Military Movement Training Program Improves Jump-Landing Mechanics Associated With Anterior Cruciate Ligament Injury Risk

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As part of the physical education program at the United States Military Academy, all cadets complete a movement training course designed to develop skills and improve performance in military-related physical tasks as well as obstacle navigation. The purpose of this study was to determine if completion of this course would also result in changes in jump-landing technique that reduce the risk of anterior cruciate ligament (ACL) injury. Analysis of landing mechanics on a two-footed jump landing from a height of 30 cm with a three-dimensional motion capture system synchronized with two force plates revealed both positive and negative changes. Video assessment using the Landing Error Scoring System (LESS) revealed an overall improved landing technique (p = .001) when compared to baseline assessments. The studied military movement course appears to elicit mixed but overall improved lower extremity jump-landing mechanics associated with risk for ACL injury. (Journal of Surgical Orthopaedic Advances 22(1):66–70, 2013)

Key words: ACL, biomechanics, military, prevention

Anterior cruciate ligament (ACL) injuries are common in young athletes and military personnel (1–3). The recognition of the disparity between male and female ACL injury rates (4) has led to a recent increase in biomechanical analysis of ACL risk factors. Unfortunately, the exact biomechanical risk profile remains elusive because of the complex interplay of biomechanical factors. Some biomechanical risk factors for noncontact ACL tears have been determined, to include knee abduction angle and moment (valgus). In addition, some intervention strategies have been successfully employed (5).

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Materials and Methods

Design and Setting

Subjects were recruited by nonuniformed personnel during the summers of 2005 and 2006 before their freshman year. During the consenting process, volunteers completed baseline questionnaires focused on demographic, prior injury, and physical activity data, particularly related to the lower extremity. Physical data pertaining to kinetics, kinematics, and strength were collected over the course of five academic quarters (2.5 semesters) beginning September 2005 and ending November 2006. This study was reviewed and approved by the Keller Army Community Hospital Institutional Review Board and the U.S. Army Clinical Investigation Research Office.

The Military Movement course is a mandatory course for first-year students at our institution and emphasizes activities that promote kinesthetic awareness, agility, and balance. This study considered the Military Movement

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course as a potential intervention that may affect the students' lower extremity strength and promote proper mechanics during a jump-landing maneuver. The course is taught over 19 lessons that are 50 minutes in length. Data were collected during four separate 8-week terms of the course.

Data were collected for a number of dependent variables relating to lower extremity kinematics, kinetics, and muscular strength. A total of 46 separate kinematic and kinetic variables were collected during the jump and landing maneuver. Data were collected at the ankle, hip, and, most importantly, the knee. Included in the data are values relating to ground reaction forces and landing time as well as contact and maximum ranges of motion for the joints evaluated. Specific kinematic and kinetic variables measured through motion analysis testing were selected and organized into two categories. Five specific variables previously identified as potential risk factors in injury to the ACL were of interest in the study: maximum knee abduction/adduction, maximum knee abduction/adduction moment, maximum tibial internal/external rotation, maximum tibial internal/external rotation moment, and maximum tibial anterior shear. Seven additional variables relating to mechanical factors in motion include knee flexion at contact, maximum knee flexion, knee abduction/adduction at contact, hip internal/external rotation at contact, maximum ground reaction force vertically, maximum vertical loading rate, and landing time.

Subjects

Of 2444 eligible subjects, a total of 273 subjects (158 male, 115 female) underwent intervention and completed the physical battery of tests. All subjects met the following criteria: (*a*) age between 17 and 25 years, (*b*) no previous history of ACL injury, (*c*) physically active, and (*d*) not on medical excusal for any reason. No exclusions were made for race or ethnicity.

Procedures

Anthropometric measures were taken including height, weight, and lower extremity segment lengths (greater trochanter to lateral epicondyle; lateral epicodyle to lateral malleolus). Twenty-seven reflective markers were placed on anatomical landmarks. One was placed on the sacrum and the remaining 26 were placed bilaterally on the anterior and posterior superior iliac spines, greater trochanter, midline on the anterior thigh, medial and lateral epicondyles, midline on the anterior tibia, medial and lateral malleoli, posterior aspect of the calcaneus, base of the fifth metatarsal, and head of the third metatarsal.

