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Medial Longitudinal Arch Pad Influences Landing Control of the Lower Limbs during Single-Leg Jump-Landing

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Abstract

Background: Arch support has the effect of maintaining arch and correcting alignment, and it is broadly used for the prevention of sports impediment and treatment of athletes with lowered MLA and foot problems. The fact that the morphological change of MLA damages balance sense and postural control, it was reported that the insole supporting the arch of MLA improved postural balance. There are several studies regarding the effects of arch support; however, its effects on landing control have not been clarified. Therefore, in our research, we discussed the effect of MLA support for landing control, using lower limb dynamic alignment and the moment during landing as indexes. **Methods:** This study measured the landing motion to be evaluated was to jump from a platform with a height of 30 cm by taking-off with a single foot, and landing on a single foot on a floor reaction force gauge placed ahead and stay still for three seconds for the subjects were 13 healthy females. A soft 6 mm Boron sheet cut in the size of 9 × 3.5 cm, applied with double-sided tape (MLA pad) was used for arch support (hereafter referred to as "pad"). For the lower limb evaluation, an 8-camera with a three-dimensional behavioral analyzer (CORTEX, NAC product, sampling frequency: 120 Hz) and a floor reaction force gauge (AMTI product, sampling frequency: 1000 Hz) were used. Ten successful jump-landing tests for each limb were used for further analyses using Visual 3D software (Cmotion Inc., Kingston, Canada). Analysis objects were knee joint bending angle and valgus angle during landing; knee joint maximum bending angle; bending knee joint valgus angle, hip joint bending angle, adduction angle, ankle joint plantar flexion angle, varus angle at the time of knee joint maximum bending angle; and each joint moment. For statistical processing, the average value of three trials out of five trials was regarded as a representative value. **Results:** Regarding joint angles, significant differences were observed in maximum knee joint bending angle, knee joint bending angle during maximum valgus knee joint and ankle joint varus angle during knee joint maximum bending angle between before and after intervention. No significant differences were observed in other joint angles. Regarding joint moments, no significant difference was observed in each joint moment before and after the intervention. **Significance:** The decrease of knee joint valgus angle during landing by the use of MLA pad suggests the possibility of decreasing the risk of ACL injury. As the incidence of ACL injury in females is higher than that of males, and the evaluation for females had proceeded, it can be useful information for the prevention of ACL injury.

Keywords

Medial Longitudinal Arch Pad, Single-Leg Jump-Landing, Landing Control

1. Introduction

It is known that the landing motion in sports is a motion by which athletes are easily injured [1] [2], and the injuries during landing account for 80% of the non-contact type injuries of the anterior cruciate ligament (ACL). The knee-in position during landing, which is the site prone to injury, is regarded as a typical example, and it is considered that the stress on the knee valgus caused by external rotation of hip joint eventually leads to stretching stress of ACL and finally resulting in injury.

During loading postures such as standing and landing, the medial longitudinal arch (MLA) extends its effect on the dynamic knee valgus [3]. MLA is a shape-changeable arch structure [4] and the changes in its height exert influence on the plantar pressure distribution [5], affecting the absorption of the power from the land surface [6], muscular activity [7], stability [8] and loading posture [9]. In addition, it affects foot pronation [10], internal rotation of the tibia [11] and the actions of knee varus and valgus, so that when MLA decreases, foot pronates and concomitantly knee joint valgus movement occurs and causes ACL injury. In short, the changes in MLA can affect balance sense, and the skin of the sole of the foot, ligament constituting MLA, the sensory input from intrinsic and extrinsic mechanoreceptor located in the tendon of muscles and joint capsule, and the flexibility and stability of MLA are closely related to standing position and walking balance [12]. The change of MLA damages foot stability as well as the relationship between feet and land surface, and it creates a harmful effect on balance.

Meanwhile, regarding ACL injuries having the risk factor of knee-in position during landing [13] [14], it is pointed out that the injury frequency is higher in a non-dominant left foot, which is inferior in supporting function than in a dominant right foot.

