The Effects of the Functional Garment on the Biomechanics During the Single Leg Drop Landing.

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Abstract

Background: Female athletes with an anterior cruciate ligament (ACL) injury should decrease both dynamic valgus of the knee and related kinematics of the lower limb during single leg drop landing (SLDL). A functional biomechanics garment (FBG) may help prevent injury by improved kinematics during motion. The purpose of this study was to investigate the effects of the FBG on the biomechanics of SLDL.

Methods: Seventeen female university basketball players participated in this study. Characteristics of the FBG were designed based on biomechanics during weight-loaded performance of human movement such as gait, running, and jumping. Lower limb kinematic and kinetic data were calculated using a three-dimensional motion analysis system during a SLDL task with and without the FBG. The hip, knee, and ankle angles and joint moments were automatically calculated from the standard plug-in gait lower body model. The average values of lower limb kinematics and kinetics in the sagittal and frontal planes from 3 SLDL with and without FBG were measured and compared.

Results: The maximum varus angle of the knee showed a significant difference between with FBG (15.3 ± 15.1 degrees) and without FBG (5.9 ± 15.4 degrees). ($p < 0.01$; effect size 0.6)

Conclusion: Use of the FBG decreases dynamic knee valgus, which reduces risk of knee injury. The FBG can reduce dynamic knee valgus during SLDL in athletic rehabilitation and to play a role in the prevention of knee injury.

Background

Many athletes must coordinate and control a variety of dynamic sporting movements (i.e., running, sidestepping with change of direction, and landing with stepping) during training and competition. Efficient and safe joint mechanics can be maintained by muscle force during the successfully coordinated dynamic performance. Poor joint mechanics during sports movements such as running, landing, and change of direction has been linked to both acute and overuse sports injuries [1, 2]. In a non-contact anterior cruciate ligament (ACL) injury, single-leg landing and side stepping are responsible for up to 80% of all injuries [3–6]. Therefore, the kinematics of the single-leg landing, an experimental task that best represents non-contact ACL injury scenarios, are assessed in both biomechanics research and athletic rehabilitation fields [7]. Several researchers have reported that repetitive high-risk performance, such as large coronal plane excursion, may increase the tendency for dynamic valgus and ACL injury [6, 8–10]. Hewett et al. demonstrated that coronal plane motion at the knee is greater during a landing task in athletes with an ACL injury than in athletes without injury [9]. They showed that increased knee abduction angle at initial contact, as well as peak knee abduction angle and peak knee abduction moment during drop vertical jump are highly sensitive and specific to predicting non-contact ACL injury risk in female athletes [9, 11]. Moreover, lower limb coronal plane motion of hip abduction–adduction and ankle eversion–inversion in female athletes during landing is correlated with an increased risk of non-contact

ACL injury in female athletes [9, 10, 12, 13]. Koga et al. suggested that valgus loading is a contributing factor in the ACL injury mechanism and that internal tibial rotation is coupled with valgus motion [14, 15]. Therefore, in athletic rehabilitation for ACL reconstruction, it is important for female athletes with ACL injury to decrease both the dynamic valgus of the knee and related kinematics of the lower limb during single leg landing motion.

A new rehabilitation is being used widely that is based on criteria for body function and biomechanics after ACL reconstruction. Filbay et al. suggested in their review that rehabilitation for ACL reconstruction consists of five distinct phases: Preoperative phase, Acute phase, Intermediate phase, Late phase, and Continued injury prevention phase [16]. From the intermediate to the continued injury prevention phase, patients with ACL reconstruction require both basic and specific performance-based sports skill training with dynamic knee stability, and this should be acquired while monitoring the quality of the movements such as dynamic knee valgus in the clinical setting [17, 18]. Therefore, physical therapists assess both the quality and quantity of knee stability during performance based tests, such as Y-balance test, single leg hopping, and single leg landing. The failure rate of rehabilitation after ACL reconstruction is approximately 25% [19–21], even though neuromuscular training with the best evidence for effective rehabilitation is performed. Unfortunately, the failure rate is higher if patients who cannot return to preinjury levels of sports activity are included [22]. Therefore, athletic rehabilitation after ACL reconstruction needs further development. In particular, a method for the prevention of dynamic knee valgus remains unclear.

Functional garments may be a new injury prevention strategy. Currently, both novice and professional-level athletes are using functional garments, which compress the body to improve the body function with the goals of improving athletic performance, increasing muscular endurance, and enhancing recovery. Several researchers have reported that compression garments improve proprioception [23–25] and balance [26–29]. Zamporri J et al. reported that a compression garment can slightly alter the hip abduction range of motion only during landing from a drop vertical jump [30]. However, little is known as to their effect on kinematics during the motion.

