during which ACL injury occurs and to the populations at heightened risk of ACL injury and also hip, trunk, core, and upper body mechanics are associated with lower extremity biomechanical and neuromuscular factors of each landing phase should be better to be examined for futher information.

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Conflict of Interest
The authors declare there are no conflict of interest.

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