Original article

Association between hip abductor function, rear-foot dynamic alignment, and dynamic knee valgus during single-leg squats and drop landings

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Abstract

Background: Preventing anterior cruciate ligament (ACL) injuries is very important for athletes, and dynamic knee valgus is considered a risk factor for non-contact ACL injury. However, little is known about whether the functions of the hip abductor and rear-foot increase dynamic knee valgus. A two-dimensional (2D) video-based screening test focused on hip abductor and rear-foot functions among factors involved in dynamic knee valgus. The present study determined associations between hip and rear-foot dynamic alignment and dynamic knee valgus.

Methods: This cross-sectional study recruited 130 female basketball players (258 legs) from nine high-school teams. The players performed single-leg squats and single-leg drop landings to provide knee-in (KID) and hip-out (HOD) distances on 2D video images. Hip and rear-foot dynamic alignment was evaluated using a dynamic Trendelenburg test (DTT) and a dynamic heel-floor test (HFT).

Results: The Chi-square test revealed no significant difference in the prevalence of DTT-positivity between single-leg squats (28.7%) and single-leg drop landings (23.3%). The prevalence of HFT-positivity was significantly greater during landings (51.4%) than during single-leg squats (31.0%, \( p < 0.01 \)). The KID values for both single-leg squats and single-leg drop landings were greater in the DTT-positive than in the DTT-negative group (15.1 ± 5.4 cm and 20.2 ± 7.5 cm, \( p < 0.001 \)). The KID values for both single-leg squats and single-leg drop landings were greater in the DTT-positive than in the HFT-negative group (15.2 ± 1.9 cm and 17.6 ± 2.8 cm, \( p < 0.001 \)). The KID values for both single-leg squats and single-leg drop landings were greater in the HFT-positive than in the HFT-negative group (12.2 ± 5.1 cm, \( p < 0.01 \); 14.7 ± 7.2 cm, \( p < 0.001 \)), whereas HOD values for these tasks did not significantly differ between the two groups.

Conclusion: Dynamic hip mal-alignment might be associated with both greater KID and HOD, whereas rear-foot eversion is associated only with greater KID. Hip abductor and rear-foot dysfunction are important factors for dynamic knee valgus and thus evaluating DTT and HFT will help to prevent dynamic knee valgus.

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Keywords: 2D screening test; ACL injury; Dynamic alignment; Hip abductor and rear-foot function; Prevention

1. Introduction

A high proportion of anterior cruciate ligament (ACL) injuries occur during sports activities. Over 70% of all ACL injuries sustained while playing basketball are non-contact and occur while landing from jumps, or while rapidly stopping and changing direction without direct body contact. The incidence of ACL injury is three- to five-fold higher among female than male athletes, and the peak age of ACL injury in females is 16 years. Typical non-contact ACL injuries comprise a combination of knee valgus, slight flexion and a posterior shift in the center of gravity. A prospective study of 205 female adolescent athletes by Hewett et al. identified knee abduction angles and moments as reliable predictors of ACL...
injury using three-dimensional (3D) joint kinematic and kinetic analyses. They found that nine athletes with ACL injury had significantly greater knee abduction angles and abduction moments than uninjured athletes during vertical drop jumps.9

Many ACL injury prevention programs have been developed based on these injury mechanisms or biomechanical data, and evidence has indicated the effectiveness of exercise.10–16 On the other hand, the same program to prevent ACL injury is often applied to all players in a team as part of an integrated protocol. Among them, Hewett et al.13 and Myer et al.14,15 evaluated dynamic knee valgus using a drop jump test from a height of 31 cm and identified high-risk players. They provided jump-training programs such as wall-jumps to those at high risk with a view to improving their jumping and landing techniques. These prevention programs increased knee stability and decreased knee injury rates in female athletes. Noyes et al.16 have also measured normalized knee separation distance using the drop-jump screening test and developed a neuromuscular training program. However, little is known about whether or not the function of the hip and foot of the other leg increases dynamic knee valgus.17