We have produced a functional biomechanics garment (FBG) based on the biomechanics of braking and inducing joint motion during athletic performance such as jump, running, and change of direction. The FBG may help break the dynamic valgus of the knee at the landing of the jump. The aim of this study was to investigate the effects of the FBG on the biomechanics of the single leg drop landing.

Methods

Subjects

This was a cross-sectional study. Twenty-one female university basketball players participated in this study. The inclusion criterium was having >3 years of experience as a basketball player. Exclusion criteria were subjects with any pain of the lower leg at time of testing and subjects who could not wear the FBG. One subject did not have informed consent with this study, and 3 subjects without data were excluded.

Finally, 17 subjects (age, 20.3 ± 0.8 years old; height, 160.0 ± 7.4 cm; body weight, 55.5 ± 8.1 kg) participated in this study. (Figure 1) The study duration was from April to December 2019, and variables were measured in a laboratory setting.

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Morinomiya University of Medical Sciences (Approval number: 2019-130). The subjects were informed of the potential risks of the study and provided signed informed consent. Informed written consent was obtained for all subjects. This study was funded by Toyota Tsusho Corporation and Fukusuke Corporation.

Experiments

The FBG is a compression garment that adheres from the buttock to the heel. The characteristics of the FBG were designed based on biomechanics during weight-loaded performance of human movement such as gait, running, and jumping. The FBG consists of two important parts, a rigid part and an elastic part, that mainly support the following during landing: 1) Hip extension moment, 2) Hip abduction moment, 3) Knee extension moment, 4) Knee varus moment, and 5) plantar flexion moment. (Figure 2)

Lower limb kinematic and kinetic data were calculated using a three-dimensional motion analysis system consisting of 8-infrared cameras (100Hz Vicon cameras, Vicon co, Oxford, UK) and 2-force plates (1000Hz, AMTI OR6 series, AMTI, USA) during an SLDL task with and without the FBG. The SLDL began with subjects standing barefoot on a 0.3-meter-high platform (placed 30 cm from the edge of the force plate) with their left lower limb initially loaded in single leg standing. Subjects were then required to drop forward onto the left leg, landing on the force plate in front of the platform and adopting their own natural landing style. Upon landing, subjects were required to rebound jump as quickly as possible on the test leg. Each subject was required to complete 3 SLDLs on the left limb. Landing phase was defined as the time from the foot contact on the force plate to the time when the center of mass is the lowest.

Sixteen retroreflective markers were mounted following the standard plug in gait lower body model. All markers were tracked by the motion analysis system. Markers were secured to specific locations and anatomic landmarks, including the bilateral thigh, leg, foot, and pelvis, for each participant and were used to calculate joint centers and segment positions and to track segment motion during the SLDL. The hip, knee, and ankle angles and joint moments were calculated automatically using Nexus2 (Vicon co, Oxford, UK), and a low pass Butterworth digital filter (10Hz) was used to filter marker trajectories and ground reaction force data. Hip flexion and adduction angle, knee flexion and varus angle, ankle plantarflexion angle at both foot contact and the maximum value during the landing, and excursion of each motion during landing were calculated. Hip flexion and adduction moment, knee flexion and varus moment, and ankle plantar flexion moment were calculated at both the foot contact and the timing when the vertical ground reaction force was maximum. The average value of 3 performances with and without FBG were measured and compared.

Analysis

The sample size was determined by GPower 3 Software (version 3.1.9.4) using the paired t-test. Paired t-test was performed to analyze any difference in both kinematics and kinetics data between with and without FBG. Effect sizes of the difference between with and without FBG were calculated by Cohen's d. A significance level of 0.05 was used for all analyses, and all analyses were completed in SPSS software (SPSS ver25, IBM co., Armonk, NY).

Results

Kinematics data of the lower limb are shown in Table 1. At foot contact, dorsi-flexion of the ankle with FBG (-24.0 ± 6.2 degrees) was significantly different from that without FBG (-21.6 ± 5.1 degrees). The varus angle of the knee with FBG (3.4 ± 5.0 degrees) was significantly larger than that without FBG (1.2 ± 5.4 degrees). Other kinematics data of foot contact were not significantly different between with and without FBG.

At the maximum kinematics, only the varus angle of the knee showed a significant difference between with FBG (15.3 ± 15.1 degrees) and without FBG (5.9 ± 15.4 degrees). Other kinematics data at the maximum kinematics during landing were not significantly different between with and without FBG.

