Association Between Landing Error Scoring System (LESS) Items and the Incidence Rate of Lower Extremity Stress Fracture

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Background: Lower extremity stress fracture injuries are a major cause of morbidity in physically active populations. The ability to screen for modifiable risk factors associated with injury is critical in developing injury-prevention programs.

Purpose: To determine if baseline Landing Error Scoring System (LESS) scores are associated with the incidence rate of lower extremity stress fracture.

Study Design: Cohort study; Level of evidence, 2.

Methods: A total of 1772 participants with no history of lower extremity stress fracture were included. At preinjury baseline, the authors conducted a lower extremity movement assessment during a jump-landing task using the LESS. Incident lower extremity stress fractures were identified during a 4-year follow-up period. Potential incident cases were reviewed by 2 sports medicine fellowship–trained orthopaedic surgeons blinded to baseline LESS data. Univariate and multivariable Poisson regression models were used to estimate the association between baseline total LESS scores, individual LESS items, and the incidence rate ratio (IRR) of lower extremity stress fracture.

Results: A total of 94 incident lower extremity stress fractures were documented, for a 5.3% (95% CI, 4.3%-6.5%) cumulative incidence. The overall LESS score was associated with the incidence rate of lower extremity stress fracture. For every additional movement error documented at baseline, there was a 15% increase in the incidence rate of lower extremity stress fracture (IRR, 1.15 [95% CI, 1.02-1.31]; $P = .025$). In univariate analyses, ankle flexion, stance width, asymmetrical landing, and trunk flexion at initial contact, in addition to overall impression, were associated with the incidence rate of stress fracture. After controlling for sex and year of entry into the study cohort, participants who consistently landed flat-footed or heel-to-toe were 2.33 times (95% CI, 1.36-3.97; $P = .002$) more likely to sustain a lower extremity stress fracture. Similarly, participants who consistently demonstrated asymmetric landing at initial contact were 2.53 times (95% CI, 1.34-4.74; $P = .004$) more likely to sustain a stress fracture.

Conclusion: Components of the LESS may be associated with increased lower extremity stress fracture risk and may be helpful in efficiently assessing high-risk lower extremity biomechanics in large groups.

Keywords: stress fractures; injury prevention; epidemiology; risk factors; movement screening

Physically active populations (eg, athletes, first responders, and military personnel) are particularly susceptible to musculoskeletal injury,[12] especially injury of the lower extremity.[2] Commonly, lower extremity injury results from overloading of soft tissue structures (eg, ligaments, meniscus/cartilage, bone) due to maladapted movement patterns.[11] Globally, movement patterns can influence the magnitude of load and deformation placed on soft tissue structures, which contributes to injury risk and plays a critical role in injury mechanisms.[3,5,14,17,23,31,34] Despite the potential importance of lower extremity movement patterns in identifying individuals at increased risk for injury, limited high-quality data exist regarding the association between lower extremity biomechanical movement

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patterns, loading, and the risk for lower extremity stress fracture injuries.[11,37]

Lower extremity stress fractures are a major cause of morbidity in athletes and military populations,[7,16,21] resulting in significant time loss from training, competition, and duty. These consequences can negatively affect competitive and military readiness. In the military, the risk of stress fractures is particularly high for new recruits who undergo high-intensity physical training, which often places novel movement-related stresses on the lower extremity that can result in injury.[13] Specifically, increased ground-reaction forces have been associated with lower extremity stress fractures,[4,24,25] and neuromuscular training programs to reduce ground-reaction forces during activity have been suggested as a potential target for injury-prevention interventions.[26,37] Some evidence suggests that particular biomechanical movement patterns may be associated with elevated ground-reaction forces and an increased risk for stress fracture in runners and military personnel.[16,24-26] For example, excessive tibial shock has been demonstrated to distinguish between runners with tibial stress fractures and uninjured controls.[24] Despite the known association between biomechanical movement patterns and risk for the development of stress fracture in runners, little is known of this relationship in military populations.