It is reported that the frequency of injuries of females is higher from two to seven times than that of males [15] [16]. Females increase knee joint valgus angle more than males, so that they are easy to hold knee-in position, and furthermore, their decrease of forward tilt angle of the trunk and increase of lateral bending toward injury side are factors in the injury incidence rate [13]. Once they get injured, they have to break away from competition for a long period, so it is one of the injuries against which countermeasures for protection and intervention are very important for female athletes who frequently get injured.

Knee-in, which is injured foot position, is caused not only by the decrease of knee joint function, but also often caused by the functional decreases in ankle joint touching the ground during landing and also the hip joint neighboring the knee, and it increases the knee valgus moment during movement [17]. Knee-in is recorded as dynamic knee valgus, which is the combination of hip joint adduction, hip joint internal rotation, lower leg internal rotation or foot pronation, and its increase heightens the risk of non-contact type ACL injuries [18] [19].

As an intervention to MLA, training and conditioning for the prevention of ACL injury and treatment with equipment were conducted. As a direct intervention to land surface and the sole of the foot, we focused attention on an approach using a pad aimed at arch support.

Because of the fact that the morphological change of MLA damages balance sense and postural control, Karatas *et al.* [20] reported that the insole supporting the arch of MLA improved postural balance. In short, it is possible that arch support improves foot stability at the time of ACL injury and serves as prevention and treatment. Arch support has the effect of maintaining arch and correcting alignment, and it is broadly used for the prevention of sports impediment and treatment of athletes with lowered MLA and foot problems. There are several studies regarding the effects of arch support; however, its effects on landing control have not been clarified.

Therefore, in our research, we discussed the effect of MLA support for landing control, using lower limb dynamic alignment and the moment during landing as indexes.

2. Subjects

The subjects were 13 healthy females having no orthopedic disease in the lower limbs or waist or no neurological disease, and none of them had pain during landing motion. The non-dominant foot was evaluated, opposite to the one the kicking ball as a definition. Subjects were recruited through the university bulletin board. They had been previously informed about the aim of this research and their consents were obtained.

3. Method

For the lower limb evaluation, an 8-camera with a three-dimensional behavioral analyzer (CORTEX, NAC product, sampling frequency: 120 Hz) and a floor reaction force gauge (AMTI product, sampling frequency: 1000 Hz) were used. The parts of the body attached with reflective markers were decided in accordance with Helen Hayes model recommended by NAC Co. as follows; top of head, front part of the head, back part of the head, right and left acromions, right shoulder blade, right and left olecranons, right and left styloid process of radius, right and left anterior superior iliac spines, right and left anterior surfaces of thigh, right and left lateral femoral tuberosity, right and left front of the lower limb, right and left lateral malleoli, right and left medial malleoli, right and left heel bones, right and left second metatarsal bones and sacram bone, 29 parts in total. The evaluation and attaching of reflective markers were conducted by the same person so as to avoid errors.

The landing motion to be evaluated was to jump from a platform with a height of 30 cm by taking-off with a single foot, and landing on a single leg on a floor reaction force gauge placed ahead and stay still for three seconds (**Figure 1**). They landed on their non-dominant foot. The definition of non-dominant foot is the one opposite to the foot kicking a ball. A soft 6 mm Boron sheet cut in the size of 9 × 3.5 cm, applied with double-sided tape (MLA pad) was used for arch support (hereafter referred to as "pad"). The subjects were asked to perform the task movement five times without the intervention of the pad at first and an evaluation was conducted. Then, they pasted the pad prepared previously on their medial longitudinal arch, and a similar evaluation was conducted. For landing on single-foot movement, they were asked to stand on a single foot on the platform, and when their upright position became stable, to land on the ground after a sign from a tester. At this time, the tester asked subjects to pay attention to not jumping up from the platform and asked them land on the floor reaction force gauge placed ahead. Furthermore, in order to exclude the influence of upper limbs, they were asked to cross their upper limbs in front of chest on the platform until landing. The cases where they could not maintain a standing posture on a single foot and where the opposite side foot touched the floor were regarded as failed trials.