Claiborne et al.18 identified a negative correlation between hip abduction peak torque and valgus knee motion during single-leg squats. Jacobs et al.19 reported that hip abductor peak torque is lower and knee valgus is larger during landing among females than males. However, Thijs et al.20 found no significant correlation between hip muscle strength and the amount of knee valgus moment during a forward lunge. Additionally, the conventional Trendelenburg test is an established method of evaluation for gluteus medius muscle weakness. Takacs and Hunt21 reported that the knee adduction moment significantly increases with contralateral pelvic drop compared with level pelvis trials. The results of these studies suggested that static lower leg alignment differs from dynamic function. Therefore, our screening test uses a dynamic Trendelenburg test (DTT) to assess contralateral pelvic drop during single-leg squats and single-leg drop landings to determine dynamic hip abductor muscle dysfunction.22

Rear-foot eversion is thought to be coupled with tibial internal rotation not only while standing but also during the stance phase of gait or running.23–25 Excessive pronation of the foot during exercise has frequently been cited as a risk factor for lower limb injury.26,27 Many investigators consider excessive eversion as a rear-foot angle of greater than 4°–6°.28–32 Some static measures such as calcaneal angle have been investigated as possible predictors of dynamic rear-foot motion.33,34 However, static rear-foot alignment has not been found to be an accurate predictor of dynamic knee valgus. In addition, few reports describing the relationship between rear-foot alignment and dynamic knee valgus have been published to date, even though navicular drop is greater among athletes with than without ACL injuries.35,36 Therefore, our screening test used a dynamic heel-floor test (HFT) to assess >5° of rear-foot eversion during single-leg squats and single-leg drop landings.22

Most investigators measure angles of knee valgus from the frontal plane on two-dimensional (2D) video-based screening images.37,38 However, even though the dynamic alignment of knee-in and hip-out differ kinematically and kinetically, both knee valgus angles might be similar in 2D video analysis. Therefore, we measured dynamic knee valgus during single-leg squats and drop landings on 2D video images using knee-in distance (KID) to reflect knee inward displacement and hip-out distance (HOD) to reflect pelvic outward displacement. This study aimed to determine the functional association between the alignment of hip and rear-foot dynamics with dynamic knee valgus. We speculated that the amount of dynamic knee valgus would be greater in female basketball players with hip abductor dysfunction and rear-foot dynamic eversion.

2. Materials and methods

2.1. Participants

This cross-sectional study recruited 130 females, Japanese high-school basketball players (258 legs; age, 16.9 ± 0.6 years; basketball experience, 6.7 ± 2.0 years; height, 161.6 ± 5.8 cm; weight, 54.0 ± 6.3 kg) from nine high-school basketball teams. Injury history included Osgood-Schlatter disease (n = 12), overuse syndrome (n = 28), and acute injury (n = 9) including ACL injury (n = 2). The two players with a history of ACL injury had undergone reconstruction surgery over 1 year before participating in the present study. Although 37 athletes (44 legs) had experienced knee pain, they could play basketball without difficulty. The exclusion criteria comprised prior knee injury that involved surgery and pain upon performing the tasks required in the study. Thus, the players with ACL damage that had been treated by surgical reconstruction were excluded and data from 258 legs were analyzed.

The Research Ethics Committee of the School of Nursing and Rehabilitation Sciences at Showa University approved the study protocol. Written informed consent was obtained from all participants, their parents, and head coaches.