Previous stress fracture risk studies have relied on expensive laboratory-based biomechanical analyses,[24-26,29] which are impractical for use during large-scale assessments needed in military and athletic settings. The Landing Error Scoring System (LESS) is a standardized clinical assessment tool used to identify improper lower extremity movement patterns during a jump-landing task that involves no high-cost motion analysis equipment. LESS items can validly and reliably assess jump-landing biomechanics with good interrater (intraclass correlation coefficient [ICC], 0.84; standard error of measurement [SEM], 0.71) and intrarater (ICC, 0.91; SEM, 0.42) reliability.[28] Most importantly, the LESS is a rapid, economical, and user-friendly movement screening tool requiring only standard video cameras and tripods for equipment, about 60 to 90 seconds of testing time per participant, and about 5 minutes per participant for video scoring.

The ability to efficiently and prospectively identify lower extremity biomechanical risk factors associated with subsequent injury in large populations is a critical first step in developing and implementing effective injury screening and prevention programs in high-risk populations. The purpose of this study was to determine if baseline movement patterns, assessed using the LESS, were associated with the subsequent incidence rate of lower extremity stress fracture in military service academy cadets. Our hypothesis was that the total LESS score and individual LESS items would be positively associated with stress fracture injury risk.

METHODS

Study Design and Setting

We designed and conducted a prospective cohort study utilizing the baseline movement screening collected from incoming cadets at the United States Military Academy (USMA) at West Point, New York, between 2005 and 2008. The study protocol was reviewed and approved by the institutional review board at our institution. Lower extremity stress fracture cases were identified through active surveillance using existing electronic injury surveillance systems during a 4-year follow-up period. The medical records of all potential cases were reviewed by an adjudication committee of sports medicine fellowship–trained orthopaedic surgeons to verify the case status of all lower extremity stress fractures identified during the follow-up period.

Study Participants

The parent study (JUMP-ACL [Joint Undertaking to Monitor and Prevent Anterior Cruciate Ligament Injury]) enrolled men and women entering the 3 military service academies between 2005 and 2008, and the population for the current study specifically included cadets who entered the JUMP-ACL cohort at the USMA. Of those admitted to the USMA, approximately 82% of women and 32% of men were invited to participate in the study. Women, who represented approximately 18% of the USMA population, were oversampled in the JUMP-ACL cohort as a whole in order to obtain sufficient numbers for adequate representation of both sexes. All participants were physically healthy at the

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Ethical approval for this study was obtained from the Keller Army Community Hospital.

