Single Leg Squat Test and Its Relationship to Dynamic Knee Valgus and Injury Risk Screening

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Abstract

Background: Lower extremity injuries are common in athletes. Valid tests to assess for risk of injury that are easily performed during a preparticipation sports physical examination are lacking. Two-dimensional (2D) analysis of the drop-jump test can identify athletes at risk, but it is too expensive and cumbersome to use in this setting.

Objective: To identify if those who perform a "positive" (abnormal postures) single leg squat (SLS) test also exhibit greater "dynamic valgus" on the 2D drop-jump test. Our secondary purpose was to assess whether group differences in gender, age, or body mass index are evident between those who exhibit a positive SLS test result versus a negative SLS test result. Also, we wanted to determine any gender differences with the 2D drop-jump test.

Design: A cross-sectional study.

Setting: Private practice, preparticipation sports physical examinations.

Participants: A total of 142 middle school and high school athletes.

Methods: Participants performed a SLS test and a drop-jump test during their preparticipation sports physical examination. Individuals were partitioned into groups based on the outcome of their SLS test (positive SLS group versus negative SLS group). Independent sample t-tests were used to evaluate SLS group differences in the drop-jump test, age, and body mass index, and the $\chi^2$ test was used to evaluate SLS group differences in gender ($P \leq .05$).

Main Outcome Measurements: The SLS test and drop-jump test.

Results: Seventy-three of the 142 athletes (51%) had a positive SLS test result, whereas 69 athletes (49%) had a negative SLS test result. Individuals in the positive SLS group had a significantly lower knee-hip ratio, indicative of greater dynamic knee valgus, than did those in the negative SLS group ($P = .02$). Individual characteristics between SLS groups including gender, age, and body mass index were similar.

Conclusion: The SLS test is a reasonable tool to use in preparticipation sports physical examinations to assess for dynamic knee valgus and the potential risk of lower extremity injury.

Introduction

Lower extremity injury in sports is common in high school athletes, ranging from 29%-89% of all injuries sustained in 1 year [1]. The incidence of lower extremity injury in high school athletes was 1.33 per 1000 athletic exposures, which represents 807,222 nationally per year [2]. Some lower extremity injuries, such as anterior cruciate knee ligament (ACL) injuries, result in significant time loss from sport and an increased risk of osteoarthritis later in life [3]. Girls’ soccer has the highest incidence of ACL injury in the 14-18-years-old age group, at 14.08 per 100,000 athletic exposures, with football the second highest incidence, at 13.8 per 100,000 athletic exposures [4]. Interest in sport injury prevention has been expanding in the past 10-15 years, particularly in light of injury prevention programs that have been shown to reduce injury rates of the ACL and other lower extremity injuries [5-10]. Implementation of these injury prevention programs can be challenging and are not readily available. An alternative to generalized injury prevention training for all athletes would be to prescreen athletes and stratify individual risk of injury. This type of prescreening may allow targeted prevention techniques for individual athletes [11].

Clinical biomechanical tests proposed to identify at-risk athletes for lower extremity injuries include the single leg squat (SLS) test [12,13], drop-jump test...
Participants

Participants consisted of 142 athletes (92 girls and 50 boys; mean (standard deviation) age, 13.8 ± 1.8 years) who were recruited at preparticipation sports physical examinations from 4 physical examination sessions over a 2-year period (Table 1). Athletes with previous lower extremity injuries were excluded from participating in the study. The participants were composed of middle school and high school athletes who were participating in cross country, track, soccer, football, wrestling, volleyball, Nordic and alpine ski racing, lacrosse, and basketball. All the athletes signed assent forms and their parents signed consent forms before participation.

Methods

Procedures

The participants were evaluated while performing an SLS test and a 2D drop-jump test. Evaluators were licensed physical therapists, orthotists, or certified athletic trainers who had undergone training in the testing methods. Each of these tests was performed on the same day (ie, the day of their preparticipation sports physical examination). Data were obtained in a blinded fashion for the SLS test and the 2D drop-jump test results, in that participants completed the SLS test at the SLS testing session and the 2D drop-jump test at the 2D drop-jump test station, which was located in a different room.