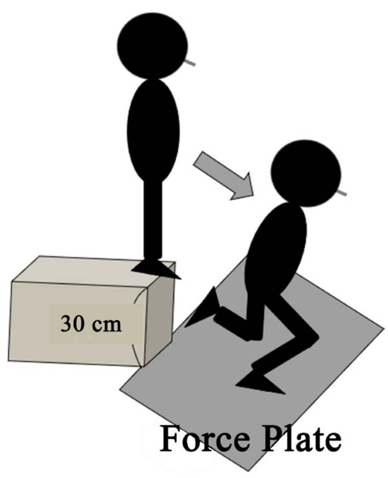

Figure 1. The methods used to measure the landing motion.

Ten successful jump-landing tests for each limb were used for further analyses using Visual 3D software (Cmotion Inc., Kingston, Canada). Analysis objects were knee joint bending angle and valgus angle during landing; knee joint maximum bending angle; bending knee joint valgus angle, hip joint bending angle, adduction angle, ankle joint plantar flexion angle, varus angle at the time of knee joint maximum bending angle; and each joint moment. For statistical processing, the average value of three trials out of five trials was regarded as a representative value. A paired t-test was used for the analyses of normality data and Wilcoxon signed ranks test was used for abnormality data. Significance level was 5%.

4. Results

Subjects' characteristics are shown in **Table 1**. Regarding joint angles, significant differences were observed in maximum knee joint bending angle, knee joint bending angle during maximum valgus knee joint and ankle joint varus angle during knee joint maximum bending angle between before and after intervention. No significant differences were observed in other joint angles (**Table 2**).

Regarding joint moments, no significant difference was observed in each joint moment before and after the intervention (**Table 3**).

Table 1. Characteristics of study subjects.

Parameters	n = 13
Body height (cm)	157.3 ± 5.1
Body weight (kg)	51.2 ± 5.2

Table 2. Landing foot ankle angle.

Kinematic (degree)	pre intervention	post intervention
Knee joint valgus angle	−1.4 ± 4.1	−1.3 ± 4.1
Knee valgus angle at landing	2.7 ± 2.8	2.0 ± 3.2
Knee flexion angle during maximum valgus knee joint	30.2 ± 15.7	34.8 ± 19.3*
Maximum knee flexion angle	60.3 ± 5.7	62.9 ± 6.7*
Knee flexion angle at landing	19.9 ± 4.5	20.5 ± 4.9
Knee valgus angle at maximum knee flexion	4.9 ± 5.7	3.9 ± 6.1
Hip flexion angle at maximum knee flexion	42.5 ± 9.1	41.6 ± 8.8
Hip adduction angle at maximum knee flexion	−2.9 ± 5.9	−2.8 ± 5.2
Ankle dorsiflexion angle at maximum knee flexion	16.9 ± 2.9	16.7 ± 2.7
Ankle inversion angle at maximum knee flexion	−4.5 ± 2.3	−2.5 ± 3.8*

Knee joint and hip joint angle: + = flexion, − = extension, + = varus, − = valgus, + = abduction, − = adduction, ankle joint angle: + = dorsiflexion, − = plantarflexion, + = inversion, − = eversion, + = abduction (Data are expressed as mean ± standard deviation. *Significant effect, $p < 0.05$).

Table 3. Lower limb joint moment during landing motion.