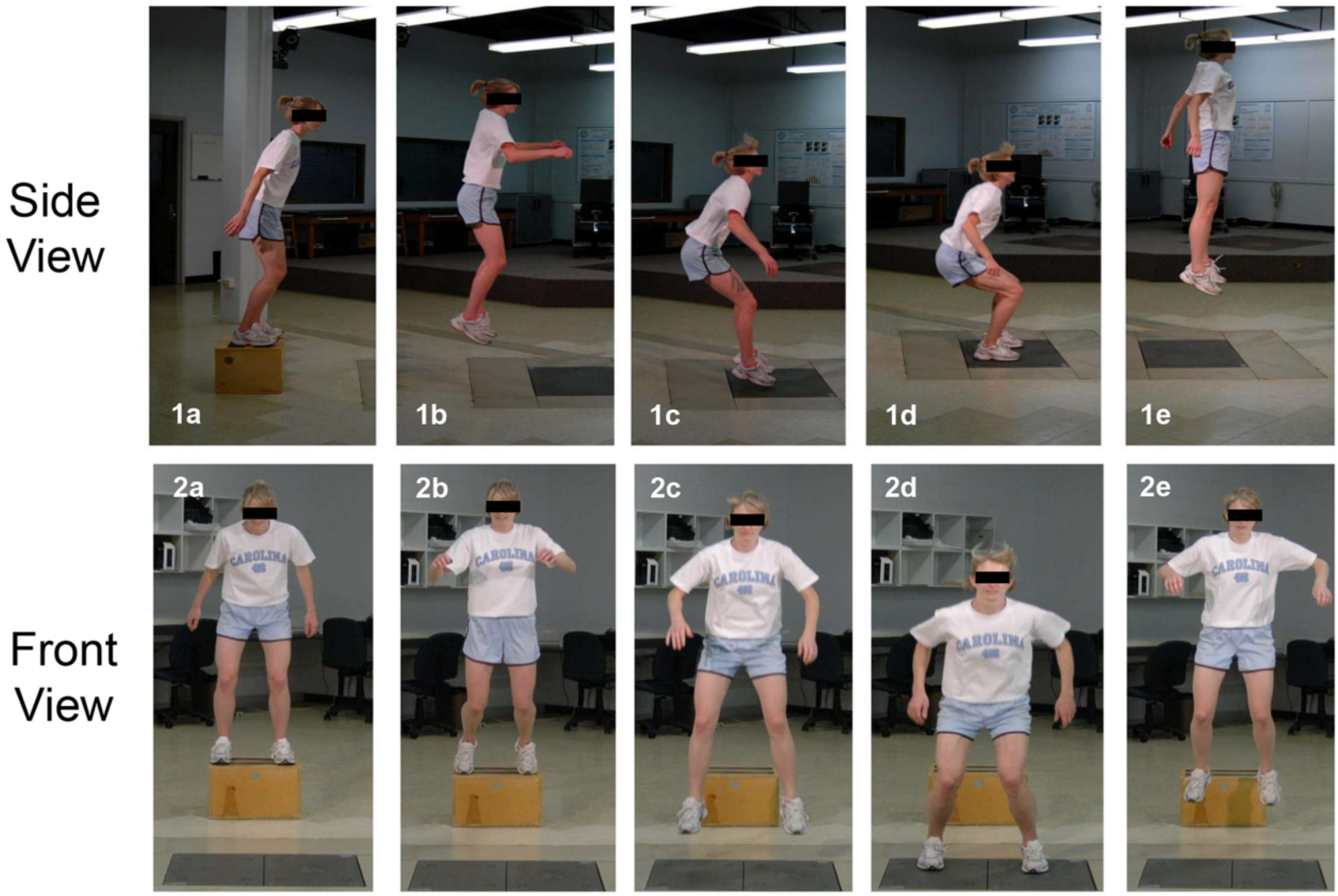

Figure 1. Lower extremity biomechanics assessment. The standardized jump-landing task consists of 2 segments performed sequentially. First, the participant jumps down from the elevated take-off box and lands at a distance approximately half their height (*1a-d* and *2a-d*). Second, the participant immediately jumps vertically upward as high as possible (*1e* and *2e*).

time of baseline, having met USMA entrance basic training standards and sports activity requirements,[33] and as such, no participants were excluded from baseline testing.

Data Collection and Reduction Procedures

At the time of enrollment and consent, all participants were asked to complete a baseline questionnaire that contained questions about demographics, lower extremity injury history, and physical activity history. The baseline questionnaire specifically asked about a history of lower extremity stress fracture before entry to the USMA. All participants completed the lower extremity movement assessment described below while wearing the same attire, consisting of shorts, t-shirt, and standard-issue running shoes, and all baseline testing was completed within the first 4 weeks after arriving at the academy.

Jump-Landing Task

Participants performed a standardized jump-landing maneuver involving a forward jump off a 30 cm–high platform to a distance equal to 50% of the participant's body height from the front edge of the platform. Participants were instructed to jump straight forward off the 30 cm–high platform, minimizing vertical motion. After landing, the participants were instructed to immediately recoil and perform a rebound jump for maximum vertical height. Participants were instructed to attempt to perform the initial jump down off the platform and subsequent rebound jump in as continuous a motion as possible. There was no landing target after the rebound jump. Two standard video cameras were positioned as described by Padua et al[28] to capture frontal and sagittal plane motion during the jump-landing task. Before testing, participants were allowed to perform 2 practice trials to familiarize themselves with the jump-landing maneuver. During testing, the participants performed 3 separate jump-landing trials. A 30-second rest interval was allowed between each jump-landing trial to minimize potential fatigue. A schematic of the jump-landing test procedures is provided in Figure 1.