There were significant differences in dorsiflexion excursion (with FBG, 49.4 ± 6.7 degrees; without FBG, 46.5 ± 5.1 degrees), varus excursion (with FBG, 11.9 ± 11.5 degrees; without FBG, 4.7 ± 11.4 degrees), and the flexion excursion of the hip (with FBG, 21.5 ± 8.1 degree; without FBG, 24.0 ± 6.7 degrees) between with and without FBG.

The joint moments during the SLDL are shown in Table 2. At foot contact, the dorsiflexion moment of the ankle was significantly different between with FBG (2.7 ± 0.6 Nm) and without FBG (2.9 ± 0.5 Nm). The adduction moment of the hip with FBG (1.1 ± 0.6 Nm) was significantly smaller than without FBG (1.4 ± 0.8 Nm). There is no significant difference between with and without FBG in the other joint moments.

Discussion

The aim of this study was to investigate the effects of the FBG on biomechanics of the SLDL. The FBG decreased dorsi-flexion of the ankle at foot contact, and increased the maximum varus angle, the varus angle at foot contact, and the varus excursion. In particular, the effect size of the varus angle of the knee was more than 0.5. Moreover, the hip adduction moment, which increased dynamic knee valgus, was decreased at foot contact with FBG. Therefore, we found that the FBG could decrease dynamic knee valgus and adductor moment of the hip, both of which increase the risk of knee injury, such as ACL injury.

It is known that valgus loading is a contributing factor in the ACL injury mechanism, and internal tibial rotation is coupled with valgus motion [15]. Therefore, the knee abduction angle, external knee abduction moment, and internal tibial rotation angle are extremely important for the assessment of non-contact ACL injury.

Functional compression garments can decrease fatigue and muscle damage [31–33]. Hanzlíková et al. showed improved knee kinematics with ACL reconstruction during dynamic tasks using the proprioceptive knee braces [27]. However, there are few studies that investigated the effects of biomechanics during the sports activity. Zamporri J et al. reported that a compression garment can alter hip abduction range of motion only during landing from a drop vertical jump [30]. Therefore, the effects of a functional garment on biomechanics are unclear. Surprisingly, our FBG affected biomechanics during the SLDL. In addition, the dynamic knee valgus and hip adduction angle during the landing, which are risk factors of an ACL tear, were decreased using the FBG.

The physiological effects of the compression garment might be due to increased proprioceptive stimulation of the skeletal muscles [30, 34]. In the current study, the FBG may have increased proprioceptive stimulation, however, the FBG was designed to control knee motion, which is different from other compression wear. The FBG functioned to support the muscle activities needed during landing through the high rigid part and the high elastic part (Figure 2). The FBG was needed to control the extension and abduction moment of the hip and varus moment of the knee during the landing. The FBG was constructed with both a rigid part of the hip, which weaved tight thread along the gluteus maximus and medius muscles and the iliotibial band, and an elastic part, which weaved elastic thread along the medial support structure of the thigh such as the pes anserinus. The rigid part of the hip could counter the excessive adduction and flexion of the hip, and the elastic part of the thigh could support the varus moment when the elastic part stretched. The rigid and elastic parts of the FBG were expected to assist the hip extensor and abductor moment and varus moment of the knee, respectively. Therefore, the subjects with FBG could control the frontal motion of the knee, which has a risk of knee injury, such as the dynamic valgus of the knee during the SLDL.

In the clinical decision whether to return an athlete to activity/sports, knee function and quality of motion after ACL reconstruction should be assessed. When the patients achieved both the function and performance needed, the patients with ACL reconstruction could begin the next phase of rehabilitation. Physical therapists should pay attention to the quality of movement such as dynamic knee valgus, hip and trunk control, and knee flexion angle during the jump tasks involving SLDL, which are used as the next step of postoperative rehabilitation [17, 18]. The re-injury prevention program for the ACL addresses the muscle strength of both the hip abductors and extensors, as well as neuro-muscular training [15, 35, 36]. The FBG might assist to decrease the dynamic knee valgus during SLDL.

Our study had some limitations. First, we could not compare our FBG with other compression garments. There is no control compression garment. However, a few studies have shown changes in kinematics using a compression garment. Therefore, it is clear that the FBG may change biomechanics during motion. Second, the FBG could change the biomechanics during the motion, however, we could not assess the muscle activities during SLDL with the FBG. The FBG may have decreased the muscle activities, because the FBGs assisted joint movements. In future study, muscle activities during motion with FBG should be assessed. Third, the subjects that participated in this study did not have ACL deficits. It remains unclear that the FBG can control dynamic valgus during landing in subjects with ACL deficits.

