

Low Limb Muscle Activation and Joint Angle in the Sagittal Plane During Drop Landing from Various Heights

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Abstract. [Purpose] The purpose of study was to verify various strategies for the prevention of injury in normal adults and to identify the risk factors of body injury by the biomechanical analysis of drop landing with selected external loads that are commonly experienced in daily living causing load on the foot, ankle and the entire body as well as an increase in impulse. [Subjects] The subjects of this study were 14 normal adults. [Methods] Measurements were carried out while the participants drop-landed from the heights of 20, 40 and 60 cm. [Results] The muscle activation of the individual muscles until the posture was stabilized significantly increased in the abductor hallucis, medial gastrocnemius, biceps femoris and vastus lateralis as the drop height increased. In addition, the movement of the individual joints to correct the posture while landing showed that the flexion angles of the hip joint and knee joint increased as the drop height increased. [Conclusion] We found that there was a great change in the muscle activation at the drop height of 40 cm and the flexion angle also changed at the drop height of 40 cm, indicating that 40 cm may be the drop height at which the strategy for the postural balance of humans changes while landing.

Key words: Electromyogram, Landing, Motion analysis

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INTRODUCTION

Landing refers to free falling from a certain level to the ground by gravity. While landing, loads are applied to the individual joints of the lower limbs by the reaction force of the ground, and the shock is absorbed and injury is prevented by the coordination of various muscles and ligaments¹⁾. In addition, as the reaction force of the ground becomes larger during landing, the impulse transferred to the individual joints is increased, and eccentric contraction is found in the muscles of the lower limbs that control the body position and muscle compensation is found in the trunk and the upper limbs to reduce the increased impulse²⁾. The drop height from which landing is started³⁾ and the angle of the lower limb joint while landing may be factors affecting the ground reaction force and the muscle actions¹⁾.

In general, causes to the injury of lower limbs, including the foot and ankle, are determined by the magnitude or ratio of the force or load acting on it. Factors affecting the magnitude or ratio of the load include speed of the movement, the drop height prior to landing, shape of footwear, body weight, shape of the ground surface while landing, landing strategy and external loads such as a bag or burden⁴⁻⁶⁾. Additionally, the ground reaction force to the

lower limbs, that support the body weight while walking, and the flexion angle of the knee joints control the magnitude of the force applied to the body by controlling the impulse of landing. The ratio of the load or the applied force affects the amount of stress applied to the tissue and injury is caused by repeated stress⁷⁾. In this study, we verified various strategies for the prevention of injury in normal adults and identified the risk factors of body injury by biomechanical analysis of landing with selected external loads that are commonly experienced in daily living causing load on the foot, ankle and entire body as well as an increase in impulse.

SUBJECTS AND METHODS

The subjects of this study were 14 normal male (n=7) and female (n=7) adults in their twenties. They had an average age of 23.07 ± 3.36 years, an average body weight of 62.21 ± 8.85 kg an average height of 168.92 ± 9.31 cm, an average foot size of 251.07 ± 19.03 mm, an average leg length of 858.92 ± 56.71 mm, an average knee width of 104.14 ± 4.94 mm, and an average ankle width of 69.78 ± 4.80 mm.

For this study, a 100-cm wide and 50-cm long, wooden platform was fabricated to create a stage for the drop to the

Table 1. Comparison of muscle activation on landing from various heights (unit: %MVIC)

Muscle	20cm	40cm	60cm
Abductor hallucis*	20.32 ± 3.53 ^a	19.89 ± 2.13 ^a	22.61 ± 3.09 ^b
Tibialis anterior	18.80 ± 5.17	19.64 ± 4.10	22.25 ± 3.97
Medial gastrocnemius*	23.78 ± 2.66 ^a	23.21 ± 4.50 ^a	29.75 ± 3.51 ^b
Biceps femoris*	23.90 ± 3.00 ^a	38.64 ± 4.66 ^b	40.85 ± 3.82 ^b
Vastus medialis	29.47 ± 4.71	30.57 ± 4.61	30.85 ± 3.23
Vastus lateralis*	26.35 ± 3.27 ^a	29.82 ± 3.90 ^b	29.11 ± 3.97 ^b
Rectus abdominis	18.50 ± 3.71	18.14 ± 4.83	18.14 ± 5.26
Erector spinae	30.42 ± 2.44	31.92 ± 2.78	32.21 ± 3.19

Mean ± SD.

NOTE. Each value represents the mean ± SD. The values with different superscripts in the same column are significantly different: $p < 0.05$, Tukey's post hoc test.

floor. The height was randomly adjusted to 20, 40 or 60 cm, and the lower limb movement in the sagittal plane and the lower limb muscle activity were analyzed while the subjects landed.

For the landing, the subjects were asked to look straight ahead in the straight standing position with their feet apart at the width of their shoulders, and perform a landing so that both feet would contact the floor at the same time. Sufficient practice was carried out and the landing was measured 3 times. Twelve Vicon MX-F40 infrared cameras, a data station, a control PC, and a Vicon motion system (Vicon, England) composed of 25-mm reflection markers were used for the motion analysis of the joints of lower limbs in the sagittal plane. The Vicon MX camera reconstructs the 2-dimensional images obtained by the individual cameras from the optical markers at 120 frames per second to a 3-dimensional motion analysis by interpreting the Euler angles. The analogue signals are input through an Ultramet system that measures the individual segmental signals of the body in each body plane (sagittal plane, frontal plane and horizontal plane) and synchronizes the camera signals and the data in the Nexus software of Vicon. The luminous markers used to delineate a subject's body were attached to the segmental points of the pelvis, upper and lower limbs, while the 25-mm reflection markers used in the image analysis were attached only to the lower limbs of the subjects following the Plug-in gait maker set, a kinematic segmental axis model. All the motion analysis was conducted using Polygon software (Vicon, England).