The videos (side and front views) were later reviewed by trained LESS raters who evaluated the videos for the presence or absence of 17 standard jump-landing movement "errors."[28] Each LESS item was considered to be present if it was observed on $\geq$2 of the 3 trials. An individual rater scored all 3 trials for a single participant, and a total of 15 raters were used for the entire cohort. Video scoring for the LESS was previously determined to be valid in relation to 3-dimensional (3D) motion analysis and reliable (interrater ICC, 0.84; SEM, 0.71; and intrarater ICC, 0.91; SEM, 0.42) in a subset of participants from the same cohort, and details about the validity and reliability of the LESS in this cohort can be found in the literature.[28] Additionally, all raters were calibrated before and during scoring through ongoing trainings and range and consistency checks of the data.[28] Analysis of means per scorer indicated no scoring effects.

Injury Surveillance and Outcomes

Active surveillance was conducted within the cohort as part of study procedures during the 4-year follow-up period. Incident injuries were identified using the Defense Medical Surveillance System (DMSS). Using previously established methodology,[6] we queried the DMSS for each participant in the study cohort to identify any ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) codes consistent with lower extremity stress fracture injury during the follow-up period. Similar methodology was also used to query the Cadet Illness and Injury Tracking System, which documents all cadet injuries and illnesses at the USMA.[35,36] Incident injuries initially identified through these surveillance systems were subsequently verified through a standardized review of each injured participant's medical record by an adjudication committee consisting of 2 sports medicine fellowship–trained orthopaedic surgeons (B.D.O. and S.J.S.) with more than 30 years of combined experience as military physicians. Potential cases were reviewed independently by each surgeon. In cases where there was disagreement, both surgeons reviewed each case together, and incident stress fracture cases in the current study were required to have consensus on case status among the reviewers. Stress fracture cases were confirmed based on the medical history, imaging, and physical examination findings documented in the Armed Forces Health Longitudinal Technology Application. Both orthopaedic surgeons were blinded to all baseline LESS assessments at the time cases were reviewed.

Statistical Analyses

The primary outcome of interest was the incidence rate of lower extremity stress fracture during the follow-up period. Initially, means and standard deviations were calculated for continuous variables, and frequencies and proportions were calculated for categorical variables. The associations between baseline LESS performance and the subsequent incidence rate of lower extremity stress fracture were examined for the total LESS scale score as well as for each individual LESS item. Univariate and multivariable Poisson regression models were used to estimate the association between baseline movement patterns (LESS scores) and the incidence rate ratio (IRR) of lower extremity stress fracture during follow-up. Multivariable models statistically

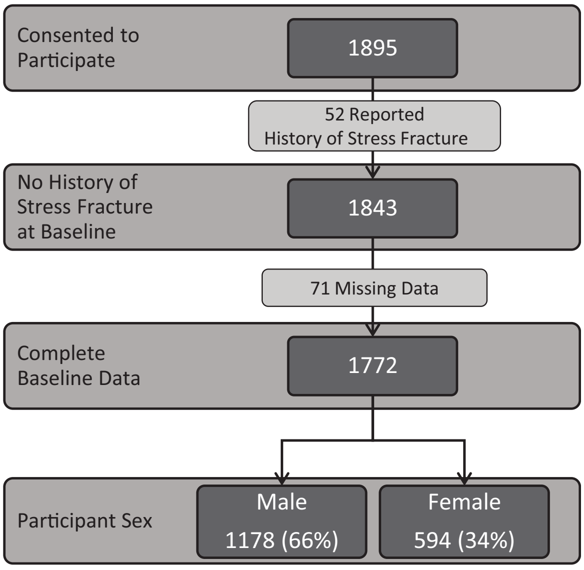

Figure 2. Breakdown of cadet inclusion in the study.

controlled for the influence of potential confounding variables, including sex and year of entry into the JUMP-ACL cohort (2005-2008). All analyses were conducted using Stata SE Version 10.0 software (StataCorp), and all comparisons used a type 1 error rate of 5%.

RESULTS

A total of 1895 cadets were eligible for inclusion in the current study. Fifty-two participants reported a history of stress fracture at baseline and were excluded from further analyses. An additional 71 participants were excluded because they did not have baseline LESS scores, leaving 1772 eligible participants. A breakdown of participant inclusion in this study is provided in Figure 2.

