A Prospective Evaluation of the Landing Error Scoring System (LESS) as a Screening Tool for Anterior Cruciate Ligament Injury Risk

By: Helen C. Smith, Robert J. Johnson, Sandra J. Shultz, Timothy Tourville, Leigh Ann Holterman, James Slauterbeck, Pamela M. Vacek, and Bruce D. Beynnon

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Abstract:

Background: Anterior cruciate ligament (ACL) injuries are immediately disabling, costly, take a significant amount of time to rehabilitate, and are associated with an increased risk of developing posttraumatic osteoarthritis of the knee. Specific multiplanar movement patterns of the lower extremity, such as those associated with the drop vertical jump (DVJ) test, have been shown to be associated with an increased risk of suffering noncontact ACL injuries. The Landing Error Scoring System (LESS) has been developed as a tool that can be applied to identify individuals who display at-risk movement patterns during the DVJ.
Hypothesis: An increase in LESS score is associated with an increased risk of noncontact ACL injury.
Study Design: Case-control study; Level of evidence, 3.
Methods: Over a 3-year interval, 5047 high school and college participants performed preseason DVJ tests that were recorded using commercial video cameras. All participants were followed for ACL injury during their sports season, and video data from injured participants and matched controls were then assessed with the LESS. Conditional logistic regression analysis was used to examine the association between LESS score and ACL injury risk in all participants as well as subgroups of female, male, high school, and college participants.
Results: There was no relationship between the risk of suffering ACL injury and LESS score whether measured as a continuous or a categorical variable. This was the case for all participants combined (odds ratio, 1.04 per unit increase in LESS score; 95% confidence interval, 0.80-1.35) as well as within each subgroup (odds ratio range, 0.99-1.14).
Conclusion: The LESS did not predict ACL injury in our cohort of high school and college athletes.

Keywords: knee kinematics | ACL injury | injury risk | jump landing

Article:

Injuries to the anterior cruciate ligament (ACL) of the knee are immediately disabling, costly, and take a significant amount of time to rehabilitate. These injuries are also associated with long-term complications and early onset of osteoarthritis of the knee, a disease that currently has no cure.[9,10,14] An estimated 80 000 to 250 000 ACL injuries occur each year, many in young, active individuals.[5] Injury rates as high as 2.8 and 3.2 injuries per 10 000 athlete exposures in women's collegiate basketball and soccer, respectively, have also been reported.[11] These injury rates in otherwise young, healthy individuals have led to research efforts designed to identify factors that are associated with an increased risk of suffering ACL injury. The ultimate goal of such research is to identify individuals at increased risk who may benefit from targeted interventions.

Biomechanical risk factors and specific at-risk multiplanar movement patterns for noncontact ACL injuries have been identified using dynamic tests such as the drop vertical jump (DVJ).[5,6,18,19] During the landing phase of the DVJ, these movement patterns include increased valgus or abduction angle at the knee, increased intersegmental abduction moment at the knee, greater ground-reaction force, shorter stance time, lower activation of the semitendinosus muscle, and increased activation of the vastus lateralis muscle.[6,18,23] This research has been accomplished in laboratory settings with complex measurement systems that have the capacity to characterize the 3-dimensional kinematics of the lower extremity and trunk during at-risk activities such as landing from a jump. While the use of these measurement techniques has led to significant advances in our understanding of the relationship between lower extremity landing biomechanics and risk of noncontact ACL injury, they are complex and not easy to apply as large-scale screening tools in the populations at risk for injury. There is a need for valid and simple screening tools that can identify individuals with at-risk movement patterns.