SLS Test

This test was conducted similarly to the SLS test described by Sciascia and Kibler [12]. The barefooted athletes were asked to place their hands on their hips and stand on one limb and flex the opposing limb to 90°. They then were instructed to perform an SLS to 30° of knee flexion and then return to a fully extended knee position (Figure 1). Visual inspection was used to estimate whether the participants squatted to 30°. If not, then the rater would give verbal cues to either increase or decrease the amount of knee flexion in subsequent squats. The participants performed the SLS test 3 times in a row on each leg. The investigator noted any abnormal responses, which consisted of arms flailing, the Trendelenburg sign, or collapse of the supporting knee into valgus, which indicated an abnormal response [12]. We defined a positive SLS test result as more than two-thirds of abnormal responses on either leg of the 6 total trials (3 SLS trials on each leg). Each participant was given either a positive or a negative score on the SLS test. A positive SLS test result may be suggestive of poor lower extremity mechanics, reduced core strength, or hip abductor weakness.

2D Drop-Jump Test

This test was conducted as described by Noyes et al [16]. A Sony DCR-HC92 Mini DV Handycam Camcorder (Sony Electronics Inc, San Diego, CA) was connected to a Dell Latitude E6400 laptop (Dell Inc, Round Rock, TX) equipped with Dartfish ProSuite 4.5.2.0 video software (Dartfish Software, Alpharetta, GA). The camcorder then was placed on a DYNEX Digital Series 60” Universal Tripod (Dynex Products, Richfield, MN). The tripod, which stood at 102.24 cm in height, was placed 365.76 cm in front of a box of 32.0 cm in height and 34.0 cm in width.

The participants were barefoot during the drop-jump test. Orange Styrofoam (Dow Chemical Co, Midland, MI) spheres were placed by a physical therapist onto each

Table 1

<table>
<thead>
<tr>
<th>Participant characteristics</th>
<th>Group Mean</th>
<th>Group Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Girls</td>
<td>Age, y</td>
<td>BMI, kg/m²</td>
</tr>
<tr>
<td>No. Boys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive SLS group</td>
<td>48</td>
<td>13.6</td>
</tr>
<tr>
<td>Negative SLS group</td>
<td>44</td>
<td>13.8</td>
</tr>
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BMI = body mass index; SLS = single leg squat.
subject’s left and right greater trochanter, and the center of the left and right patellas. A solid black backdrop was used behind the jump box to accentuate contrast and visibility of the orange spheres. The participants were instructed to step up onto the box and directly face the camera. Each athlete was then cued by the physical therapist who was monitoring the video camera to jump down from the box onto the floor by using both feet and then proceed to jump straight up in the air as high as he or she could by using both feet. Each participant was given these instructions for a total of 3 trials.

High-speed video analysis by using Dartfish ProSuite 4.5.2.0 video software was used to assess the distance between the hips and the knees in the frontal plane during the drop-jump test. All Dartfish analyses were conducted by a single investigator (V.U.) blinded to the SLS test results. Hip distance was measured from hip markers with the participant in the quiet stance. Knee distance (from mid marker right knee to mid marker left knee) was measured at maximum knee flexion landing from the box (Figure 2). The distance between the knees was normalized by the hip separation distance (knee-hip ratio), and this value was used as an indicator of lower limb alignment in the frontal plane (ie, dynamic knee valgus). The knee-hip ratio was calculated by taking the knee distance at maximum knee flexion and by dividing it by the hip distance at a quiet stance. The knee-hip ratio then was used as an indicator of lower limb alignment in the frontal plane (ie, dynamic knee valgus). A lower knee-hip ratio is suggestive of greater knee valgus or frontal plane collapse.

Statistics

The participants were partitioned into groups based on the outcome of their SLS tests. Therefore, we had a positive SLS group and a negative SLS group. Independent sample t-tests were used to evaluate SLS group differences in the knee-hip ratio (ie, dynamic knee valgus), age, and BMI. A χ² test was used to evaluate SLS group differences in gender. In addition, independent sample t-tests were used to evaluate gender differences in the knee-hip ratio measured during the 2D drop-jump test. All data were analyzed by using SPSS (version 21.0; SPSS Inc, Chicago, IL), with an a priori α level of .05.

To assess interrater reliability of the more subjective SLS test, we used a subset of 78 participants (51 girls and 27 boys). Interrater reliability was assessed by using a second and third rater for these participants. These 3 raters consisted of 2 physical therapists (PT1 (C.D.P.) and PT2) and a certified athletic trainer (ATC). All 3 raters observed the same athlete at the same time but were blinded to the others’ results. Interrater reliability was determined for 3 trials for the 3 observers. The Spearman correlation was used to assess interrater reliability. Spearman correlation coefficients were calculated by using an α of .05 for all rater pairings (PT1-PT2, PT1-ATC, PT2-ATC). The range in values is from −1.0 (which indicates perfect inverse correlation) to 1.0 (which indicates perfect correlation).