Once the reflective markers were in place, a jump platform 31 cm in height was set at a distance equivalent to 50% of the subject's height from two floor-mounted AMTI force plates (Fig. 1). Subjects were instructed to stand on top of the jump platform and jump forward, landing with one foot on each force plate. Immediately on landing, the subject jumped as high as possible. Each subject completed one practice jump followed by three recorded trials. If the subject's foot missed the force plate, the jump was repeated.

Kinetic and kinematic analyses of subjects performing a jump-landing technique were recorded using a three-dimensional motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) equipped with EVArT motion capture software. Lower extremity biomechanical data were recorded at 200 Hz using a nine-camera Motion Analysis Corporation Eagle digital system. Forces were recorded at 1000 Hz using two AMTI OR6-7 force plates that were embedded in the floor.

Landing Error Scoring System (LESS) (6) developed by the Sports Medicine Research Laboratory at the University of North Carolina (UNC), Chapel Hill was performed during the final two terms of Military Movement data collection at the preliminary and postintervention testing sessions ($n = 98$). LESS data were collected using Sony digital video cameras positioned in the frontal and sagittal planes at distances of 147.25 and 149.5 inches, respectively, as well as elevated from the floor to the center of the lens 36 inches. The subjects were filmed performing three trials of the above described jump and landing sequence.

Last, a clinician assessed the isometric strength of the quadriceps, hip external rotators, hip internal rotators,

FIGURE 1 Photograph of the testing apparatus.

hamstrings, gluteus maximus, and gluteus medius, in that order using a handheld dynamometer manufactured by Laffayette. For each muscle test, two 5-second maximum effort trials were recorded with peak force measurements used for analysis. Strength data were collected on the dominant leg only. Leg dominance was defined as the leg with which the subject would kick a ball.

In November 2005 just following the onset of the first session of data collection, interrater and intrarater reliability testing was performed to ensure uniform testing and validity in results. Pearson correlation coefficient, Crobach α, and intraclass correlation were the coefficients calculated to measure reliability. Additionally, the standard error of measurement was computed to allow a prediction of expected error using the tests studied. All indications suggest excellent intrarater as well as interrrater reliability for the isometric muscle strength testing.

Data Processing

Using the EVArT motion capture software, kinetic and kinematic data were tracked and exported, so analyses of various components of the jump-landing sequence could be evaluated. Rigid body reconstruction and kinematic analyses on these data were performed using Visual 3D software (C-Motion Corporation).

The LESS score required multiple viewing of the videotape, so jumps could be evaluated on 17 parameters that may identify potential problems in jump-landing mechanics. Initially, each jump was viewed in its entirety from the frontal plane in real time. The rater then rewound and scored the knee position at the moment of initial contact with the ground and then advanced the tape to the completion of the landing movement, scoring the remaining items. The entire frontal plane view was then replayed in real time to verify the scoring. This procedure was repeated for the sagittal plane view. To ensure that the LESS was scored consistently, UNC has developed a set of training materials that were used by the LESS scorers (6).

Data Analysis

Descriptive statistics including means and standard deviations were calculated for key demographic variables and each dependent variable. Repeated measures and mixed model analysis of variance (ANOVA) models were fitted to each of the dependent variables of interest to evaluate our research hypotheses and specific aims. The primary independent variable of interest was time, which was a repeated factor and consisted of three levels (preintervention, postintervention, and follow-up 30 days after the intervention). We were also interested in gender as an independent variable. As a result, mixed ANOVA models stratified by gender and time were used to examine changes over time by gender. Pairwise comparisons were conducted to further evaluate between-group differences where appropriate. The level established for statistical significance was set at $p \leq .05$.

