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Demographic Characteristics and Their Association with Instantaneous Lower Extremity Injury Occurrence in a Division I Athletic Population.

Elisabeth A. Kelley, MS, ATC[1]*; Jennifer A. Hogg, PhD, ATC[2]; Lani Gao, PhD[3]; Justin P. Waxman, PhD[4]; Sandra J. Shultz, PhD, ATC, FNATA, FACSM[5]
[1]Erlanger Sports and Health Institute, Erlanger Health System, Chattanooga, TN
[2]Department of Health and Human Performance, The University of Tennessee at Chattanooga, Chattanooga, TN
[3]Department of Mathematics, The University of Tennessee at Chattanooga, Chattanooga, TN
[4]Biomechanics Division, S-E-A, Ltd., Columbus, OH
[5]Department of Kinesiology, The University of North Carolina at Greensboro, Greensboro, NC

*Corresponding Author:
Name: Elisabeth A. Kelley
Address: 1100 E. 3rd Street, Suite G-102, Chattanooga, TN 37403
Telephone: (334) 201-2569
Email: elisabeth.kelley@erlanger.org
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Demographic Characteristics and Their Association with Instantaneous Lower Extremity Injury Occurrence in a Division I Athletic Population.

Context: Temporal prediction of lower extremity (LE) injury risk will benefit clinicians by allowing them to better leverage limited resources and target athletes most at risk.

Objective: To characterize instantaneous risk of LE injury by demographic factors sex, sport, body mass index (BMI), and previous injury history. Instantaneous injury risk was defined as injury risk at any given point in time following baseline measurement.

Design: Descriptive epidemiology study.

Setting: NCAA Division I athletic program.

Patients or Other Participants: 278 NCAA Division I varsity student-athletes (119 males, 159 females).

Main Outcome Measure(s): LE injuries were tracked for 237±235 days. Sex-stratified univariate Cox regression models investigated the association between time to first LE injury and BMI, sport, and previous LE injury history. Relative risk ratios and Kaplan-Meier curves were generated. Variables identified in the univariate analysis were included in a multivariate Cox regression model.

Results: Females displayed similar instantaneous LE injury risk compared to males (HR=1.29, 95%CI=[0.91,1.83], p=0.16). Overweight athletes (BMI>25 kg/m^2) had similar instantaneous LE injury risk compared with athletes with BMI<25 kg/m^2 (HR=1.23, 95%CI=[0.84,1.82], p=0.29). Athletes with previous LE injuries were not more likely to sustain subsequent LE injury than athletes with no previous injury (HR=1.09, 95%CI=[0.76,1.54], p=0.64). Basketball (HR=3.12, 95%CI=[1.51,6.44], p=0.002) and soccer (HR=2.78, 95%CI=[1.46,5.31], p=0.002) athletes had higher risk of LE injury than cross-country athletes. In the multivariate model, females were at greater LE injury risk than males (HR=1.55, 95%CI=[1.00,2.39], p=0.05), and males with BMI>25 kg/m^2 were at greater risk than all other athletes (HR=0.44, 95%CI=[0.19,1.00], p=0.05).

Conclusions: In a collegiate athletic population, previous LE injury history was not a significant contributor to risk of future LE injury, while being female or being male with BMI>25 kg/m^2 resulted in increased risk of LE injury. Clinicians can use these data to extrapolate LE injury risk occurrence to specific populations.

Key Words: prospective; injury tracking; risk factors; Cox regression

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Key Points:

- Female athletes displayed a greater risk of instantaneous LE injury, particularly among athletes with no history of previous LE injury.
- Athletes with previous LE injury were not at a greater risk of future LE injury compared to athletes without a history of previous injury.
- When sex and BMI were taken into consideration together, males with BMI >25 kg/m^2 were at greater risk of LE injury than all other athletes.