The final composition of the study cohort was 34% women (n = 594) and 66% men (n = 1178). At study baseline, participants had a mean age (± SD) of 18.7 ± 0.9 years (range, 17-23 years) and a mean body mass index of 23.9 ± 2.8 kg/m.[2] The demographic characteristics of the participants are provided in Table 1.

The mean baseline LESS score for men was 4.83 ± 1.59, and the mean score for women was 5.52 ± 1.51. During the follow-up period, 94 incident lower extremity stress fractures were determined to have occurred in the study cohort. The cumulative incidence of stress fracture over the 4-year follow-up was 5.3% (95% CI, 4.3%-6.5%). Of the 94 incident lower extremity stress fractures documented during the follow-up period, 49 (52.1%) were in the tibia, 24 (25.5%) were in the metatarsals, 11 (11.7%) were in the fibula, and 10 (10.6%) were in various other sites. The majority of stress fractures documented during the surveillance period (n = 55) were sustained by female participants.

In univariate analyses, the total LESS score at baseline was associated with the incidence rate of lower extremity stress fracture during follow-up. There was a 15% increase

TABLE 1
Baseline Demographic Characteristics of the Study Participants[a]

	Overall, N = 1772	Men, n = 1178; 66%	Women, n = 594; 34%
Cohort (missing = 0)			
2005	396 (22.3)	272 (23.1)	124 (20.9)
2006	462 (26.1)	335 (28.4)	127 (21.4)
2007	521 (29.4)	335 (28.4)	186 (31.3)
2008	393 (22.2)	236 (20.0)	157 (26.4)
Race (missing = 29)			
White	1359 (78.0)	931 (80.3)	428 (73.4)
Black	97 (5.6)	49 (4.2)	48 (8.2)
American Indian	11 (0.6)	5 (0.4)	6 (1.0)
Asian	98 (5.6)	62 (5.3)	36 (6.2)
Pacific Islander	4 (0.2)	1 (0.1)	3 (0.5)
>1 race	110 (6.3)	74 (6.4)	36 (6.2)
Other	64 (3.7)	38 (3.3)	26 (4.5)
Ethnicity (missing = 15)			
Non-Hispanic	1595 (90.8)	1074 (91.8)	521 (88.8)
Hispanic	162 (9.2)	96 (8.2)	66 (11.2)
BMI (missing = 0)	23.94 ± 2.84	24.32 ± 3.00	23.19 ± 2.30
Age, y (missing = 13)	18.74 ± 0.94	18.85 ± 1.01	18.53 ± 0.73

[a]Data are reported as n (%) or mean ± SD. BMI, body mass index.

in the incidence rate of lower extremity stress fracture during follow-up (IRR, 1.15 [95% CI, 1.02-1.31]; $P = .025$) for every additional movement error documented at baseline. Based on univariate analyses, several individual LESS items at baseline were also associated with the incidence rate of stress fracture during follow-up (see Table 2 for a complete list of LESS items). Lack of ankle plantarflexion at initial contact (LESS item 5; IRR, 1.68 [95% CI, 0.99-2.84]; $P = .054$), narrow stance width at initial contact (LESS item 8; IRR, 0.35 [95% CI, 0.14-0.88]; $P = .026$), wide stance width at initial contact (LESS item 9; IRR, 2.46 [95% CI, 1.34-4.55]; $P = .004$), asymmetrical foot-landing pattern at initial contact (LESS item 10; IRR, 2.64 [95% CI, 1.39-5.00]; $P = .003$), lack of trunk flexion at maximum knee flexion (LESS item 13; IRR, 1.64 [95% CI, 1.03-2.59]; $P = .036$), and overall impression (LESS item 15; IRR, 1.74 [95% CI, 1.09-2.79]; $P = .021$) were significantly associated with the incidence rate of stress fracture.