To obtain the measurement values of the electromyography, the surface electrodes were attached to the middle part of the center where the muscle is most activated. It was located by manual muscle testing in parallel with the muscle fiber direction, and the electric potential difference was measured between two electrodes separated by 2-cm. To minimize the skin resistance, the parts to which the electrodes were to be attached were washed with alcohol and completely dried, and then, the two electrodes, the active electrode and the ground electrode, coated with electrolyte gel, were attached to the skin. The muscle activation was measured using MP150 (Biopac

System, USA) and Ag-Ag/Cl (Biopac, diameter 2 cm) surface electrodes. The electromyography signals were collected at a sampling rate of 100 Hz from the analogue physiological signals. They were processed by full-wave rectification and the root-mean-square (RMS) value was saved on a computer file for data processing. For data processing, Acqknowledge 3.8.1 (Biopac System, USA) software was used to perform interval filtering in the 30-500 Hz range and notch filtering at 60 Hz for normal mode rejection.

The body parts to which the electrodes were attached were the abductor hallucis, tibialis anterior, medial gastrocnemius, vastus medialis, vastus lateralis, biceps femoris, rectus abdominis and erector spinae (lumbar 4-5 level). The muscle activation signals while landing were standardized by using percentage MVIC (% MVIC), the muscle activation values divided by the MVIC (Maximal Voluntary Isometric Contraction) expressed as a percentage.

One-way ANOVA was performed to compare the changes of the muscle activation and the lower limbs at the different landing heights, and Tukey's post-hoc test was used to show the differences dependent on the height.

RESULTS

The muscle activation of the individual muscles until posture was stabilized while landing was significantly increased in the abductor hallucis, medial gastrocnemius, biceps femoris and vastus lateralis as the drop height increased (Table 1) ($p < 0.05$). Tukey's post-hoc test showed that the activities of the abductor hallucis was significantly increased at the drop height of 60 cm and those of the biceps femoris and vastus lateralis were significantly changed at the drop height of 40 cm. In addition, with respect to the movement of the individual joints correcting the posture while landing, the flexion angles of the hip joint and knee joint were increased as the drop height increased. Tukey's post-hoc test showed that the flexion angles of the hip joint and knee joint increased at the drop height of 40 cm (Table 2) ($p < 0.05$).

Table 2. Comparison of joint angles on landing from various heights (unit:°)

Joint	20cm	40cm	60cm
Hip joint*	38.00 ± 8.40 ^a	53.15 ± 19.89 ^b	51.51 ± 10.28 ^b
Knee joint*	70.71 ± 8.57 ^a	80.55 ± 9.36 ^b	86.73 ± 14.67 ^b
Ankle joint	32.50 ± 4.19	31.02 ± 5.10	32.02 ± 7.60

Mean ± SD

NOTE. Each value represents the mean ± SD. The values with different superscripts in the same column are significantly different : $p < 0.05$, Tukey's post hoc test.

DISCUSSION

Landing commonly occurs in sports or activities of daily living and the load involved in landing affects the foot in contact with the ground as well as the spine through the lower limbs⁸). Thus, landing affects the whole body and may cause injury to various joints, ligaments and muscles of the lower limbs and body, if the shock from the external ground reaction force is not properly controlled by the inner force generated by the musculoskeletal system⁹).

In this study, the flexion angles of the hip joint and knee joint of the lower limbs were all increased as the drop height of the landing increased. This may be because of the reaction to reduce the impulse of landing and it is in agreement with the result of Blackburn and Padua¹⁰) that the flexion of the trunk increases the flexion of the hip joint and knee joint in the sagittal plane in order to reduce the risk of anterior cruciate ligament injury. The reason why there was no change in the flexion angle of the ankle joint dependent on the height may be because the joints of the distal parts absorb a strong impulse regardless of the height, and the biomechanics that absorb the impulse through the joints of the proximal part may come into operation as the ground reaction force becomes larger. This result is consistent with the result of Runge et al.¹¹) who showed that postural response mechanisms to landing included a stepwise strategy using the ankle and hip strategy.

This study also showed that the muscle activities of the lower limb muscles while landing were significantly increased in the abductor hallucis, medial gastrocnemius, biceps femoris, and vastus lateralis as the drop height increased. The increase of the muscle activity of the abductor hallucis may be to maintain the foot arch as the load increased. Devita and Skelly¹²) reported that foot plantar flexors and knee joint extensors are the most important muscles for deceleration during landing. In this study, more muscle activation was also found in the biceps femoris and medial gastrocnemius as the load increased due to increase of the drop height, and those muscles may have absorbed most of the impulse. Muscle activation increased with increase of the drop height, but the flexion angle of the

ankle joint did not change with increase the drop height because of muscle co-contraction to maintain body stability while landing.

We also found that there was a great change in the muscle activation of the biceps femoris and medial gastrocnemius at the drop height of 40 cm and the flexion angle of the hip joint and knee joint changed at the drop height of 40 cm, indicating that 40 cm may be the drop height at which the strategy for the postural balance of humans changes while landing. In addition, repeated landings from that height may increase the risk of musculoskeletal injury.

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