2.2. Procedures

The participants wore fitted dark shorts and were tested barefoot. Flat markers (9 mm in diameter) were placed at the anterior superior iliac spine (ASIS), the center of each patella, the center of the insertion of each Achilles tendon, the tibial tuberosity and the hallucis of both the right and left legs. They performed single-leg squats and single-leg drop landings from a 30 × 50-cm (height × width) box. Digital video cameras (Sony, Tokyo, Japan) were placed on stands in front and at the back of the participants and frontal images were recorded at 30 Hz. One stand was positioned about 4 m in front of each participant. The center of the front camera lens was adjusted to the height of the knees of participants while standing on a 30-cm high box. The other stand was positioned 4 m behind the box. The center of the back camera lens was positioned at the height of the insertion of the Achilles tendon.
Before the trials of single-leg squats, a research assistant measured each knee flexion angle using a goniometer and announced when it reached 60°. All participants practiced sufficiently to achieve the prescribed knee angle. The knee flexion angle of 60° was decided with consideration for balance ability while performing single-leg squats, as well as a report of low anterior shear forces between 0° and 60° knee flexion. The participants clasped their hands behind their backs and balanced on one leg with the contralateral knee bent to about 90°. A sequence of single-leg squats was repeated by bending the knee of the supporting leg to 60° and then straightening it until one successful trial was completed. For the single-leg landing trial, the participants maintained balance while standing on one leg on the box and jumped from 30 cm to land directly in front of the box on the ipsilateral leg. They repeated a few single-leg landings until one trial was successful in consideration of fatigue, because Geiser et al. found that knee abduction angle increases during jumps in the hip abductor fatigue protocol. A trial in which the participant did not move the hands from behind the back or the landing foot from the floor and maintained balance on the landing leg for >2 s was deemed successful.

2.3. Data analysis

2D images were captured onto an external hard disk drive that was plugged into a laptop computer. The point of maximal knee valgus was analyzed during single-leg squats and single-leg landings using Dartfish Software 4.5 ProSuite Version (Dartfish, Fribourg, Switzerland). KID and HOD were measured on 2D video images of dynamic knee valgus (Fig. 1). The KID was defined as the distance from the hallux to the point where the line connecting the center of the patella and ASIS intersects the floor. The HOD was defined as the distance from the hallux to the projection of ASIS on the floor.

Hip abductor function was evaluated using a DTT during single-leg squats and single-leg landings. The DTT was considered positive if the non-weight-bearing pelvis descended to a point below the weight-bearing pelvis according to a line drawn parallel to the Dartfish images. Rear-foot dynamic alignment was evaluated using an HFT during single-leg squats and drop landings. The HFT was considered positive if rear-foot eversion was ≥5° in Dartfish images (Fig. 2).

2.4. Statistical analysis

Means ± SD were calculated for KID and HOD during single-leg squats and single-leg drop landings. DTT-positive and HFT-positive are shown as (+), whereas DTT-negative and HFT-negative are shown as (−). The prevalences of DTT-positive and HFT-positive single-leg squats and single-leg drop landings were compared using the Chi-square test. The significance of differences in KID between DTT (HFT)-positive and -negative groups during single-leg squats and drop landings was analyzed using unpaired Student t tests. The HOD was also compared between DTT (HFT)-positive and -negative groups during single-leg squats and drop landings using t tests. Statistical significance was established at a level of p < 0.05. All data were analyzed using SPSS 14.0 statistical software (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Prevalence of DTT- and HFT-positivity

During single-leg squats, 74 (28.7%) and 184 (71.3%) legs were DTT-positive and -negative, respectively; during single-
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Leg drop landings, 58 (23.3%) and 191 (76.7%) legs were DTT-positive and -negative, respectively. The prevalence of DTT-positivity did not significantly differ between single-leg squats and single-leg drop landings.

Rear-foot eversion of ≥5° was found in 80 (31.0%) HFT-positive legs and in 178 (69.0%) HFT-negative legs while performing single-leg squats. During single-leg drop landings, 128 (51.4%) legs were HFT-positive and 121 (48.6%) were HFT-negative. The prevalence of HFT-positivity was significantly greater for single-leg drop landings than for single-leg squats (p < 0.01).

3.2. KID and HOD values during single-leg squats and drop landings (Table 1)

With respect to dynamic knee valgus during single-leg squats, the KID values in the DTT-positive group were twice as high as those in the DTT-negative group (p < 0.001). The Hod values were significantly greater in the DTT-positive group (p < 0.001). Whereas the KID values in the HFT-positve group were significantly greater than in the HFT-negative group (p < 0.001), the Hod values did not significantly differ. This study indicates that both knee-in and hip-out values increase in athletes with lowered hip abductor function, but knee-in values increase, whereas hip-out values do not change in athletes with decreased rear-foot function. With regard to dynamic knee valgus during single-leg drop landings, the KID values were 2.2-fold greater and the Hod values were significantly greater in the DTT-positive than in the DTT-negative group (p < 0.001). Furthermore, the KID values were significantly greater in the HFT-positive than in the HFT-negative group (p < 0.001). The Hod values did not significantly differ between the groups.