The abductor muscle strength of the hip may have decreased in subjects with ACL deficits, and subjects with some functional impairments such as muscle weakness may benefit similarly from the FBG. Lastly, the SLDL was used to assess the risk factor of knee function during tasks that closely mimic ACL injuries during sport participation. However, the SLDL is based on closed skill tasks, and sport requires open skills in addition to closed skills. Open skills have a reactive element to execute the motor task, usually in addition to decision-making, often in a fatigued state. Therefore, more research examining a prospective cohort is needed to investigate the prevention effects of the FBG on ACL deficits not only during closed skill tasks, but also during open skill tasks.

Conclusions

Use of the FBG decreases dynamic knee valgus, which reduces risk of knee injury. The FBG can reduce dynamic knee valgus during SLDL in athletic rehabilitation and to play a role in the prevention of knee injury.

Abbreviations

ACL: anterior cruciate ligament; SLDL: single leg drop landing; FBG: functional biomechanics garment

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Morinomiya University of Medical Sciences (Approval number: 2019-130). The subjects were informed of the potential risks of the study and provided signed informed consent. Informed written consent was obtained for all subjects.

Consent for publication

Not applicable

Availability of data and material

The datasets generated and analyzed during the present study are not publicly available. Upon request, the corresponding author will share the data set.

Competing interests

This study was funded by Toyota Tsusho Corporation and Fukusuke Corporation. And, none of the authors have any commercial or financial involvements in connection with this study that represent or appear to represent any conflicts of interest.

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Authors' contributions

SKudo conceived and designed research. TM, SKatayama, AY, and RT collected data. SKudo analyzed data, and wrote the manuscript. SKudo revised the manuscript and supported by all authors. All authors have read and approved the manuscript

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Tables

Table 1. Kinematics of the lower limb during SLDL

		without FBG			FBG			p-value	effect size
foot contact	Ankle D/F	-21.6	±	5.1	-24.0	±	6.2	0.04	0.5
	Knee Flex	13.9	±	6.0	11.7	±	7.7	0.23	0.3
	Knee Varus	1.2	±	5.4	3.4	±	5.0	0.04	0.5
	Hip Flex	22.0	±	7.4	20.7	±	10.2	0.38	0.2
	Hip Add	-9.9	±	4.0	-10.6	±	4.7	0.46	0.2
Maximum	Ankle D/F	24.8	±	5.8	25.4	±	6.3	0.60	0.1
	Knee Flex	59.7	±	13.3	58.1	±	16.6	0.50	0.2
	Knee Varus	5.9	±	15.4	15.3	±	15.1	0.01	0.6
	Hip Flex	45.9	±	10.9	42.2	±	13.6	0.05	0.5
	Hip Add	5.8	±	6.5	4.0	±	7.6	0.21	0.3
Excursion	Ankle D/F	46.5	±	5.1	49.4	±	6.7	0.01	0.5
	Knee Flex	45.8	±	10.3	46.4	±	11.9	0.64	0.1
	Knee Varus	4.7	±	11.4	11.9	±	11.5	0.01	0.6
	Hip Flex	24.0	±	6.7	21.5	±	8.1	0.04	0.5
	Hip Add	15.7	±	4.2	14.5	±	6.0	0.30	0.3

Table 2. Joint moment of the lower limb during SLDL

		without FBG			FBG			p-value	effect size
foot contact	Ankle D/F moment	2.9	±	0.5	2.7	±	0.6	0.02	0.5
	Knee Flex moment	1.2	±	0.8	1.1	±	0.8	0.62	0.1
	Knee varus moment	1.2	±	0.4	1.0	±	0.4	0.07	0.4
	Hip Flex moment	1.2	±	0.9	1.4	±	0.5	0.12	0.4
	Hip adductor moment	1.4	±	0.8	1.1	±	0.6	0.04	0.5
Maximum	Ankle D/F moment	3.0	±	0.6	2.8	±	0.5	0.09	0.4
	Knee Flex moment	1.6	±	0.9	1.6	±	1.0	0.87	0.0
	Knee varus moment	1.5	±	0.4	1.4	±	0.6	0.10	0.4
	Hip Flex moment	1.8	±	0.9	2.0	±	0.5	0.25	0.3
	Hip adductor moment	1.6	±	0.9	1.4	±	0.7	0.18	0.3

Figures

Figure 1

Flow chart

Figure 2

Photographs of the functional biomechanics garment / Solid and dash lines shows rigid and elastic part, respectively. The single leg drop landing (SLDL) required a high extensor and abductor moment. The gray solid line on the hip and lateral thigh (C), which aligns along the iliotibial band (A) and gluteus maximus (B), assists in braking the hip adduction against the adductor external moment. The elastic part of the medial thigh, which aligns along the vastus medialis and pes anserinus, assist the extension and varus moment of the knee during SLDL.