Original Research

Prediction of ACL Injuries from Vertical Jump Kinetics in Division 1 Collegiate Athletes

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Background

The incidence of ACL injuries continues to rise secondary to an increase in sport participation. Evidence supports the use of force plate testing to quantify kinetics during rehabilitation after injury and recovery; however, there is limited current research regarding if jump kinetics can identify athletes who are at higher risk for injury. Altered kinetics could potentially lead to abnormal force dissipation and resultant injury.

Purpose

The purpose of this investigation was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes.

Study Design

Retrospective cohort.

Methods

Vertical jump testing is performed by all healthy varsity collegiate athletes at several intervals throughout the athletic year at a Division I institution using a commercially available force plate system with dedicated software. Athletes who sustained an ACL injury between 1/1/15 and 6/1/19 were identified (n=16) and compared to healthy athletes who participated in the same sports (n = 262). ACL injuries were considered for this study if they occurred no more than 10 weeks after a jump test. The outcome variables were load, explode, and drive, operationally defined as the average eccentric rate of force development, average relative concentric force, and concentric relative impulse, respectively, which the system normalized to T scores. Mann-Whitney U tests were used to assess group differences for load, explode, drive, and the ratio between the variables. Logistic regression was used to determine if the battery of variables could predict whether or not an athlete would sustain an ACL injury. The p-value was set to 0.10 for the Mann-Whitney U tests, and 0.05 for the logistic regression.

Results

Significant differences between the ACL and healthy groups were seen for explode (p=0.08), drive (p=0.06), load:explode ratio (p=0.06), and explode:drive ratio (p=0.03). Explode and drive, when entered into the regression equation, showed the ability to predict injury, χ^2= 6.8, df = 2, p=0.03.

Conclusions

The vertical jump force plate variables were able to identify athletes who sustained an

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ACL injury within 66 days of testing. Athletes who sustained an ACL injury demonstrated altered kinetics and less ability to transmit forces during the vertical jump.

Level of Evidence

3.

INTRODUCTION

Noncontact anterior cruciate ligament (ACL) injuries continue to be problematic in the athletic population, with more than 120,000 injuries occurring every year in the United States.[1] These injuries most commonly occur in high school and college athletes.[1] Although ACL injury prevention programs have grown in popularity, especially with the competitive athlete population, there continues to be an increase in the number of injuries every year, secondary to an increase in sport participation.[1,2] Although contact ACL injuries may occur, over 70% of ACL injuries occur in a noncontact mechanism,[3,4] with approximately 100,000 injuries per year within the NCAA alone. ACL injury can lead to short term disability and functional impairments, and often results in hastened knee articular cartilage destruction and osteoarthritis.[5]

Extensive research on clinical movement screening assessments has been completed to identify athletes at risk for injury (e.g.: Y-balance, FMS, drop jump screening test, etc.). Current literature has questioned the validity, sensitivity, or internal consistency of such assessments as predictive modalities. Lab-based kinetic and kinematic measures during various jump – landing tasks have been found to be predictive of ACL injuries. Hewett and colleagues[6] found that in female athletes, those who later sustained an ACL injury had a 2.5 times greater knee abduction moment, a 20% higher ground reaction force, and a 16% shorter stance time during a jump landing task than non-injured athletes. Several non-modifiable risk factors for ACL injuries have been identified in the literature; modifiable risk factors have also been identified, which puts injury risk detection at paramount importance. To this end, neuromuscular and biomechanical risk factors may be addressed through preventative training programs.[2]

Lab-based biomechanical measures are the gold standard for detecting kinematic and kinetic deviations;[7–9] force plate systems, which can also be utilized clinically or in training rooms, are reliable and valid measurement systems which can potentially be used for injury detection as well as performance enhancement. Force plate testing which involves vertical or drop jumps has been used in the literature primarily to detect asymmetries after lower extremity injuries.[10–12] Drop landing mechanics have been investigated at time of return to sport in athletes status post (s/p) anterior cruciate ligament reconstruction (ACLR).[13] Transverse plane hip kinetics, frontal plane knee kinematics during landing, sagittal plane knee moments at landing, and deficits in postural stability predicted a second injury in this population with excellent sensitivity (0.92) and specificity (0.88). In 2015, Baumgart and colleagues[14] found that patients s/p ACL reconstruction showed ground reaction force asymmetries during unilateral and bilateral movements more than two years post-surgery. Three compensation strategies were found in patients with low subjective knee function: a reduced eccentric load, an interlimb compensation during bilateral movements, and the avoidance of high vertical impact forces. Kinematic differences have been found to persist 20 years after an ACLR.[15] Evidence supports the use of force plate testing to quantify kinetics during rehabilitation after injury and recovery; however, there is limited current research regarding the role of jump kinetics for injury prevention or prediction purposes.