4. Discussion

More female than male basketball athletes sustain ACL injuries,

of which almost 70% are non-contact. A potential link has been suggested between excessive dynamic knee valgus while landing or cutting and ACL injury risk. Dynamic knee valgus is defined as the position or movement of the distal femur towards, and the distal tibia away from the midline of the body. Factors involved in dynamic knee valgus are considered to include not only the strength of the quadriceps femoris muscle but also that of other parts of the leg. Some investigators have recently screened athletes with a risk of ACL injury and provided them with effective prevention programs.

The present study focused on hip abductor and rear-foot functions among the factors involved in dynamic knee valgus and conducted screening tests using single-leg squats and single-leg drop landings. The hypothesis that dynamic knee valgus is increased in athletes with lowered hip abductor and rear-foot function was tested. The results indicated associations between hip abductor function, rear-foot function, and dynamic knee valgus.

Most investigators have reported that athletes with weak hip abduction or external rotation strength have increased dynamic knee valgus. Claiborne et al. identified a negative correlation between knee valgus and hip abduction peak torque (r = −0.37) during single-leg squats in a 3D assessment of hip muscle strength and frontal plane knee motion. Geiser et al. reported that the knee angle at initial ground contact becomes abducted during jumps in the hip abductor fatigue protocol. We designed the DTT to assess hip abductor muscle dysfunction during dynamic behavior, although the conventional Trendelenburg test is an established method of evaluating gluteus medius muscle weakness while standing. The present study showed that about 30% of the legs were DTT-positive and that the KID values in the DTT-positive group were twice as high as those in the negative group. However, the conventional Trendelenburg test was negative even for DTT-positive participants. The DTT might reflect not only gluteus medius muscle strength but also hip external rotation muscle strength.

Khamis and Yizhar reported that calcaneus eversion consequentially increases while standing on wedges, and that the shank and thigh rotate internally. Souza et al. suggested a temporal coupling of rear-foot eversion with hip internal rotation and rear-foot inversion with hip external rotation during the standing phase of walking. Pohl et al. also indicated a closer correlation between rear-foot eversion and shank internal rotation while running.

Therefore, an increase in hip adduction and internal rotation probably caused the KID values to increase in the DTT-positive group.

Rear-foot eversion is thought to be coupled with tibial internal rotation while standing, walking, and running. Khamis and Yizhar reported that calcaneus eversion consequently increases while standing on wedges, and that the shank and thigh rotate internally. Souza et al. suggested a temporal coupling of rear-foot eversion with hip internal rotation and rear-foot inversion with hip external rotation during the standing phase of walking. Pohl et al. also indicated a closer correlation between rear-foot eversion and shank internal rotation while running. Therefore, considering the kinetic chain of the lower extremities, the medial longitudinal arch appeared to be lower in accordance with rear-foot eversion and, owing to the medial tilting of the shank, the KID values increased in the HFT-positive group. Meanwhile, since the pelvic position had shifted medially in conjunction with the medial tilting of the shank, the Hod values did not significantly differ. Besides, excessive eversion of the

Table 1

Knee-in distance (KID) and hip-out distance (HOD) values during single-leg squats and single-leg drop landings.

<table>
<thead>
<tr>
<th>Single-leg squats</th>
<th>Single-leg drop landings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
</tr>
<tr>
<td>DTT (+)</td>
<td>74</td>
</tr>
<tr>
<td>DTT (−)</td>
<td>184</td>
</tr>
<tr>
<td>HFT (+)</td>
<td>80</td>
</tr>
<tr>
<td>HFT (−)</td>
<td>178</td>
</tr>
</tbody>
</table>

*p < 0.001, compared with DTT (+) or HFT (+) values. Abbreviations: DTT = dynamic Trendelenburg test; HFT = dynamic heel-floor test.
for lower limb injury. However, dynamic rear-foot alignment is not an accurate predictor of dynamic knee valgus, though navicular drop is greater among athletes with than without ACL injuries. Johanson et al. determined the effects of different orthotic posting methods on controlling abnormal foot pronation during ambulation. They indicated that posting the rear-foot was more effective in controlling foot pronation than posting the forefoot. The HFT assesses rear-foot dynamic alignment and not the medial longitudinal arch. The practicality and versatility of the 2D video analysis supports the notion that HFT is a helpful tool for evaluating rear-foot function.