The Landing Error Scoring System (LESS) is a reliable clinical screening tool that was developed to identify individuals at increased risk of suffering noncontact ACL injury through evaluation of landing biomechanics associated with the DVJ test.[18] Poor landing technique during the DVJ test has previously been shown to be associated with an increased risk of knee ligament injury.[6] The LESS is based on a continuous 17-point scale that assesses lower extremity and trunk positioning at the point of initial contact with the ground, maximum flexion, and global fluidity and range of motion when landing from a DVJ through analysis of frontal and sagittal plane video data. The LESS scoring construct has been previously published by the developers.[18] A higher LESS score indicates poor landing technique, while a lower LESS score indicates good landing technique. Intrarater and interrater reliability of the LESS has been established as good to excellent.[16,18] The correlation of LESS scores with the previous, established standard of 3-dimensional kinematic motion about the lower extremity has also been described.[16,18]

This study was designed to evaluate the LESS in a population of high school and college athletes. Our objective was to determine if the LESS can be used to identify an individual at increased risk of suffering a noncontact ACL injury. To our knowledge, the LESS has not been applied in a case-control or cohort study to determine its association with risk of ACL injury. Our hypothesis was that the LESS will be able to predict individuals at increased risk of suffering ACL injury, where a higher LESS score indicates an individual at increased risk of sustaining an ACL injury.

MATERIALS AND METHODS

Participants

The Committee on Human Research in the Medical Sciences Review Board approved this study. All participants and/or their legal guardians signed informed consent forms. This study was designed as a prospective cohort study with a nested case-control analysis. There were 18 high schools and 8 colleges that participated in the preseason screenings. During the 3-year period that started at the fall season of 2008 and ran through the winter season of 2011, a total of 5047 screenings of college and high school athletes using the DVJ testing procedure were performed before their competitive athletic seasons began.18 Athletes participated in organized varsity sports at the high school or college level in the surrounding region. All competed in sports that are associated with sustaining noncontact ACL injuries: soccer (n = 1257), football (n = 293), rugby (n = 61), field hockey (n = 446), basketball (n = 1422), gymnastics (n = 55), lacrosse (n = 1496), and volleyball (n = 17). Some athletes participated in more than one sport per year and/or the same sport over multiple seasons and so were screened several times over the 3 years. Because this has no bearing on the case-control statistical analysis, these individuals were considered different participants each time they were screened. There were a total of 3876 unique athletes who participated in the screenings (2021 male and 1855 female participants). There were 2910 high school athletes and 966 college athletes. All participants were followed by the certified athletic training staff at each institution during their sports seasons to identify those who subsequently suffered a grade III noncontact injury to the ACL. A noncontact ACL injury mechanism was defined by our group as an event with no direct contact to the ACL-injured knee from another athlete, the ground, or extraneous structure. Athletes were not included who reported direct contact to the knee or where the injury mechanism was not clear. The ACL rupture was initially evaluated by an orthopaedic surgeon and subsequently confirmed with magnetic resonance imaging (MRI) and arthroscopic visualization at the time of surgery. Injured participants were invited to participate in the study and were matched with up to 3 controls from the same team who were the same sex, were the same age within 1 year, and agreed to participate in the study. Participants and their matched controls were screened on the same date, and athletes who had a history of ACL injury in either knee before the study were excluded.

Testing and Data Processing Procedures

During a preseason team meeting, each participant underwent a preparticipation screening that involved 3 practice DVJ trials, followed by 3 test DVJ trials according to the LESS protocol described by Padua et al.[18] The DVJ involved participants jumping from a 30-cm-high plyometric box onto the ground, landing with both feet at a distance of approximately 50% of their height in front of the box, and jumping immediately back into the air as high as they were able. Frontal and sagittal view video data were acquired using standard HDV video camcorders (Canon Vixia HF200 and HV30, Canon Inc, Tokyo, Japan) that were positioned according to the LESS protocol (Figure 1).[18] Preparticipation DVJ video data obtained from the injured participants and matched controls were viewed by a trained investigator (H.S.) and scored using the standard LESS protocol.[18] The values obtained from 3 trials were averaged to obtain a participant's LESS score. The investigator was not blinded to injury status. The video analysis was completed using Dartfish ProSuite software (Dartfish Ltd, Fribourg, Switzerland).

