Comparative Analysis of Maximum Vertical Reaction Force and Lower Limbs on Drop Landing between Normal and Flat Foot Group

With comparison of maximum vertical reaction force and lower limb on drop landing between normal and flat foot group, this study is to provide fundamental data of the prevention of injury and the treatment of exercise which are frequently occurred on flat foot group’s drop landing. The surface electrodes were stuck on lateral gastrocnemius muscle, medial gastrocnemius muscle, tibialis anterior and the drop landing on a force plate of 40cm was performed with a normal group who had no musculoskeletal disease and a flat foot group of 9 people who had feet examinations. Vertical reaction force were significantly statistically different between two groups(p<.001). Muscle activity of lower limbs in all three parts were not statistically different but showed high tendency on average in the flat foot group. The flat foot group had difficulties in diversification of impact burden and high muscle activity. Therefore, it was suggested that muscular strengthening of knee joints and planter flexions of foot joints which were highly affected in impact absorption will be required.

Key words: drop landing; flat foot; vertical reaction force; muscle activity

INTRODUCTION

The human being that moves by erect bipedalism has a medial longitudinal arch for shock absorption and weight disperse(1) and the foot of human being might be classified into 3 big categories of high arch foot(pes cavus foot), normal arch foot and flat foot(pes planus).

The flat foot is a clinical deformity that makes the entire sole of the foot adhere to the ground surface, owing to the longitudinal arch’s disappearance or falling down(2).

Though the cause the flat foot was not yet clearly determined, it is presumed that the flat foot can be caused not only by the inherent or hereditary factors but also by such postnatal factors as the wrong footwear, the wrong gait or posture, walking on the asphalt or concrete road, paralysis, pronation foot, accident and the obesity(3).

As per various reports on flat foot, 5% of Korean population are flat footed(4) and walking under the condition of longitudinal archs collapse may cause pain, degenerative arthritis and stress fracture of bones(5), and the flat foot is more frequently injured(6).

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The motion of free fall from a certain high place or the motion of falling after a leap is called as drop landing and the motion of leap and drop landing can be often watched in such familiar sports as a volleyball, a basketball and a soccer.

The landing motion is a passive move, falling merely by the weight and gravity from a certain height and the vertical reaction force sharply increases at the moment of landing as the potential energy of a body increases at the moment of body’s contact with the ground.

Therefore, the maximal vertical reaction force and the change of kinematic factors of a body that work at the time of landing are judged to have relevance to the riskiness of joint-musculoskeletal injury.

The maximal vertical reaction force at the time of sorption on twin feet after a leap is 3.5~7.1 times of one’s weight(7). They have reported that the maximal vertical reaction force was gauged to be 3 times of one’s weight when the landing was tried from the height 50cm(8).

Each individual muscle fiber, mobilized in eccentric contraction by which the landing is to be conducted mainly, is obliged to show its strength to the full,
because the eccentric contraction has the less number of active motor units or the less frequency of mobilized stimulus than the concentric contraction. On account of this fact, the stress at time of eccentric contraction is bigger and thus the feasibility of being injured is also higher at time of eccentric contraction than concentric contraction(9). The maximal vertical reaction force at the moment of landing is directly proportional to the speed and height of landing.

As per, the higher the landing height goes, the bigger the size of maximal vertical reaction force becomes and as per(10), the maximal vertical reaction force upsizes due to obesity, because the obesity has more momentum at time of landing than the normal weight(11).

Reviewing the researches with respect to the difference of plantar pressure between normal foot and pes were seen to have reported that the maximal pressure at metatarsus declined in case of flat foot and the normal foot showed less riskiness of injury at medial, lateral and metatarsal parts(12).

Also there was a report that the flat foot showed a dull function of shock, absorption. Besides, reported there was a significant gap between normal foot and flat foot, in terms of motor ability(13).

The motion of drop landing induces a mediation between the strong impact force and muscles and requires an extension motion of lower limbs joint. Such a motion causes a hard eccentric contraction of lower limbs triceps and raises a hard stress in the parts of ankle joint and knee joint. Nigg and Wakeling reported when the frequency of impact force is similar to the natural frequency of soft tissue, the change of muscle activity reaches the highest point(14).

Nigg et al., maintained "the impact force decreases sharply when the foot connected to the lower legs and thigh segment, touches the ground. When the impact force decreases, the muscle minimizes, the soft tissue vibration through changing its own natural frequency and through strengthening the function of impact absorption and thus, the muscle can prevent itself from being injured"(15).

As seen above, diverse approaches towards the study on a drop landing have been made but a lot of them targeted only normal people. Therefore, the domestic research as regards flat foot is actually in absolute lack.