National Collegiate Athletic Association (NCAA) athletes experience approximately 13.8 injuries per 1000 athlete-exposures (AEs) during games and 4.0 injuries per 1000 AEs during practices, with more than 50% of all injuries involving the lower extremities (LE).[1] As many as 76% of female Division I athletes are injured in a given season,[2] while only 43% of all athletes are reported to be injured.[3] Over the course of a 4-year collegiate career, the occurrence of at least one sports-related injury is reported by 90% of student athletes.[4] Furthermore, knee, lower leg, ankle, and foot injuries account for more than half of all *severe* injuries (restricted sport participation >3 weeks) reported in NCAA programs.[5] Due to long-lasting repercussions on physical function[6] and increased financial burden[7], there is a need for reliable identification of injury risk factors in order to provide clinicians with the means to mitigate future injury occurrence. Understanding the combined influences and interactions between various demographic characteristics and LE injury occurrence *over time* is a necessary step toward this aim.

Inclusion of multiple risk factors in the prediction of sport-related injury is important because of the interactions among potential risk factors such as sport, sex, and body mass index (BMI). Relatively few studies have assessed the combined impact of such demographic factors on risk of LE injury at the collegiate level.[8-10] Accurate prediction of LE injury occurrence in athletes provides clinicians the opportunity to implement injury prevention programs to target athletes most at risk. A systematic review of the literature showed that females participating in contact sports are approximately three to five times more likely to sustain a non-contact anterior cruciate ligament (ACL) injury compared to males, though evidence is mixed regarding whether this risk extends to other LE injuries.[11,12] For instance, no significant differences were reported in incidence rates of *first-time* ankle sprains between male and female athletes; however, in the sport of basketball, females had significantly greater risk of first-time ankle sprain compared to males.[8] These results suggest a possible interaction between sport and sex in terms of injury rates, such that injury risks are not the same for each sex, and it demonstrates a need to include such factors as determinants of all LE injuries.

BMI has been documented to play a role in LE injury risk, but the majority of studies pertaining to BMI have been conducted in military or youth populations. A prospective study including collegiate-aged cadets revealed that BMI was a significant predictor of ACL injury in females.[13] Higher BMI has been reported to contribute to increased risk of first-time musculoskeletal injury[14] and ankle injury in soldiers.[15] The effect of BMI on injury risk in adolescents, however, has been inconclusive, with some studies documenting higher risk of injury in individuals with high BMI (IRR=2.07, 95% CI: 1.00-6.94),[16] while some researchers find protective effects of high BMI (OR=0.64, 95% CI: 0.51,0.80).[17] It is possible that the effect of BMI on injury risk could be more clear when accounting for sex and/or sport. Compared to normal-weighted athletes of the same sport, obese softball and girls' basketball players sustained more knee injuries, while obese wrestling, volleyball, and football players sustained more ankle and foot injuries.[18] These results further argue for interactions among BMI, sport, and sex.

Additionally, previous injury history is a well-documented risk factor for subsequent injury.[19,20] It has been reported that athletes with a previous history of LE injuries, including hamstring strains, ACL ruptures, Achilles tendon ruptures, and ankle sprains, are at a higher risk of subsequent LE injury in high school, collegiate, and professional athletics.[21-24] To this end, it is proposed that previous injury results in neuromuscular deficits, muscle imbalances, and changes in LE biomechanics.[21,25] Coupled with inadequate rehabilitation, subsequent injuries often ensue.

Instantaneous injury risk is an injury risk metric largely unexplored in current sports medicine literature and may offer valuable information for clinicians seeking to mitigate potential for injury. Often quantified through *time-to-event* analyses, instantaneous injury risk captures both *if* and *when* an athlete sustains an injury. In this way, it expands on a simple dichotomous "yes/no" and infers on the rate at which athletes become injured. A Cox regression is the most common form of time-to-event analysis, as it yields both hazard rate ratios (i.e., *if* an injury occurs) and survival curves (i.e., *when* an injury occurs).[14,22,24,26-29] A hazard ratio of 1.20 indicates that a particular group has a 20% greater chance of being injured at any given point in time compared to a reference group, while the reference group will take 1.2 times longer to be injured. Survival curves provide a visual representation of when it can be expected an individual becomes injured. A sharp decline seen in a curve indicates a drop in the 'survival' of the group (i.e., more of the group experiences an injury at this point in time). This information would be valuable for resource-limited clinicians as they seek to mitigate future injuries through targeted interventions.