As no studies to date have used force plate variables from the vertical jump to predict ACL injuries, the purpose of this investigation was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes.

METHODS

Approval was obtained from our institution's institutional review board. Data were collected from 1/1/2015-6/1/19. Vertical jump testing was performed by all healthy varsity collegiate athletes at several intervals throughout the athletic year, using a commercially available force plate system (Sparta Science, Menlo Park, CA). After a standard warm-up, subjects were then adequately familiarized with the jump testing with two submaximal practice jumps before testing. The testing procedure consisted of each subject performing a series of six consecutive vertical jumps, with a 15-second rest period in between each jump. No other instruction was given on the technique to be used during the jumps. This testing protocol is used as the standard of practice for all varsity athletes as part of their strength and conditioning program.

Athletes who sustained a non-contact ACL injury between 1/1/15 and 6/1/19 were identified (n=18). Athletes were excluded if they did not perform the vertical jump testing within 10 weeks prior to their injury; 16 ACL injuries were included in the analysis. Injuries by sport were: field hockey (1), football (2), men's lacrosse (4), men's soccer (1), women's lacrosse (5), women's soccer (2), and wrestling (1). For the healthy cohort (n=262), exclusion criteria were athletes who later sustained a different lower extremity injury, a trunk/lumbar spine injury, or if they participated in a sport in which no athlete sustained an ACL injury. The purpose of excluding those sports was to improve the homogeneity of the healthy cohort by excluding sports in which non-contact ACL injuries were uncommon. If more than one jump trial was performed, the jump data included in the analysis was performed at the same time in the season as the injured athletes. Injuries were documented by the team athletic trainers directly into the software, then verified with the health care organization's electronic medical documentation system.

Initial data analysis utilized the Sparta Science system software to analyze the force-time curve and breakdown the vertical jump into three components: load, explode, and

Table 1: Force Plate Vertical Jump Variable Means (SDs) and Group Differences

Variable	Uninjured Mean (SD)	Injured Mean (SD)	Test Statistic	*p*-value	Effect Size (Cohen's *d*)
Load	48.2 (8.5)	48.4 (9.5)	1792	0.89	0.02
Explode	49.4 (8.5)	45.0 (6.8)	1331	0.08*	0.52
Drive	52.0 (8.6)	57.3 (9.2)	2386	0.06*	0.61
Load:Explode	0.99 (0.20)	1.08 (0.19)	2373	0.06*	0.45
Explode:Drive	0.99 (0.32)	0.81 (0.19)	1181	0.03*	-0.57
Load:Drive	0.96 (0.28)	0.86 (0.20)	1552	0.33	-0.36

*significant difference at *p* < 0.10

drive. Load, explode, and drive were operationally defined as the average eccentric rate of force development, average relative vertical concentric force, and average relative vertical concentric impulse, respectively (Figure 1).

STATISTICAL ANALYSIS

Raw scores were normalized to T-scores by sex by the Sparta Science software. SPSS 26 was used for the remainder of the statistical analysis. Data were assessed for normality by Shapiro-Wilk and Kolmogorov-Smirnov tests, histograms and boxplots. Outliers were removed (no more than 5% of data). Secondary to the unequal number of subjects between groups, non-parametric tests (Mann-Whitney U) examined differences between groups for load, explode, and drive; additionally, group differences were assessed for ratios between variables (load:explode, explode:drive, and load:drive). For the logistic regression, univariate tests were used to determine if differences existed between groups for any single variable, with *P* = 0.10. Variables which reached significance were to be used loaded stepwise into a logistic regression to assess if the battery of tests could predict group. The significance for the logistic regression was set to *P*=0.05. Effect sizes (Cohen's *d*) were calculated for each variable and for the regression equation to assess the magnitude of differences.

RESULTS

Sixteen athletes (8 females, 8 males) who sustained an ACL tear were included, with time to injury ranging from 1-66 days (mean: 17 days). The athletes who later sustained an ACL injury participated in field hockey (1), football (2), men (4) and women's (5) lacrosse, men's (1) and women's (2) soccer, and wrestling (1). Means (standard deviations), Mann-Whitney U results, and effect sizes are listed in Table 1.