Results

Seventy-three of the 142 athletes (51%) had a positive SLS test result, whereas 69 athletes (49%) had a negative SLS test result. Individuals in the positive SLS group (ratio, 0.47) had a significantly lower knee-hip ratio (ratio, 0.47), which was indicative of greater dynamic knee valgus, than did those in the negative SLS group (ratio, 0.55) (P = .02). Regarding the outcome of the interrater reliability test on the subset of SLS test results data, all 3 raters were highly correlated. PT1 and PT2 were the most correlated (0.72), whereas ATC was
correlated with PT1 and PT2 at 0.45. Individual characteristics between the SLS groups, including gender, age, and BMI were similar. The positive SLS group consisted of 25 boys and 48 girls, whereas the negative SLS group consisted of 25 boys and 44 girls, and there was no difference in gender between the SLS groups ($P = .80$). There also was no statistical difference among ages of the athletes in each group (average positive SLS group age = 13.6; average negative SLS group = 13.8 years; $P = .53$). Finally, there was no statistical difference in BMI between the groups (average positive SLS group BMI = 20.3 kg/m$^2$; average negative SLS group BMI = 20.8 kg/m$^2$; $P = .47$). When comparing the knee-hip ratios of the boys and girls during the 2D drop-jump test, we found that the female athletes exhibited significantly lower knee-hip ratios compared with the male athletes (female group average knee-hip ratio = 0.45; male group average knee-hip ratio = 0.63; $P = .003$).

**Discussion**

Evaluating dynamic knee valgus is important in assessing the risk for lower extremity injury because it has been associated with an increased risk of ACL injury [15]. Our findings indicate that the SLS test provides similar information regarding dynamic knee postures to the 2D drop-jump test. The SLS test is a simple screening tool that can be used in the physician’s office or during large-scale preparticipation physical examinations to screen for athletes with poor knee control. The results of this study that examined middle and high school athletes are similar to those reported by Strensrud et al [13] who found a strong relationship between dynamic knee valgus during the SLS test and 2D drop-jump landings in elite handball players. The primary differences between the current study and that of Strensrud et al [13] were participant characteristics and difficulty of the testing protocol. The study by Strensrud et al [13] was limited to female handball players with a mean age was 22 years. However, our investigation included younger (mean age, 13 years) male and female athletes who were participating in a variety of sports. Furthermore, the SLS test technique used in their study required 90° of knee flexion with a plumb bob. In contrast, our SLS test was simpler and could easily be used in a physician’s office or during sports physical examinations with no additional equipment.

In young adults, the SLS test results showed good interrater and intrarater reliability that correlated well with 3D analysis of peak knee flexion, knee mediolateral displacement, and hip adduction [26]. The SLS test results compared with 2D and 3D video analysis was valid and reliable in young, healthy adults for mediolateral knee motion and hip function [26-29]. Thus, as seen in our study of younger recreational athletes and in other studies of young adult recreational and elite athletes, the SLS test can reliably predict dynamic knee valgus. With the SLS test results, we found no significant difference in dynamic knee valgus between boys and girls. Dwyer et al [30] had similar findings at the knee in a group of collegiate athletes. In addition, no gender differences in peak knee valgus or frontal plane

**Figure 2.** The two-dimensional drop-jump test normalized knee separation distance was measured as the knee separation distance at peak knee flexion during landing (A) divided by the hip separation distance measured during quiet stance (B).
movement was found with the SLS test results in a group of young adults [23]. In contrast, a study of collegiate age athletes demonstrated significant gender differences in knee varus and valgus, and in ground reaction forces during the SLS test when using a 3D kinematic analysis [25]. The sensitivity of 3D analysis with measurement of joint angles likely explains this difference. In another study, of 46 collegiate athletes, gender differences with the SLS test results were identified with female athletes exhibiting greater knee valgus [24]. Gender differences or lack thereof in the above studies may reflect differences in methodology, subject characteristics (age or level of athlete), or variations in the definition of an abnormal SLS test result.