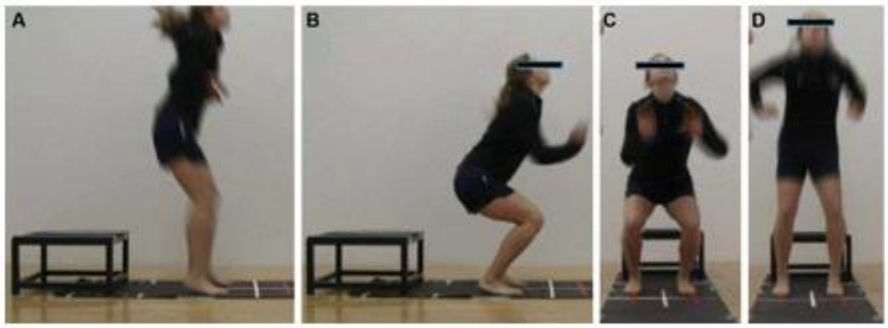

Figure 1.
The drop vertical jump shown from the lateral camera view at initial contact (A) and maximum flexion (B) and from the frontal camera view at initial contact (C) and maximum flexion (D).

Statistical Methods

Reliability

Two investigators went through a series of practice and learning sessions with an established LESS evaluator to ensure that they applied it in the same manner as the developers. They then independently scored the DVJ videos for a subset of 10 participants at 2 time points, separated by 1 week, to determine intrarater and interrater reliability of the LESS. The reliability of scores was assessed by concurrently estimating the between-round and between-investigator intraclass correlation coefficients (ICCs) using the method described by Ellasziw et al[2] for random rater effects.

Assessment of the LESS

The objective of our study was to apply the LESS as it was developed.[18] The LESS scores were analyzed as a continuous variable as well as on the categorical scale previously described by the developers as poor (>6), moderate (>5 to ≤ 6), good (>4 to ≤ 5), and excellent (≤ 4).[18] Statistical analyses were performed using conditional logistic regression on both the continuous and categorical LESS scores to determine if there was an increase in risk of ACL injury associated with an increase in LESS score. Conditional logistic regression directly compares participants to their respective matched controls and thus controls for exposure time as well as potential differences in landing techniques because of type of sport, sex, and age. We selected 3 controls per case because this number has been shown to provide good relative efficiency, with only minor improvements in statistical power if additional controls are used.[21] Odds ratios (ORs) with 95% confidence intervals (95% CIs) were reported for all analyses. Significance was set at $P < .05$. Conditional logistic regression analyses were performed on data from all participants as well as the following subgroups: female, male, high school, and college participants. All data were analyzed using SAS (version 9.2, SAS Institute Inc, Cary, North Carolina).

RESULTS

Reliability
Agreement in LESS scores between raters and between repeat assessments by the same rater was excellent. The ICC value for intrarater reliability was 0.97, while the ICC for interrater reliability was 0.92. The measurement errors for the 2 investigators were 0.45 and 0.59.

Assessment of the LESS
A total of 32 participants (21 female, 11 male) from the cohort of 3876 individuals suffered noncontact ACL injuries, and 28 (19 female, 9 male) of these injured participants agreed to let us analyze their data and were retained in the study. These 28 injured athletes were matched with controls (44 female, 20 male) for a total sample size of 92 participants (age, 18.3 ± 2 years; mass, 70.9 ± 15.6 kg; height, 171.9 ± 12.4 cm) (Table 1). The time interval between preparticipation screening and injury was an average of 224 days (standard deviation [SD], 150 days; range, 1-434 days).