In multivariable analyses controlling for sex and cohort, 2 of these LESS items were most strongly associated with injury: flat-footed/heel-to-toe landing and asymmetric landing. Participants who consistently landed flat-footed or heel-to-toe (lack of ankle plantarflexion; LESS item 5) were 2.33 times (IRR, 2.33 [95% CI, 1.36-3.97]; $P = .002$) more likely to sustain a lower extremity stress fracture during follow-up. Furthermore, the incidence rate for lower extremity stress fracture increased with the number of trials in which the participant exhibited this error, demonstrating a dose-dependent relationship. Specifically, participants who landed flat-footed or heel-to-toe in 2 or more trials were more than twice as likely to sustain a stress fracture during follow-up (Table 3).

Similarly, participants who consistently demonstrated an asymmetric foot-landing pattern at initial contact (ie, feet do not contact the ground simultaneously; LESS item 10) were 2.53 times (IRR, 2.53 [95% CI, 1.34-4.74]; $P = .004$) more likely to sustain a stress fracture during follow-up. None of the other individual LESS items or total LESS score was associated with the incidence rate of lower extremity stress fracture after controlling for the influence of sex and year of entry into the cohort.

DISCUSSION

This prospective cohort study examined the association between baseline biomechanical movement patterns, as assessed by the LESS, and the subsequent incidence rate for lower extremity stress fracture. In univariate analyses, we observed that the total LESS score and several individual LESS items (ankle flexion, initial foot contact, stance width, asymmetrical landing, and trunk flexion at initial contact as well as overall impression) at preinjury baseline were associated with the incidence rate of lower extremity stress fracture during follow-up. In multivariable analyses controlling for sex and year of entry into the cohort, only participants who consistently landed flat-footed or heel-to-toe and those who had an asymmetric foot-landing pattern at initial contact experienced greater incidence rates for lower extremity stress fracture during follow-up. For those who land flat-footed or heel-to-toe, we observed a dose-dependent relationship between the number of trials where this movement error was observed at baseline and the incidence of lower extremity stress fracture during the follow-up period. To our knowledge, this is the first prospective cohort study to use the LESS to provide insight regarding baseline biomechanical movement patterns and the subsequent risk of lower extremity stress fracture during follow-up. Our results provide insight into identifiable and potentially modifiable kinematic factors associated with lower extremity stress fracture risk.

TABLE 2
Association of Individual LESS Items With Incidence of Stress Fracture[a]

LESS Item	Operational Definition[b]	IRR (95% CI)	*P*
1) Knee flexion angle at initial contact	At the time point of initial contact, if the knee of the test leg is flexed more than 30°, score YES. If the knee is not flexed more than 30°, score NO.	**0.73** (0.45-1.19)	.201
2) Knee valgus angle at initial contact	At the time point of initial contact, draw a line straight down from the center of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES.	**1.43** (0.80-2.53)	.227
3) Trunk flexion angle at initial contact	At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES.	**1.25** (0.74-2.10)	.402
4) Lateral trunk flexion at initial contact	At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO.	**1.16** (0.52-2.59)	.723
5) Ankle plantarflexion angle at initial contact	If the foot of the test leg lands toe-to-heel, score YES. If the foot of the test leg lands heel-to-toe or with a flat foot, score NO.	**1.68** (0.99-2.84)	.055
6) Foot position: toe out	If the foot of the test leg is externally rotated more than 30° between the time period of initial contact and max knee flexion, score YES. If the foot is not externally rotated more than 30° between the time period of initial contact to max knee flexion, score NO.	**0.62** (0.30-1.27)	.193
7) Foot position: toe in	If the foot of the test leg is internally more than 30° between the time period of initial contact and max knee flexion, score YES. If the foot is not internally rotated more than 30° between the time period of initial contact to max knee flexion, score NO.	**0.48** (0.04-5.73)	.562
8) Stance width: narrow	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot, score less than shoulder width (narrow): YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	**0.35** (0.14-0.88)	**.026**
9) Stance width: wide	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg, score greater than shoulder width (wide): YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	**2.46** (1.34-4.55)	**.004**
10) Symmetric initial foot contact	If one foot lands before the other or if one foot lands heel-to-toe and the other lands toe-to-heel, score NO. If the feet land symmetrically, score YES.	**2.64** (1.39-5.00)	**.003**
11) Knee flexion displacement	If the knee of the test leg flexes more than 45° from initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45°, score NO.	**0.89** (0.44-1.81)	.749
12) Knee valgus displacement	At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO.	**1.52** (0.95-2.44)	.081
13) Trunk flexion at maximum knee flexion	If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO.	**1.64** (1.03-2.59)	**.036**
14) Joint displacement: sagittal plane	Watch the sagittal plane motion at the hips and knees from initial contact to max knee flexion angle. If the participant goes through large displacement of the trunk, hips, and knees, score SOFT. If the participant goes through some trunk, hip, and knee displacement but not a large amount, score AVERAGE. If the participant goes through very little, if any, trunk, hip, and knee displacement, score STIFF.	**1.35** (0.93-1.97)	.118
15) Overall impression of jump	Score EXCELLENT if the participant displays a soft landing and no frontal plane motion at the knee. Score POOR if the participant displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE.	**1.74** (1.09-2.79)	**.021**
16) Hip flexion angle at initial contact	At the time point of initial contact, if the thigh of the test leg is in line with the trunk, then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES.	**1.96** (0.34-11.37)	.451
17) Hip flexion at maximum knee flexion	If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES.	**1.45** (0.74-2.86)	.279
Overall LESS score	—	**1.15** (1.02-1.31)	**.025**