Results

A total of 273 subjects (158 male, 115 female) underwent baseline testing and the intervention of the Military Movement course. Several changes were noted when preintervention and postintervention kinematic and kinetic data for males and females were evaluated collectively. Subjects demonstrated significantly improved landing technique as assessed with the LESS. Following the Military Movement course, subjects demonstrated significantly lower LESS scores ($p < .0001$) when compared to their baseline assessments before the intervention.

Biomechanical Changes

Kinematic analysis revealed that subjects exhibited significantly greater hip abduction at contact with the ground ($p = .012$), at the deepest portion of the landing maneuver ($p < .0001$), and at the moment of maximum hip abduction throughout the jump-landing maneuver ($p < .0001$) following the intervention. Changes in external moments were observed at the hip during the jump-landing task. The absolute hip internal rotation moment maximum was significantly lower following the intervention ($p = .052$), which corresponded with lower relative hip internal rotation moment maximum ($p = .025$).

Similar to the hip, kinematic changes were also observed at the knee following the intervention. Subjects had greater abduction at the knee at the moment of maximum knee abduction ($p = .037$). Changes in external moments were also observed at the knee during the jump-landing task. The absolute knee flexion moment maximum was significantly greater ($p = .030$) following the intervention. Similarly, the relative knee flexion moment maximum was also significantly greater ($p = .042$) following the intervention. The absolute knee abduction moment maximum was also significantly greater ($p = .006$) following the intervention. Finally, the relative knee internal rotation moment maximum was significantly lower ($p = .001$) following the intervention.

Other biomechanical changes were observed following the intervention compared with baseline. Subjects demonstrated significantly greater landing times ($p = .013$) and significant increases in anterior tibial sheer ($p = .003$) following the intervention. Kinetic analysis revealed

TABLE 1 ANOVA results for biomechanical and landing variables

	Preintervention		Postintervention		
Variable	Mean	SD	Mean	SD	*p* Value
Hip Ab/Add Deep	−5.722	7.011	−8.316	6.928	.000
Hip Ab/Add Contact	−7.088	4.245	−8.086	4.363	.012
Landing Time	0.216	0.058	0.2313	0.073	.013
Hip Ab/Ad Max	−3.365	5.612	−5.399	5.297	.000
Knee Ab/Ad Max	−7.849	7.433	−9.331	7.927	.037
Pk Ant Tibial Shear	337.6	182.2	384.4	153.3	.003
Max GRF M-L	117.3	128	157.9	116.1	.000
Abs Hip I/E Rot mom Max	39.35	30.77	34.25	25.16	.052
Rel Hip I/E Rot mom Max	0.55	0.44	0.46	0.33	.025
Abs Knee Ab/Ad mom Max	−19.82	23.17	−26.17	26.2	.006
Abs Knee Flex mom Max	−34.95	25.71	−40.15	25.81	.030
Rel Knee Flex mom Max	−0.476	0.334	−0.540	0.333	.042
Rel Knee I/E Rot mom Max	−0.542	0.278	−0.441	0.253	.001
LESS	5.01	1.83	4.48	1.97	.000

significant increases in lateral ground reaction forces ($p < .0001$) during the jump-landing maneuver following the intervention. A complete listing of the variables tested is in Table 1.

Gender Comparison

Significant kinematic and kinetic changes were observed in both males and females following the intervention. When stratified by gender, both males and females exhibited significantly greater hip abduction at the deepest portion of the landing maneuver (males, $p = .002$; females, $p = .013$) and at the moment of maximum hip abduction throughout the jump-landing maneuver (males, $p = .005$; females, $p = .007$). When examining lower body muscular strength, both males ($p = .007$) and females ($p = .001$) exhibited significantly lower peak hip abduction strength following the intervention. Males exhibited significantly greater strength when compared to females on all muscular strength variables both before and after the intervention. No significant time by gender interactions were observed. All other observed changes were gender specific.