Accordingly, this research intended to implement a comparative analysis on the maximal vertical reaction force and the muscle activity of lower limbs between the groups of normal foot and flat foot and the researches would like to suggest the basic data for exercise therapies, based on this analysis.

**MATERIALS AND METHODS**

**Subjects**

18 students who are attending N university in Cheonan city were recruited as subjects for this study and they were divided into two groups: one was of 9 subjects of normal foot, the other was of 9 subjects of flat foot. The students who volunteered to serve as subjects were given an explanation of all experimental procedures and had no problem at all to undergo the experiments.

None of them have had the history of lower limbs musculoskeletal disease for the past 6 months and the subjects who have been surgically modified due to the illness and injury of lower limbs, were excluded. General characteristics of subjects are seen in Table 1.

<table>
<thead>
<tr>
<th>Table 1. General characteristics of subjects</th>
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<tbody>
<tr>
<td>Feature</td>
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<tr>
<td>Height(cm)</td>
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<tr>
<td>Weight(kg)</td>
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<tr>
<td>Age</td>
</tr>
<tr>
<td>Foot size(cm)</td>
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<tr>
<td>Gender(m/f)</td>
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<td>BMI(kg/m²)</td>
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</table>

**Measurement Items and Procedure**

**Measurement tool**

The experimental apparatuses, shown below in Table 2 were used for this research.

<table>
<thead>
<tr>
<th>Table 2. Measurement tool</th>
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<tbody>
<tr>
<td>Instrument</td>
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</tr>
<tr>
<td>Electromyograph</td>
</tr>
<tr>
<td>Motion analyser</td>
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<tr>
<td>Vertical reaction force</td>
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<td>Electronic weighing scale</td>
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</tbody>
</table>

**Experimental Procedure and Method**

The shape of foot arch was investigated through a
sole print paper on which a sole print was put. First
the 18 participating subjects had sole of right foot be
inked by touching the printer and left the sole print
on a white paper.
That is, the right foot was placed on a white paper
for 3 seconds, taking the whole weight of the body on
the right foot and left a sole print on the paper(16).
The interpreting manners, using the foot printer
come as under.

![Foot Print Diagram]

**Fig. 1.**, Interpreting manners of sole print

1. The far left outside point of first metatarsal head
2. The far left outside point of calcaneus
3. The far right outside point of 5th metatarsal head
4. The far right outside point of calcaneus
5. The center of balance of 2nd toe
6. The crossing of line A and line B
   - line A: the direct line, linking ① and ②
   - line B: the direct line, linking ③ and ④
   - line H: the direct line, linking ⑤ and ⑥
7. The longitudinal length of foot arch
8. The transverse length of foot arch
   If the foot arch is located in the part of HA, it is a
   normal foot and if located in the part of HB, it is
   a flat foot. When there is no shape of foot arch, it
   is a pes cavus foot(high arch foot).

**Measurement of muscle activity by EMG**

To examine the muscle activity of lower limbs at
the time of drop landing, pocket EMG was used for
both groups.
In order to reduce errors, the subjects were given
an explanation of the experiment purpose and the
directions.
The researcher had the subjects undergo enough
warm-ups to prevent any wound and to collect the
data of good quality and the subjects in their shorts
had the electrode attachment parts shaved and dis-
fected.
The electrode was continuously attached to the
same person for the unity of this experiment.
Electrode was attached to each belly of lateral gas-
trocnemius muscle, medial gastrocnemius muscle
and tibialis anterior, which act for the motion of
drop landing as well as walking(17).
All subjects were briefed on the motion of drop
landing and a wooden box for experiment, of which
the height was 40cm(18).
An explanation on how to place the feet at landing
was also given to them and preliminary tests of more
than 5 times were implemented in order to induce
the subjects to execute a natural landing, prior to the
real test.

![Testing Position]

**Fig. 2.**, Testing position

![Maximal Vertical Reaction Force]

**Fig. 3.**, The maximal vertical reaction force,
The real test was implement two times, repeatedly and the subjects were not allowed to jump at the time of vertical landing.

The landing results of the subjects who landed only on one foot or failed to fix the feet on the ground due to losing their balance, were exempted.

Data Analysis

Variables for the comparative analysis between the 2 groups of normal and flat foot on the maximal vertical reaction force and the muscle activity went through the process of statistical treatment and, through the treatment, the mean value of the test data of 2 times were gained and applied.

The maximal vertical reaction force was obtained through calculating the maximum value at the moment of landing and the outcome data were standardized, being divided by the body weight (BW) of the subjects (Fig. 3).