[a]Boldface *P* values indicate a significant association with incidence rate of stress fracture at follow-up ($P < .05$). IRR, incidence rate ratio; LESS, Landing Error Scoring System.
[b]From Padua et al (2009).[28]

After controlling for potential confounding variables, items for ankle flexion and asymmetric landing at initial contact were best associated with subsequent stress fracture risk.[10] Specifically, our findings suggest that those who land with limited sagittal plane motion at the ankle are at greatest risk for stress fracture; it is likely that this limited sagittal plane motion at the ankle also contributes to increased peak ground-reaction forces during activity in those who eventually sustain lower extremity stress fractures.[1,38] The role of increased loading due to

TABLE 3
Dose-Dependent Relationship Between Ankle Plantarflexion Angle at Initial Contact and Stress Fracture Incidence[a]

LESS Item 5: Ankle Plantarflexion Angle at Initial Contact	IRR (95% CI)[b]	P
0/3 errors	1.00	
1/3 errors	1.35 (0.68-2.66)	.387
2/3 errors	2.10 (1.03-4.27)	**.040**
3/3 errors	2.22 (1.25-3.95)	**.007**

[a]Boldface P values indicate a significant association with incidence rate of stress fracture at follow-up ($P < .05$). IRR, incidence rate ratio; LESS, Landing Error Scoring System.

[b]Adjusted for sex and year of inclusion into study cohort.

alterations in movement biomechanics and anatomical alignment have long been speculated as a key factor in stress fracture development, although a definitive prospective relationship between these factors and injury has yet to be established.[1,4,16,25,26,34,38] These findings are consistent with traditional 3D motion analysis results reported previously, which suggest that increased vertical and medial ground-reaction forces at baseline are associated with the subsequent incidence rate of lower extremity stress fracture during follow-up.[10] Additionally, our findings are also consistent with previous work by Milner et al.[26] The authors did not find significant differences in total knee excursion or knee flexion at foot strike during gait in tibial stress fracture cases compared with controls; however, they did observe significantly greater knee stiffness in stress fracture cases, and tibial shock was correlated with knee stiffness. Other studies have also reported an association between peak ground-reaction forces and stress fracture,[18,19,25] while some have not[4]; however, most of these prior studies were cross-sectional, so it is not possible to tell whether the loading patterns observed in these studies were a risk factor for or the result of lower extremity stress fracture.