TABLE 1
Demographics of Study Participants

	Cases, n	Controls, n	Age, mean ± SD (range), y	Height, mean ± SD (range), cm	Mass, mean ± SD (range), kg
Sex					
Female	19	44	18.0 ± 1.74 (14-22)	165.3 ± 5.64 (152.4-177.8)	63.04 ± 7.94 (50.3-80)
Male	9	20	18.48 ± 2.47 (14-23)	181.8 ± 8.57 (165.1-208.28)	82.62 ± 13.41 (66.2-121.11)
Age					
High school	18	38	16.88 ± 1.17 (14-18)	169.53 ± 8.49 (152.4-187.96)	66.67 ± 11.17 (50.3-113.4)
College	10	26	20.17 ± 1.34 (18-23)	172.23 ± 12.39 (152.3-208.28)	73.36 ± 16.00 (50.3-121.11)
Sport					
Lacrosse	14	36	18.66 ± 1.88 (16-23)	171.09 ± 8.72 (152.4-193.04)	69.08 ± 11.39 (54.4-98.9)
Soccer	6	11	18.24 ± 2.33 (14-21)	164.88 ± 5.55 (152.4-172.72)	62.02 ± 7.55 (50.3-73)
Basketball	4	9	18 ± 1.35 (16-21)	177.56 ± 14.04 (165.1-208.28)	77.28 ± 17.89 (55.8-121.11)
Football	2	3	15.2 ± 1.3 (14-17)	178.82 ± 8.54 (165.1-187.96)	86.35 ± 15.67 (76.2-113.4)
Field hockey	1	3	16.5 ± 0.58 (16-17)	163.2 ± 3.81 (160.02-167.64)	61.33 ± 10.89 (50.3-73)
Gymnastics	1	2	17 ± 1.73 (15-18)	157.9 ± 2.64 (154.94-160.02)	57.3 ± 4.97 (51.7-61.2)

The mean, standard deviation (SD), and range of the LESS scores for all cases; all controls; and female, male, high school, and college participants are shown in Table 2. Conditional logistic regression analyses using the LESS as a continuous variable did not reveal a significant relationship between LESS score and the risk of suffering ACL injury, either for all participants as a combined group (P = .32) or for subgroup analyses of female (P = .16), male (P = .67), high school (P = .37), and college participants (P = .66) (Table 3). Likewise, there was also no significant relationship between the LESS score as a categorical variable and the risk of suffering ACL injury for all participants combined (P = .35) or for female (P = .26), male (P = .98), high school (P = .49), and college participants (P = .27) (Tables 4and 5).

TABLE 2
LESS Score: Mean Values for Cases and Controls[a]

Cases		Controls	
Group	Mean (SD)	Group	Mean (SD)
All (N = 28)	5.48 (1.85)	All (N = 64)	4.98 (2.00)
Female (n = 19)	5.49 (1.85)	Female (n = 44)	4.73 (1.93)
Male (n = 9)	5.44 (1.97)	Male (n = 20)	5.53 (2.08)
High school (n = 18)	5.91 (1.86)	High school (n = 38)	5.36 (2.08)
College (n = 10)	4.70 (1.64)	College (n = 26)	4.42 (1.75)

[a]LESS, Landing Error Scoring System; SD, standard deviation.

TABLE 3
Associations Between LESS Score Considered as a Continuous Variable and Risk of ACL Injury: Odds Ratio for Each 1-Unit Increase in the LESS Score[a]

Group	Odds Ratio (95% CI)	*P* Value
All (N = 92)	1.14 (0.88-1.48)	.32
Female only (n = 63)	1.25 (0.91-1.72)	.16
Male only (n = 29)	0.89 (0.54-1.49)	.67
High school only (n = 56)	1.16 (0.84-1.59)	.37
College only (n = 36)	1.11 (0.70-1.77)	.66

[a]LESS, Landing Error Scoring System; ACL, anterior cruciate ligament; CI, confidence interval.