Several gender-specific biomechanical changes were noted among the males following the intervention. Males exhibited significantly greater landing time ($p = .052$) during the jump-landing maneuver. Changes in external moments were observed at the hip and knee during the jump-landing task. The absolute hip internal rotation moment maximum was significantly lower following the intervention for males ($p = .012$). The absolute knee flexion moment maximum was significantly greater ($p = .050$) following the intervention. Similarly, the relative knee flexion moment maximum was also significantly greater ($p = .029$) following the intervention. The absolute knee abduction moment maximum was also significantly greater ($p = .023$) following the intervention. Finally, the relative knee internal rotation moment maximum was significantly lower ($p < .0001$) following the intervention.

Fewer gender-specific biomechanical changes were observed within the females following the intervention. Females exhibited significantly greater hip adduction at contact ($p = .048$) during the jump-landing maneuver during postintervention testing. Significantly greater anterior tibial sheer ($p = .001$) and lateral maximum ground reaction forces ($p < .0001$) were also observed within the females following the intervention. The absolute hip flexion moment maximum was also significantly greater ($p = .036$) among females following the intervention. Conversely, females demonstrated more gender-specific changes in strength following the intervention when compared to males. Females also exhibited significantly lower peak knee extension and hip internal rotation strength following the intervention.

In clinical follow-up of 4 years, a total of seven ACL tears were sustained in our cohort. There we three tears in males and four tears in females. This overall ACL incidence rate is 2.6% over the 4 years at our institution and is similar to the previous reported rates in this population (3.4%; $p = .456$) (2).

Discussion

Although the importance of biomechanical factors for ACL injury risk is no longer debated, the specific factors that increase the risk profile remain unclear. It has been shown that jump-landing training programs can improve some biomechanical factors and even decrease ACL injury rates. We sought to determine the effect of an established jump-landing and body control course at our institution. We found that biomechanical profiles certainly can be adjusted, and many of our changes represent risk-reducing adaptations. These include increases in hip abduction and decreases in hip internal rotation moments, knee flexion and internal rotation moments, and landing time. Unfortunately, we also found that some negative factors developed, such as increase in knee abduction, increase in tibial sheer, and increase in lateral ground reaction force. Although it is unclear which of these factors is most important, we also noted an increase in LESS scores.

The LESS score has been a validated measure of overall landing mechanics. Padua et al. reported on the testing of 2691 collegiate athletes with the LESS score and found good to excellent inter- and intrarater reliability. Poor LESS scores were associated with increased knee valgus and hip adduction, decreased hip and knee flexion, and increased anterior tibial sheer forces (6). However, a recent 3-year prospective study of 5047 high school and collegiate athletes found no relationship between LESS score and risk for ACL injury (7).

Although the ACL injury rates have been stable at our institution, the rates are high because of our young active cohort (2). In contrast to the U.S. Naval Academy, we have not found significant differences in ACL tears by gender, despite a similar population and activity profile (1, 2). The Military Movement course is a unique course at our institution and may represent a possible explanation for this lack of gender disparity. We found that both men and women were responsive to the intervention, although overall the women subjects had fewer significant changes.

The Military Movement course at West Point is unique. It was formerly known as "Gymnastics" and features many events traditionally associated with gymnastics. The goal of this course is to give the students instruction in body control, with an emphasis on landing techniques. Unfortunately, classic gymnastics instruction involves landing with feet together. This is similar instruction to military airborne training, where a proper parachute-landing fall involves landing with feet together. Landing with feet together increases the knee abduction or valgus and may represent the increase in this parameter in our cohort. Increase in knee valgus has been shown to be a biomechanical parameter associated with increased risk for ACL tear in females (8).

This study has limitations, the first being that we were not powered to show a difference in actual ACL injury rates attributable to this intervention. Also, the intervention course was not designed to prevent ACL injuries specifically, but was a generalized body control course. In addition, we were not able to have a control group because of the mandatory nature of this course in our cohort. However, our strengths are the prospective nature of our study in a homogeneous group of high-risk young athletes and the use of the LESS scoring system.

In conclusion, we found that biomechanical parameters are certainly adaptable in military cadets undergoing jump-landing instruction. The results from this course showed an improvement in LESS scores in our cohort. These data may be helpful in planning future intervention protocols in military subjects or other young athletes.

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