Our study found no gender differences when using the SLS test to examine lower extremity movement patterns. In contrast, when we examined the influence of gender on the 2D drop-jump test alone in this population, we found that the girls exhibited decreased knee-hip ratios, which is suggestive of increased dynamic knee valgus. These findings are consistent with 2D studies with similar methodology [16,31] and in numerous 3D motion analysis studies that reported that girls exhibit greater knee valgus angles compared with their male counterparts during drop-landing tasks in high school athletes [32-34], in >12 year olds [35], and in collegiate age athletes [36-38]. Only one study that used a 2D analysis found no gender difference in drop-jump landings [39]. The predominance of data supports that gender differences exist in knee movement patterns during landing. In our study, there was a clear link between movement patterns exhibited during the SLS and the drop-jump tests movement patterns; however, differences in findings regarding gender indicate that, although related, the SLS and drop-jump tests measure different variables and offer different biomechanical challenges. One primary advantage of the SLS test over the drop-jump test is the ability to assess individual limbs.

During the data collection and reduction, it was observed that many of the athletes with poor knee control on landing had difficulty lowering their heels to the floor. This phenomenon may be due to a tight Achilles tendon but was not examined in this investigation. Bell et al [40] investigated flexibility patterns in persons with excessive medial knee displacement. They found reduced flexibility in the Achilles tendon correlated with poor frontal plane knee control. Hip strength, indirectly measured by the SLS test, also has been shown to be a component of frontal plane knee motion control [23,28]. Future studies of frontal plane knee motion should include an evaluation of hip and ankle strength and flexibility. The SLS test has shown value in other assessments as well, which were not evaluated in the current study. The SLS test identifies core strength [22] and relates to landing, running, and cutting tasks [13,23-25,41].

**Future Direction**

Risk assessment may be useful, either alone, as with the SLS test, or the subjective drop-jump test, or in combination, such as in the FMS to identify athletes at risk for injury. The FMS is not practical in a physician’s office or during large-volume preparticipation sports physical examinations. The SLS test as described in this study or an observed drop-jump test could easily be performed in the physician’s office. To fully understand the utility of the SLS test, it needs to be studied with a large cohort over time and matched with injury data to determine its predictive value. In addition, for the SLS test to be applied as a clinical test, uniformity in performance of the test is needed. Variations in the degree of knee flexion for the squat have been described from 30°-60° to maximal squat without losing balance [12,13,23-25,30].

**Limitations**

The 3D motion capture is the criterion standard technique to measure knee valgus angles. Although it is the criterion standard, the majority of clinicians do not have access to this technology, and 2D analysis has its limitations. For example, McLean et al [42] found transverse plane excursions measured in 2D accounted for a significant portion of the variance in the 3D knee valgus angle. Even though 2D has its limitations, it is considerably more affordable and has been shown to be a reliable indicator of frontal plane projection angles that correlate with 3D knee valgus angles [43]. An additional study limitation is related to clothing. Ideally, the participants would have worn a tight fitting short but, due to the nature and fast pace of the preparticipation sports physical examinations, we captured data with the participants wearing the shorts in which they arrived. A final limitation was that different SLS test raters were used during year-1 and year-2 testing.

**Conclusion**

Although injury rates for middle school athletes are unknown, lower extremity injuries in high school athletes are more than 800,000/y nationally [2]. Identifying athletes at risk for these injuries and implementing methods to prevent injury are important to keeping children active and preventing disabling sequelae, for example, posttraumatic knee arthritis. Our findings revealed that the simple SLS test can be used in the clinical setting both in providers’ offices or during large preparticipation sports physical examinations to add a component of biomechanical screening for potential injury risk reduction. It is a simple step to implement clinically in a movement toward more widespread risk injury assessment. For athletes who do not have the
opportunity to participate in large-scale ACL prevention programs, individual instruction may be helpful in reducing individual risk.

References

38. Chappell JD, Creighton RA, Giuliani C, Yu B, Garrett WE. Kine-
matics and electromyography of landing preparation in vertical
39. Barber-Westin SD. Jump-land characteristics and muscle strength
development in young athletes: a gender comparison of 1140
40. Bell DR, Padua DA, Clark MA. Muscle strength and flexibility
characteristics of people displaying excessive medial knee
lower limb biomechanics during single leg squat with running and
193-197.

Bogert AJ. Evaluation of a two dimensional analysis method as a
screening and evaluation tool for anterior cruciate ligament injury.
43. Mizner RL, Chmielewski TL, Toepke JJ, Tofte KB. Comparison of
2-dimensional measurement techniques for predicting knee angle
221-227.

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CME Question
In middle and high school athletes, with which of the following is a positive single leg squat test (SLS) shown a positive correlation?
a. female gender
b. younger age
c. body mass index
d. knee/hip ratio

Answer online at me.aapmr.org