TABLE 4
Categorical Variable Frequency[a]

LESS Category	Cases, n (%)	Controls, n (%)	Total, n (%)
Excellent (≤4)	6 (21.43)	23 (35.94)	29 (31.52)
Good (>4 to ≤5)	5 (17.86)	14 (21.88)	19 (20.65)
Moderate (>5 to ≤6)	6 (21.43)	11 (17.19)	17 (18.48)
Poor (>6)	11 (39.29)	16 (25.00)	27 (29.35)
Total	28 (30.43)	64 (69.57)	92 (100.00)

[a]LESS, Landing Error Scoring System.

TABLE 5
Association Between Categories of LESS and ACL Injury Risk: Odds Ratio[a]

Group	LESS Category (n)	Odds Ratio (95% CI)	*P* Value
All	Excellent (29)	1 (reference)	—
	Good (19)	1.49 (0.34-6.53)	.60
	Moderate (17)	2.59 (0.61-10.99)	.20
	Poor (27)	3.62 (0.87-15.11)	.08
Male	Excellent (6)	1 (reference)	—
	Good (5)	0.70 (0.06-8.89)	.78
	Moderate (7)	0.76 (0.06-9.06)	.83
	Poor (11)	1.02 (0.07-14.27)	.99
Female	Excellent (23)	1 (reference)	—
	Good (14)	2.25 (0.33-15.34)	.41
	Moderate (10)	4.74 (0.68-32.95)	.12
	Poor (16)	5.86 (0.94-36.47)	.06
High school	Excellent (13)	1 (reference)	—
	Good (11)	Unable to estimate	—
	Moderate (11)	1.32 (0.21-8.35)	.77
	Poor (21)	4.00 (0.60-26.53)	.15
College	Excellent (16)	1 (reference)	—
	Good (8)	6.08 (0.61-60.32)	.12
	Moderate (6)	11.41 (0.71-184.56)	.09
	Poor (6)	2.28 (0.12-43.06)	.58

[a]LESS, Landing Error Scoring System; ACL, anterior cruciate ligament; CI, confidence interval.

DISCUSSION

Our study was unable to demonstrate that the LESS has predictive value for identifying those at increased risk of suffering noncontact ACL injuries. This was the case when considering all participants as a group as well as for separate subgroup analyses of high school, college, male, and female participants. We screened 5047 participants over 3 years, identified 32 subsequent noncontact ACL injuries, and analyzed 28 of these injured individuals. To our knowledge, this sample of participants with noncontact ACL injuries is the largest to be evaluated with the LESS. Post hoc power analysis revealed that approximately 148 injured participants (37 in each of the 4 LESS score categories) would be needed to have 80% power of detecting an OR of 3 or larger compared with the lowest category. Based on the incidence of injury that we have observed in our study, this threshold would require screening approximately 26 000 athletes over 3 years. The effort required to accomplish such a large study is far beyond the capacity of any single research center. To gain a large enough sample of ACL-injured participants to effectively study the risk factors prospectively, it may ultimately be necessary to utilize study designs that involve multicenter collaboration,[17] and at the current point in time, it is unclear whether such a large-scale effort can be achieved. However, a nested case-control analysis, when conducted as in our study, involves random sampling of controls from risk sets (participants with comparable time at risk) and the use of conditional logistic regression. This analysis produces results that are very similar to Cox regression. Also, because both Cox regression and conditional logistic regression include the same number of cases, there is little difference in statistical power, particularly because we controlled for potential confounders in the matching of controls, and thus did not need to include them as covariates in the regression model.

Controlled laboratory studies have determined that different movement and muscle activation patterns exist between male and female athletes, and these differences may be linked to an increased risk of ACL injury.[20] Small cohort laboratory-based studies have also shown that female participants land from a DVJ with less knee flexion and increased knee valgus when compared with male participants.[1,3] However, mean LESS scores for the male (5.51 for control and injured participants combined) and female (4.96 for control and injured participants) athletes in our study did not differ significantly ($P = .22$). We also found that college participants had lower average LESS scores (4.5 for control and injured athletes), signifying better jump technique, than did high school participants (5.54 for control and injured athletes), and this finding was statistically significant ($P < .01$).