With regard to the muscle activity of lower limbs, the activities of lateral gastrocnemius muscle, medial gastrocnemius muscle and tibialis anterior were measured when the maximal vertical reaction force worked and the mean value of the measurements was applied to the research.

To investigate the difference of maximal vertical reaction force and muscle activity of lower limbs between the groups of normal foot and flat foot, independent sample t-test was used and the significance ratio was set at 5%.

### RESULTS

#### The Comparison of Maximal Vertical Reaction Force between the Group of Normal Foot and the Group of Flat Foot.

The maximal vertical reaction force at drop landing of both of the groups is as shown in Table 3. The normal foot shows the numbers of 32.26±1.91 and the flat foot shows the numbers of 29.70±2.77 and there is a statistical difference of significance between the two groups.

**Table 3. The comparison of maximal ground reaction force (N/BW)**

<table>
<thead>
<tr>
<th>Maximal vertical Reaction force</th>
<th>Normal foot Mean±SD</th>
<th>Flat foot Mean±SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.267±1.91</td>
<td>29.70±2.77</td>
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</tbody>
</table>

#### The Comparison of the Muscle Activity of Lower Limbs between the Group of Normal Foot and the Group of Flat Foot.

The muscle activity of lower limbs was gauged when the vertical reaction force worked to maximal extent and the comparison of it between two groups is as presented in Table 4. Upon comparing the mean value of all muscles’ activity, the group of flat foot showed higher activity than the group of normal foot but there was no statistical difference of significance between them.

**Table 4. The comparison of muscle activity of lower limbs (unit : mv)**

<table>
<thead>
<tr>
<th></th>
<th>Normal foot Mean±SD</th>
<th>Flat foot Mean±SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis anterior(right)</td>
<td>.300±.125</td>
<td>.034±.179</td>
<td>.655</td>
</tr>
<tr>
<td>Tibialis anterior(left)</td>
<td>.183±.076</td>
<td>.194±.096</td>
<td>.802</td>
</tr>
<tr>
<td>Lateral gastrocnemius muscle(right)</td>
<td>.191±.093</td>
<td>.191±.067</td>
<td>.995</td>
</tr>
<tr>
<td>Lateral gastrocnemius muscle(left)</td>
<td>.192±.071</td>
<td>.214±.108</td>
<td>.608</td>
</tr>
<tr>
<td>Medial gastrocnemius muscle(right)</td>
<td>.189±.075</td>
<td>.213±.102</td>
<td>.582</td>
</tr>
<tr>
<td>Medial gastrocnemius muscle(left)</td>
<td>.181±.063</td>
<td>.198±.114</td>
<td>.703</td>
</tr>
</tbody>
</table>

### DISCUSSION

#### The Comparison of Maximal Vertical Reaction Force between the Group of Normal Foot and the Group of Flat Foot.

The foot sustains the body weight and responds to the shift of center of body gravity and it has also the functions of being adapted to the ground and maintaining the balance (19). The flat foot, of which the foot arch has fallen down, is influencing on the tibial internal rotation, knock knees of knee joint.
and the internal rotation of the femoral part and it exerts a bad effect on the pelvis, so the flat foot has problem in keeping the body’s balance(20). The motion of drop landing can be seen frequently in the scenes of various sports activity as well as in the leading of daily life and it could be a cause of latent body injury or wound.

Upon comparing the maximal vertical reaction force at time of drop landing from a height of 40cm between normal foot and flat foot, the researcher found that there was a statistical difference of significance between normal foot and flat foot. The reaction force in vertical direction has two kinds of impact peak and one of them is made when a person makes the landing on front part of sole and the other is made when a person does on heel(21), and 80% of all drop landings are made on heel, also had reported that the case of landing on heel had a higher impact peak than the landing on front part(7). They have presented in a research on the plantar pressure dispersion in standing state that the normal foot had a higher pressure on medial calcaneus, whereas the flat foot had a high pressure on the part of metatarsal(22). The same research also presented that the flat foot showed a higher pressure on the part of metatarsal while it showed a salient decrease of force on the parts of lateral front part, lateral metatarsal and lateral/medial calcaneus, even in the state of walking(23). But introduced a result which is different from the result of this research, maintaining that there was no significant difference between normal foot and flat foot in terms of average pressure on the sole(24).

Self and Paine announced that the impact of landing grows bigger when the flexion movement of knee is limited(25) and the group of flat foot is considered to have shown more flexion movements of knee as a compensatory way to reduce the impact(26).

The Comparison of Muscle Activity of Lower Limbs at Time of Landing between the Group of Normal Foot and the Group of Flat Foot.