The purpose of our study was to characterize instantaneous LE injury risk (i.e., if and when an injury occurs) in a sample of NCAA Division I athletes by the following demographic factors: sex, sport, BMI, and previous LE injury history. Our operational definition of instantaneous LE injury risk was injury risk at any given point in time following baseline measurement. We hypothesized that instantaneous LE injury (injury occurring to the lower limb, hip, or lumbar spine that required evaluation by an athletic trainer or medical doctor and resulted in restriction of participation for at least one calendar day) risk would be greater (i.e., higher incidence at an earlier time point) in females, athletes with BMI >25 kg/m^2,[30] and athletes with previous LE injury.

METHODS

This was a prospective injury tracking study of a single NCAA Division I athletic department. Data were obtained concurrently with pre-participation exams from Fall 2013-Fall 2015. Athletes were included if they were 1) injury-free during the six weeks prior to data collection and 2) cleared for full participation in their respective sports. Each participant's sex and sport was obtained from athlete rosters provided by the athletic training staff and confirmed via their medical record database. Following informed written consent, body mass (kg) and height (m) were obtained via a scale and stadiometer, respectively. Each athlete's BMI was then calculated as mass divided by height squared (kg/m^2). This study was approved by the university's Institutional Review Board.

LE injury was defined as any injury occurring to the lower limb, hip, or lumbar spine that required medical attention from an athletic trainer or medical doctor and resulted in restriction of participation for at least one calendar day beyond the day of injury. All injuries meeting our definition of LE injury were captured regardless of when or where they happened; injuries were not limited to organized team practices or competitions. Lumbar spine injuries were included because lower back injuries have been documented to create lower limb motor control deficits.[31] Because recent evidence indicates that concussions may influence potential for subsequent LE injury,[27,32] concussions were also captured and reported. Previous history of LE injury was obtained through a review of each athlete's medical record maintained by the university's sports medicine and athletic training department. Injuries that occurred during an athlete's time at the university were recorded by staff athletic trainers. All injuries that occurred prior to arrival at the university were self-reported by the athlete in questionnaires completed upon arrival to the university as a freshman or transfer. Following the completion of each academic year, prospective injury data were exported from the athletic training department's injury management software and compiled. Data extracted from each prospective injury record are detailed in Table 1. Athletes were tracked until 1) their first LE injury, 2) the end of their collegiate career, or 3) until September 1, 2016, whichever occurred first. In the event of a single athlete completing multiple data collection sessions (e.g., 2013 and 2014), only the earliest session was used. Athletes were ultimately tracked for 237 ± 235 (range: 1 – 856) calendar days.

Statistical Analysis

The primary outcome variable was instantaneous LE injury risk, which was defined as the injury risk at any given time point and was quantified by the time to first injury, in calendar days. Independent (predictor) variables were sex (male or female), sport (basketball, softball, soccer, tennis, volleyball, or cross-country), BMI ($<$25 kg/m^2 or $>$25 kg/m^2), and history of previous LE injury (yes or no). Four Cox regression analyses were conducted: all athletes univariate, female univariate, male univariate, and multivariate; evidence indicates that sex is a moderating factor for injury risk, thus, separate univariate analyses were conducted in sex-stratified models. Significant sex-stratified univariates were also considered for entry into the multivariate analysis.

Hazard ratios (HRs) with 95% confidence intervals and p-values were computed for each independent variable in univariate Cox regression analyses. Relative injury risks were summarized by Kaplan-Meier curves and log rank test analysis. Variables with a p-value <0.3 in the univariate analysis were included in the multivariate Cox regression analysis. For visualization of risk profiles, Kaplan-Meier survival curves were generated. A p-value less than

0.05 was considered statistically significant. All statistical analyses were conducted in R (version 4.02, Vienna, Austria).

RESULTS

A total of 278 athletes (119 males; 159 females) were recruited from the varsity basketball, softball, soccer, tennis, volleyball, and cross-country teams. Fifty-eight athletes (21%) had no previous LE injury history or prospectively identified injury. Eighty-three athletes (30%) had previous injuries only. Twenty-five (9%) sustained prospective injuries only. One hundred twelve athletes (40%) sustained both previous injury and prospective injuries. Predictor variables are detailed in Table 1. Descriptive information for all prospective injuries is provided in Table 2.