High-risk movement patterns may serve as targets for injury screening and the development of injury-prevention interventions aimed at improving movement quality and reducing ground-reaction forces.[9] Emerging data also suggest that it may be possible to reduce stress fracture risk and prevent other musculoskeletal injuries through movement retraining programs focused on enhancing movement quality and neuromuscular control.[8,15,17,24-27] Preventive exercise interventions that successfully alter high-risk movement patterns through decreasing ground-reaction forces, minimizing leg rotation, increasing sagittal plane motion, and increasing knee and hip strength may have the potential to reduce the risk of stress fractures and lower extremity injury in athletes and during exercise and military training.[15,17] There have been numerous studies focusing on the efficacy of movement retraining interventions to prevent ACL injury.[15,27,30,32] Similar programs have also shown promising results in reducing other acute and chronic lower extremity injuries.[8] It seems reasonable that, if these movement retraining programs were modified to specifically target the high-risk movement patterns associated with stress fracture, they might have similar results. While the LESS may have utility in assessing high-risk movement patterns associated with lower extremity stress fractures, it remains unclear if movement retraining interventions are effective in reducing the risk of injury. While this is an area of active research, within our research team and beyond, the data remain preliminary and inconclusive at this time.

The LESS provides clinicians with a readily available tool to efficiently assess high-risk movement biomechanics.[20,28] Based on the present data, the LESS may have utility in screening individuals for biomechanical risk factors associated with the incidence of lower extremity stress fracture; however, further research is required to optimize this tool. Other authors have found the LESS to underperform in populations with heterogeneous lower extremity injuries.[22] Clinically, this suggests that the LESS may best be utilized in conjunction with other screening tools and known risk factors to optimize the clinical utility of the LESS as a screening tool for lower extremity stress fracture risk. Further research is required to determine if the LESS should be used individually or, more likely, in combination with other baseline factors to effectively and efficiently screen for subsequent injury risk. At a minimum, the findings of the present study suggest that this additional work to optimize the clinical utility of the LESS as a potential screening tool for lower extremity stress fracture is warranted.

Limitations and Strengths

As with any investigation, the current study has notable limitations that should be considered when interpreting the results. First, we utilized the LESS to assess baseline movement quality and lower extremity kinematics. This assessment method provided an efficient way to screen a large number of participants at baseline, but it is not the traditional gold standard of gait analysis that has been utilized to examine kinematic and kinetic variables related to lower extremity stress fracture injuries.[25,26,29] Another limitation is that kinematic risk factors identified in the current study may not be reflective of injury mechanisms, even though they are associated with subsequent injury risk. For example, landing flat-footed or heel-to-toe (risk factor) as observed on the LESS may be a surrogate for increased tibial shock or peak vertical ground-reaction forces during running (injury mechanism). Additionally, other factors may have influenced stress fracture risk but were either not feasible or not possible to collect in a large cohort, including items such as lower extremity bony morphology, maladaptive alignment, bone mineral density, and muscle compliance. Although we documented nearly 100 lower extremity stress fractures during the surveillance period for the current study, we were underpowered for subgroup analyses by specific stress fracture site, which may limit the clinical utility of our findings. This is a common limitation in studies examining stress fracture as an injury outcome.[16] Finally, despite the robust injury surveillance systems and the closed healthcare system at our institution, it is possible that some lower extremity stress fractures were never reported during the follow-up period. While this is unlikely, it cannot be ruled out.

This study also has several notable strengths. Primarily, we were able to conduct a large prospective cohort study with preinjury baseline assessments of movement quality in a population at increased risk for lower extremity stress fracture. The study was conducted at an institution with a closed healthcare system and robust injury surveillance systems in place. Further, participants were followed during their 4 years at the institution, so it is likely that nearly all incident lower extremity stress fracture cases were documented in the cohort during the follow-up period. Finally, the study cohort had relatively homogeneous exposure physical training requirements and lower extremity loading during the surveillance period.

CONCLUSION

After controlling for the influence of sex and year of entry into the study cohort, participants who landed flat-footed or heel-to-toe and those with an asymmetric foot-landing pattern at baseline were more than twice as likely to sustain incident lower extremity stress fracture injuries during follow-up. Landing flat-footed or heel-to-toe also demonstrated a dose-dependent relationship with the incidence rate of lower extremity stress fracture. These data suggest that components of the LESS may be associated with lower extremity stress fracture risk and may be helpful in efficiently assessing lower extremity biomechanics in large groups of athletes, military recruits, and other active populations for future targeted intervention and movement retraining to reduce injury risk. Further research is needed to optimize screening and predictive models for lower extremity stress fracture risk that incorporate preinjury assessments of movement quality as well as other factors that may be informative to injury risk status.

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