The damage with the sustaining organization of medial longitudinal arch causes the flat foot to show the features of heel valgus, forefoot abduction, Archilles tendon’s shortening and forefoot supina- tion(27). The more one gets older, the more the danger of being wounded increases, because the flat foot triggers the tension of fascia and muscle(28). Specially the motion of drop landing which is frequently seen in daily life and various exercises, has the riskiness of being injured(29). The drop landing affects the muscle activity(26) as it might make the lower limbs bear the overload of more than 10 times of one’s weight, depending on height(10). Triceps muscle of lower limb, lateral gastrocnemius muscle, medial gastrocnemius muscle and tibialis anterior which were known to have influences on drop landing, were also compared each other in this research, from the angle of muscle activity but there is no statistical difference of significance between normal foot and flat foot, However, it could be perceived that the numeric value with the flat foot was shown higher on average.

Toolan et al, reported the triceps surae is a muscle that forms the dynamic foot arch(30) and the strengthening of tibialis anterior and the triceps is required as a means of therapy for flat foot(31). The electromyography is a measuring apparatus to figure out the muscular disease, the contribution of muscle and the muscular fatigue and the informations for the prevention of a damage, or a remedy are provided through this tool(32). Tibialis anterior is a muscle that is principally acting in the dorsiflexion of ankle joint. They has watched female gymnasts’ cross- jump motions on a balance beam in order to compare the muscle activity of tibialis anterior at time of landing between the excellent group and the non-excellent group and found that the non-excellent group showed a higher muscle activity of tibialis anterior muscle(33). The measurement of muscle activity that was made through watching the subjects’ (22 flat foot and 21 normal foot) landing from a height of 40cm, brought us the numbers of 18.48±10.08 for normal foot and of 21.51±0.83 for flat foot and we can realize, from these numbers, that the research conforms to this research in the point that the muscle activity with flat foot is higher than that with normal foot(34). This higher muscle activity is caused because the medial longitudinal arch with flat foot can not disperse the impact and weight efficiently and this also accords with the result of a precedent research that an excessive impact like a landing might cause the injury of lower limbs, The lateral gastrocnemius muscle and medial gastrocne- mius muscle are the principally acting muscles in plantar flexion of ankle joint and the flexion of knee joint and has reported that the lateral gastrocnemius muscle showed no significant difference at time of the female gymnasts’ landing(33). And reported that the increase of EMG signal is the growth of muscular strength, which signifies the increased ability in terms of muscular utilization(35), The maintenance of muscle activity is essential to keep the stability
and balance at drop landing. The plantar flexor muscle is important to decelerate the landing speed and the research did not show any significant increase of medial gastrocnemius muscle’s activity, proving that the research accords with this research. Accordingly it is known that the flat foot strengthens the muscle activity of the musculus triceps surae, as it has difficulty in dispersing the impact of drop landing(35). Therefore, the flatfooted man needs to intensify the extensor muscle of joint knee and plantar flexor muscle of ankle joint which are much affected at time of shock absorption and also needs to minimize the feasibility of injury through strengthening the ligament, modifying the intrinsic and extrinsic muscle and amending the posture. Also the taping therapy(36) and the wearing of a biomechanical foot orthosis(37) are required for the flat foot to sustain the medial longitudinal arch. Through sustaining the medial longitudinal arch, the weight load on foot can be dispersed and the vertical reaction force can be absorbed, thus, finally it is considered the balancing sense should be improved with increase of the stability of foot(38). The researcher suggests that the kinematic and kinetic analysis on joint and muscle activity should be achieved in future researches in order to draw a meaningful conclusion with respect to the influences on flat foot and on drop landing.

CONCLUSION

In this research, the comparative analysis on the maximal vertical reaction force and the muscle activity of lower limbs at time of drop landing was performed between the two groups of normal foot and flat foot. This research measured the maximal ground reaction force and the muscle activities of lower legs under maximum reaction and compared 9 subjects of flat foot with 9 subjects of normal foot on the result. The result follows as under:

1. The difference between the 2 groups of normal foot and flat foot was statistically significant in terms of maximal ground reaction force.

2. The difference between the 2 groups of normal foot and flat foot was not statistically significant in terms of muscle activity at time of maximum reaction.

Synthesizing the research results, two facts are brought to our notice, One is there was a significant difference in maximal ground reaction force and the other is the flat foot showed a higher muscle activity on average, though there was no difference of statistical significance in muscle activity at time of maximum reaction. Therefore, the flatfooted persons are required to strengthen the extensor muscle of knee joint and the plantar flexor muscle of ankle joint, Also they are required to minimize the risk of injury through strengthening ligament, transforming intrinsic and extrinsic muscle of foot and modifying the postures. The researcher considers that the in-depth study on muscle activity should follow and the kinematic and kinetic analysis on joint should be progressed in future researches.

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