In the all athletes univariate model, female and male athletes had similar instantaneous LE injury risks (HR=1.29, 95% CI=[0.91,1.83], p=0.16) (Figure 1). Compared to athletes with no previous LE injury, athletes with previous injuries were not more likely to sustain a prospective LE injury (HR=1.09, 95% CI=[0.76,1.54], p=0.64) (Figure 2). Though not statistically significant, overweight athletes (BMI >25 kg/m^2) trended toward a higher (i.e., shorter time to first injury) risk of instantaneous LE injury than athletes with BMI <25 kg/m^2 (HR=1.23, 95% CI=[0.84,1.82], p=0.29). Basketball, softball, and soccer players had a significantly higher risk of LE injury than cross-country athletes (HR range=2.78-3.49, p range=0.002-0.002) (Figure 3). Full univariate results are presented in Table 3.

When stratified by sex, males with BMI >25 kg/m^2 were at increased risk of LE injury compared with males with BMI <25 kg/m^2 (HR=2.21, 95% CI=[1.20,4.07], p=0.009) (Figure 4a). Females with BMI <25 kg/m^2 exhibited similar LE injury risk rates to females with BMI

>25 kg/m^2 (HR=0.80, 95% CI=[0.48,1.36], p=0.41) (Figure 4b). Males with a history of previous injuries were at higher risk of future injury compared to males without previous injuries; however, this finding was not statistically significant (HR=1.74, 95% CI=[0.95,3.19], p=0.07). Sex-stratified univariate results are presented in Table 4.

Accordingly, the predictors of sex, sport, BMI, and a sex by BMI interaction are considered in the multivariate analysis. Previous LE injury was excluded. The multivariate model showed basketball (HR=2.91, 95% CI=[1.37,6.18], p=0.005), softball (HR=3.30, 95% CI=[1.47,7.42], p=0.003), and soccer (HR=2.76, 95% CI=[1.44,5.32], p=0.002) athletes had higher LE injury risk compared to cross-country athletes. Females were at greater LE injury risk than males (HR=1.55, 95%CI=[1.00,2.39], p=0.05) and males with BMI>25 kg/m^2 were at greater risk than all other athletes (HR=0.44, 95%CI=[0.19,1.00], p=0.05). Full multivariate results are presented in Table 5.

DISCUSSION

Our study was one of the first to examine demographic factors as they relate to instantaneous LE injury risk in Division I collegiate athletes. We hypothesized that instantaneous LE injury risk would be greater in females, athletes with BMI >25 kg/m^2, and athletes with previous LE injury. The results partially supported our hypotheses. Specifically, in the multivariate model, females did exhibit a greater instantaneous LE injury risk compared to males. Additionally, males with a BMI >25 kg/m^2 showed increased risk of LE injury compared to males with BMI <25 kg/m^2, but this was not evident in females or when males and females were analyzed together. Contrary to our hypothesis, and surprising based on prior research,[19,20] previous LE injury was not a significant predictor of prospective LE injury occurrence. A strength of this study is the use of instantaneous injury risk as the outcome of interest. Instantaneous injury risk is operationalized as a hazard ratio, which is similar to a relative risk ratio, but inferred *at each time point*. In other words, a hazard ratio of 1.20 indicates that, compared to a reference group, individuals have a 20% greater chance of sustaining an injury on any given day. Alternatively, individuals in the lower risk group will take 1.2 times longer to become injured.[33]

The observed LE injury rates in our study are comparable to what has been previously reported. In an NCAA Division I athletic population, 43% of student athletes experienced a LE injury over the course of a single season.[3] Although our study was over several years, our data showed that approximately 40% of the Division I athletes in our study sustained at least one LE injury within 150 days following baseline.

Previous research has indicated that females are at increased risk of LE injury compared to males.[11-12] Our results indicated that, overall, females displayed a non-significant tendency toward greater instantaneous LE injury risk compared to males; however, in post-hoc exploratory analyses, this sex effect was statistically significant when isolating athletes with no previous injury history. While sex was not a significant predictor of LE injury in our univariate analysis, it was significant in the multivariate model. Combined with BMI, the effect of sex on LE injury risk was even stronger. Because of this, if sex is to be used as a predictor of injury, BMI must be included since it affects each sex differently. BMI appears to affect males' risk for LE injury much more than females, as seen in Figure 4.