Explode and drive, when entered into the regression equation, showed the ability to predict injury, χ^2= 6.8, df = 2, *p*=0.03, with explode and drive independently showing significant prediction at *p*=0.05 and 0.03, respectively. Effect sizes (Cohen's *d*) for load, explode, and drive had effect sizes of 0.02, 0.52, and 0.61, respectively, indicating medium effect sizes for both explode and drive. The logistic regression had an effect size of 0.32, indicating a small-medium effect size.

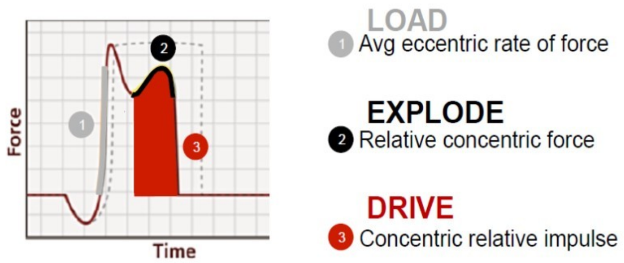

Figure 1: Force-time curve for (1) Load: average eccentric rate of force development; (2) Explode: average relative vertical concentric force; (3) Drive: average relative vertical concentric impulse.

DISCUSSION

The purpose of this study was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes using a commercially available force plate system. The results of the study demonstrated that the combination of variables used were effective in predicting athletes predisposed to ACL rupture, with explode and drive exhibiting independent predictive ability, in addition to revealing a significant deficiency in average relative concentric force in the injured group. The injured athletes were found to have imbalances: first, greater eccentric rate of force development compared to average relative concentric force; secondly, greater average relative concentric impulse compared to average relative concentric force. The medium effect sizes for the group differences for explode and drive indicate that if a larger sample size was used, a difference in these variables between groups would likely be seen, as well as in the regression analysis.

While a substantial body of evidence exists exploring kinetic and kinematic differences athletes exhibit post ACLR between limbs or compared to a healthy cohort post ACLR, there is a paucity of literature describing which functional tasks and/or variables are predictive of ACL injury.[16,17] The results of this study suggest that a relationship exists between force-time variables from a vertical jump task and an ACL injury; thus, this is a viable option for prophylactically screening athletes who may be at high risk for an ACL tear.

When identified as susceptible to injury, training to increase in average relative concentric force (explode) could potentially eliminate any significant difference in force plate means between injured and uninjured groups. While ACL injuries are multifactorial in origin and the described force plate variable jump analysis may not capture all potential deficiencies in force transmission, this study adds to current literature regarding ACL injury prediction via modifiable factors. Lower extremity proprioception, dynamic balance, hamstring strength, hamstring: quadriceps force ratio and raising awareness of potential injury are some of the many modifiable characteristics that have demonstrated effectiveness in reducing non-contact ACL injury rates.[5,18–21]

This study demonstrates a novel usage of force-time variables that are predictive of ACL injury. Further exploration of the efficacy of intervention for at-risk athletes should be investigated to the ability to reduce primary ACL injury. Additionally, further insight into the relationship between abnormal isolated load, explode, or drive versus relative abnormalities will become essential when considering modification of athlete's strength training. Continued study and application of force-plate variables may demonstrate more injury patterns of the lower extremity based on jump kinetics.

This study has several limitations. As only non-contact ACL injuries with a corresponding jump were included, the number of athletes in the injured group is small; however, the medium Cohen's *d* substantiates the results. The vertical jump task used for gathering kinematic variables was bilateral; thus, side-to-side differences and/or prediction of which lower extremity was at high injury risk could not be deduced from the data. As only Division I collegiate athletes were included, this limits generalizability to other populations; however, athletes participating in seven different sports were included. Lastly, other modifiable risk factors as potential confounders in this study were not assessed.

CONCLUSION

The kinetic variables collected from vertical jumps were able to identify athletes who later sustained an ACL injury, demonstrated by altered force-time variables. The injured athletes were found to have proportionately greater eccentric rate of force development compared to average relative concentric force, and proportionally greater average relative concentric impulse compared to average relative concentric force. These findings help validate the use of a force plate system in a clinical setting to identify athletes who are at higher risk for sustaining an ACL injury.

CONFLICTS OF INTEREST

No conflicts.

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