Kinetic (NM/kg)	pre intervention	post intervention
Maximum hip extension moment	1.5 ± 0.6	1.6 ± 0.5
Maximum knee extension moment	2.9 ± 0.5	2.9 ± 0.6
Maximum knee valgus moment	−0.3 ± 0.7	−0.4 ± 0.7
Maximum ankle plantarflexion moment	2.0 ± 0.4	1.9 ± 0.3
Hip extension moment at maximum knee flexion	1.0 ± 0.4	−1.3 ± 4.1
Knee extension moment at maximum knee flexion	1.8 ± 0.4	1.8 ± 0.3
Knee valgus moment at maximum knee flexion	0.4 ± 0.2	0.4 ± 0.3
Ankle plantar flexion moment at maximum knee flexion	1.3 ± 0.4	1.3 ± 0.3

Knee joint and hip joint angle: + = flexion, − = extension, + = varus, − = valgus, + = abduction, − = adduction, ankle joint angle: + = dorsiflexion, − = plantarflexion, + = inversion, − = eversion, + = abduction (Data are expressed as mean ± standard deviation. *Significant effect, $p < 0.05$).

5. Discussion

In this research, it was discussed what effects the intervention of using an MLA pad extended to the lower-limb joint angle and lower-limb joint moment during single-leg jump-landing.

As a result, regarding joint angles, compared with before intervention, knee joint maximum valgus angle during knee joint bending, knee joint maximum bending angle and ankle joint varus angle during maximum knee joint bending significantly increased. Even though no significant difference was observed in each joint moment before and after the intervention.

Deviat *et al.* [21] reported that, regarding knee joint angle during landing, the knee bending angle was large during the landing motion where floor reaction force decreased, and in the case where knee bending angle during landing was small, knee bending moment increased and floor reaction force also increased.

In short, it is considerable that the increase of knee joint angle during landing after intervention of MLA pad in this research suggests that an MLA pad possibly has the effect to help soft-landing. Regarding the tension degree of ACL, as Beynnon *et al.* [22] considered that the tension of either Open Kinetic Chain (OKC) and Closed Kinetic Chain (CKC) increases accompanied by the extension of knee joint angle, it is suggested that the use of an MLA pad affects the inhibition of the tension of ACL in addition to soft-landing and it also affects alleviation of extension stress.

The adduction and internal rotation of hip joint that Hewett [23] described are related to the increases of valgus and external rotation of knee joint, and similarly foot position during landing conveys the force from the floor to the foot region to the knee [24], and it is possible that a kinetic chain toward the knee valgus can occur. In short, it was considered to be important to research ACL injury by focusing on the kinetic chain from the foot region in distant parts of the body, not only from the viewpoints of trunk [25] and hip joints [26] in the proximal parts. It was considered that significant increase in ankle joint varus angle during knee joint maximum bending angle in this research means the inhibition of ankle joint valgus during landing, which can be useful for the prevention ACL injury [27] that has been said to occur in relation to foot region and knee valgus.

As discussed above, non-contact type ACL injuries generally occur when athletes land on high-risk points such as the knee valgus [28], and from video analysis, it can be said that the athletes often adopt high-risk landing control like [1] [9] [29] and [30] and take knee valgus position toward the landing point. The high value of knee valgus angle is considered to be a risk factor of ACL injury and non-contact type ACL injury [31]. Similar findings are reported by Lin *et al.* [32] "based on a stochastic biomechanical model". Valgus is supported as one of the mechanisms of ACL injury. The increase of knee valgus angle increases the risk of ACL injury, so that, in order to alleviate the risk of injury, it can be said that when landing from a jumping motion, knee valgus position should be avoided.

From the above, the decrease of knee joint valgus angle during landing by the use of MLA pad may suggest the possibility of decreasing the risk of ACL injury.

As the incidence of ACL injury in females is higher than that of males [23], and the evaluation for females had proceeded, it can be very useful information for the prevention of ACL injury. However, as it also occurs among males at a constant rate, the same evaluation should be conducted targeting males. If expanding sample size and injury mechanism are considered, it is necessary to proceed with the verification targeting athletes, too. Because the relationship between ACL injury risk and muscle activities [33] [34] has also been reported, we would like to consider the effect of MLA pads on muscle activities, too.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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