Irrespective of sex, we observed a clear sport effect with regards to instantaneous LE injury risk. Cross-country and tennis exhibited the lowest LE injury rates, while soccer and basketball showed the highest among sports that included both male and female athletes. This was expected given the nature of each sport (e.g., non-contact vs. contact sports, anticipated vs. unanticipated). Approximately 30% of cross-country athletes will experience a LE injury over the course of a year, whereas approximately 70% of basketball athletes will experience a LE injury in that same amount of time (Figure 3). Softball and volleyball, exclusively female sports, each experienced a significant number of LE injuries early in the tracking period, as depicted by the initial sharp decline of the survival curve; however, both plateaued after approximately 200 days.

Similar patterns were observed in other survival curves. For instance, survival probability drops drastically in females with no previous injury (Figure 2) and males with BMI >25 kg/m^2 (Figure 4a) throughout the first 200 days. This seems to suggest that LE injury occurrence is highest in the first 200 days of activity following a pre-participation exam and plateaus after that point. We acknowledge that tracking by calendar days is a limitation in that it does not take into account an athlete's exposure to sport; however, our data collections took place in both the fall and spring and was based on individual athlete availability, with all sports being represented at each data collection. Thus, while we are unable to reference a specific point in the season where injury is more likely to occur, the cyclical nature of our data collection mitigates any seasonal effects. The reader should be mindful that only time to *first* injury was considered. Thus, it is possible that some individuals became re-injured following return-to-play, and these subsequent injuries were not captured. Nevertheless, clinicians can use these survival curves in this way to extrapolate initial LE injury occurrence for a specific population.

The results of our study revealed that overweight athletes (BMI >25 kg/m^2) were at a 23% higher risk of LE injury compared to athletes with BMI <25 kg/m^2. While this univariate finding pertaining to BMI was not statistically significant, this could be because we only included the initial measure of BMI as a predictor. Any changes in BMI that an athlete experienced over the season or in subsequent years were not considered. Studies including both high school and military populations have revealed higher incidence rates of injuries in individuals who are overweight or obese.[14-16,18] Examination of BMI as an injury risk factor in *collegiate* populations is an area that is limited in the literature; the majority of data pertain to military or youth and high school populations. Using BMI as a predictor of injury risk in a collegiate population may pose greater challenges than in youth or high school populations. Division I collegiate athletes are more elite compared to youth and high school populations, and BMI measures often overestimate adiposity in elite athletic populations due to increased relative muscle mass typically seen in high-level athletes.[35] Because they are more elite, collegiate athletes are a more homogenous population than youth or high school cohorts and will likely display less BMI variability. The BMIs in our study were 23.1 ± 2.3 kg/m^2 for males and 23.7 ± 9.2 kg/m^2 for females. These data are comparable to previous data in a large military cohort in which respective male and female BMI means were 23.4 ± 2.7 kg/m^2 and 22.0 ± 2.0 kg/m^2, with ACL injury risk associated with BMIs greater than one standard deviation above the mean.[13]

Our multivariate findings revealed an interaction between sex and BMI – females with BMI <25 kg/m^2 had a 56% decreased risk of instantaneous LE injury compared to males with BMI >25 kg/m^2. BMI may be more useful as a risk factor within a sport where larger or smaller body size is preferred. For example, a study of high school athletes showed that over half of the football players who were injured were overweight or obese.[18] Athletes playing certain positions in football – offensive line and defensive line, for example – are often encouraged to have a larger body size to meet the demands of that position. Interestingly, our results showed males with BMI >25 kg/m^2 were at an increased risk of LE injury compared to males with BMI <25 kg/m^2, despite our study not including football data. A systematic review specific to female athletes showed higher BMI was predictive of LE injury, though there was a small mean difference (0.5 kg/m^2).[34] This, combined with our multivariate results, suggests an interaction between BMI and sex. Because BMI can represent different metrics between sexes (e.g., higher BMI in males often represents an increase in relative muscle mass, while a higher BMI in females often represents an increase in relative fat mass),[35] future studies should use more accurate measures of body composition, such as fat-free mass or fat mass, to analyze the influence of body mass on injury risk.