Dynamic knee valgus was screened in the present study by having participants perform single-leg squats and single-leg drop landings. Such single-leg tasks are important to assess individual hip abductor and rear-foot function, although many athletes will not necessarily perform the movement patterns associated with the tasks in their sport. Since the prevalence of DTT-positivity did not significantly differ between single-leg squats and single-leg drop landings, we considered that either test would be useful for evaluating dynamic knee valgus in terms of hip abductor function. Meanwhile, the prevalence of HFT-positivity was significantly high (51.4%) during single-leg landings, indicating that HFT was heavily affected during this test. Ground reaction force is several-fold greater than body weight when landing from a height and therefore skillful landing affects the likelihood of sustaining ACL injuries. Cortes et al. discovered that the hip flexion angle of HFT-positivity was significantly high (51.4%) during this test. Ground reaction force is several-fold greater than body weight when landing from a height and therefore skillful landing affects the likelihood of sustaining ACL injuries. Cortes et al. discovered that the hip flexion angle is greater and knee valgus is smaller when landing on the rear-foot compared with the forefoot. Considering the prevalence of HFT-positivity and the skill factor involved in single-leg drop landings, both single-leg squats and single-leg drop landings are needed to evaluate dynamic knee valgus in terms of rear-foot alignment. Moreover, dynamic knee valgus might need to be evaluated by measuring both KID and HOD since HOD values differed between the DTT-positive and HFT-positive groups. This test could be useful not only for basketball players but also for other athletes to assess the factors involved in dynamic knee valgus.

The major limitation of this study is that we conducted 2D analysis using a digital video camera, instead of 3D analysis that can generate accurate values of angle displacement. McLean et al. obtained an excellent regression relationship in a 2D and 3D comparison of knee valgus during side jumps. Nagano et al. also reported a significant regression relationship between 2D and 3D knee valgus angles during continuous jump landing tasks. However, since knee valgus in the frontal plane has never been compared based on distances such as KID and HOD until now, a comparison between 2D and 3D analysis using our measurement method would be meaningful. McClay and Manal indicated that differences between rear-foot eversion values are minimal compared with 2D and 3D variables when the foot is abducted between 7° and 10°. Foot placement must be aligned with the camera lens in single-leg tasks. Another limitation of this study is that we analyzed data from only one successful trial, because knee abduction angle increases during jumps in the hip abductor fatigue protocol. Since repeatability was not validated in this study, reliability over time might require assessment. On the other hand, 2D motion analysis using a digital video camera has the advantage of convenience for measurements, analyses and screening tests for ACL injuries. The present findings indicated that 2D video-based analyses such as KID, HOD, DTT, and HFT should be used to identify athletes at higher risk for ACL injury in various sport-related studies.

5. Conclusion

Hip abductor function and dynamic rear-foot alignment was screened using a 2D video camera to help develop programs to prevent ACL injury among high-risk athletes. We found that KID and HOD values for both single-leg squats and drop landings were greater in DTT-positive female basketball players with hip abductor dysfunction than DTT-negative players. On the other hand, KID values for both single-leg squats and landings were greater for HFT-positive players with rear-foot dysfunction than for HFT-negative players, whereas HOD values did not significantly differ between the groups. Therefore, dynamic hip misalignment might be associated with both greater KID and HOD, whereas rear-foot eversion is associated only with a greater KID. Hip abductor and rear-foot dysfunction were important factors for dynamic knee valgus and thus evaluating DTT and HFT should help to prevent dynamic knee valgus and decrease the frequency of ACL injuries among basketball players.

References

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