The range of LESS scores for our participants fell between 0 and 11 rather than the full possible 0-to-17 range and may have reduced our capacity to detect an association with injury risk. It is possible that LESS score varies more widely in groups that are undergoing rapid neuromuscular development, such as younger athletes, or the military population upon which the LESS was developed.[18]

The period between screening and injury was an average of 224 days, with a range of 1 and 434 days, and therefore, a majority of the study participants were screened within a 1-year time interval of the index injury. While screening participants once per year is reasonable and practical from the perspective of the demands placed on athletes at increased risk for this devastating injury, it is difficult to know how the LESS score was influenced over this time interval by changes in conditioning and maturation. To control for this, participants and controls were screened at the same time, were the same age, and were selected from the same team, and conditional logistic regression analysis was used to analyze the data. For example, if a change in DVJ landing biomechanics and subsequent LESS score did in fact occur between the testing and the injury, we would assume that the change was the same for the participants and the controls. Future work should focus on determining how jumping mechanics may change over the course of different time intervals for high school and college athletes. Another issue to consider is that the DVJ may not be the best task for evaluating ACL injury risk. While it is difficult to find a task that challenges the knee and ACL while maintaining a safe, controlled, and reproducible screening environment, measurement of landing mechanics during other types of tasks may prove more predictive of injury risk.

The LESS has been shown to correlate to other measures of ACL loading and biomechanical measures of ACL injury risk measured via 3-dimensional kinematics.[18] Some of these biomechanical factors increase the ACL strain values, including increased posterior-directed ground-reaction force combined with an anterior-directed intersegmental shear force acting at the proximal aspect of the tibia as well as increased intersegmental internal/external and varus/valgus moments at the knee.[22] Several case series studies have also been completed that attempt to identify exact mechanisms in which an individual suffers a noncontact injury to the ACL. Tibial internal rotation and knee valgus motion have been identified as common mechanisms,[7,8,15] especially for noncontact injuries, which occur when strain is applied to the ACL in multiple anatomic planes. This type of strain can occur when landing from a jump, cutting, pivoting, or performing other movements that are common in sports.[22] The correlation of LESS items with established measures of kinematic motion has been described in 2 prior works.[16,18] In these studies, low LESS scores were associated with decreased flexion motion about the hip and knee, as well as increased valgus and internal rotation moments, and increased anterior tibial shear force about the knee when landing from a jump. However, a recent controlled laboratory study has shown that landing from a jump with less knee flexion and greater ground-reaction force (a stiff landing) did not increase anterior tibial translation, varus/valgus, or internal/external rotation in comparison with a soft landing.[13] This may be one reason why the LESS, which attempts to score soft and stiff landings in combination with rotation and valgus, was not able to predict ACL injury in our group of participants.

The LESS has attempted to bridge the gap between laboratory studies of ACL strain with clinically identifiable movement patterns during sports and activities by scoring DVJ mechanics in both the sagittal and frontal planes while challenging the knee in a controlled effort to characterize errors in jump mechanics as they may occur during injury. More work needs to be done to provide convincing evidence that individuals with increased knee motion and loading during a controlled landing task such as the DVJ are at increased risk for noncontact ACL injury during athletic events. Several clinical tools designed to evaluate knee biomechanics have been developed, and we anticipate that they will be applied to a selection of at-risk populations in efforts to evaluate their associations with the risk of suffering ACL injury.[12] Before adopting the LESS and other potential clinic-based screening tools to identify athletes at increased risk of injury, these tools need to consistently be shown to carry predictive value across different age ranges, sexes, and levels of play and sports.[4] In conclusion, the LESS was not able to predict noncontact ACL injury when applied in our study of high school and college athletes who participate in sports that involve planting and cutting maneuvers.

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FOOTNOTES

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