Contrary to what is well-documented in the literature, our study revealed that, overall, athletes with previous LE injuries were not more likely to sustain a prospective LE injury compared to those with no history of previous injury. When stratified by sex, however, males with previous injuries exhibited a higher risk of future injury compared to males without. A recent study of military cadets showed that individuals with previous injury (in a cohort that was overwhelmingly male) were at greater risk of future LE injury.[36] Since the majority of the athletes in our study were female, the overall effect of previous injury may have been diminished, suggesting that biological sex may moderate the relationship between previous injury and future injury. Because we only included participants available for full participation in their sport, we would have excluded athletes who had previously sustained career-ending injuries. Thus, we cannot attribute this finding to differing exposure rates. One proposed explanation of these results is that sustaining an injury only increases an individual's future injury risk for a short period of time following the initial injury.[37] The increased risk of injury is possibly only seen while there are deficits in motor control, proprioception, or strength following an initial injury, which may exist for only a few weeks following injury. Athletes who had sustained an injury within the previous six weeks were excluded from our cohort; thus, it is possible we inadvertently excluded athletes who were truly at risk of prospective injury. Furthermore, we did not control for time since previous injury. If an athlete reported any previous LE injury, despite when it occurred, it was included in our data as a previous injury. Of interest, recent thought suggests a non-linear relationship between factors influencing injury.[37] There are many potential factors that can play a role in an athlete's risk of injury, including motor control, hormones, and the specific time within the season or game. It is possible that these factors, among others, influence the effect of previous injury on future injury. It is unlikely that a single risk factor is the sole contributor to an athlete's injury. For example, a study of NCAA Division I athletes showed that motor control has a mediating effect between previous injury and future injury, such that greater motor control during physical performance tests showed a protective effect on subsequent injury.[38] Because of this, it has been proposed that through targeted rehabilitation aimed at increasing motor control, an athlete can mitigate the detrimental effects of initial injury and ultimately reduce their risk of future injury.[22,37]

We acknowledge the presence of limitations in our study. Our small sample size did not allow us to stratify by acute and chronic injuries, which likely have different risk factors. We chose to dichotomize BMI into <25 and >25 kg/m^2 and not consider underweight (BMI <18.5) or obese (BMI >30) athletes as separate categories due to the small number of underweight and obese athletes in our cohort (9 underweight and 9 obese). Future studies should utilize larger sample sizes to examine risk factors for acute versus chronic injuries as well as stratify by multiple BMI categories. We did not control for time since previous injury, even if it was an injury sustained during childhood. Future studies should consider this factor to determine if more recent injury is predictive of sustaining a subsequent injury. Additionally, we only captured time to first LE injury. It is possible that an athlete sustained multiple injuries over the course of the study, but any subsequent injuries were not taken into consideration in our analyses. Furthermore, we only included BMI measurements at baseline. It is possible that BMI fluctuated over the course of the study. Future studies should examine whether changing one's BMI can alter their risk for injury, as well as devise implementation strategies aimed at accomplishing this goal. The use of BMI as the measure for body composition is also a limitation, as it is known that BMI does not differentiate between lean mass typically seen in high level athletes and adiposity. Future studies should look to utilize more accurate measures of body composition such as fat-free mass or fat mass.

CONCLUSIONS

In conclusion, our study demonstrated that, among our cohort of Division I athletes with no history of previous injury, females exhibited a greater (i.e., higher incidence at an earlier time point) risk of instantaneous LE injury compared to males. Previous LE injury history was not a significant predictor of future injury. BMI >25 kg/m^2 was associated with an increased risk of instantaneous LE injury in males, but not in females nor the sample as a whole. Athletes in contact sports sustained more LE injuries than athletes in non-contact sports. Clinicians can use this information to better identify athletes most at risk for LE injuries and implement proper injury prevention techniques to help mitigate those risks.

REFERENCES

1. Hootman JM, Dick R, Agel J, Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42(2):311-319.
2. Warren M, Lininger MR, Smith CA, Copp AJ, Chimera NJ, Association of functional screening tests and noncontact injuries in division I women student-athletes. *J Strength Cond Res.* 2019;34(8):2302-2311.
3. Henriquez M, Sumner J, Faherty M, Sell T, Bent B, Machine learning to predict lower extremity musculoskeletal injury risk in student athletes. *Front Sports Act Living*. 2020;2(576655).
4. Research Report: Changing the Culture of Youth Sports (2014). Safe Kids Worldwide. Available online at: https://www.safekids.org/research-report/research-report-changing-culture-youth-sports-august-2014
5. Kay MC, Register-Mihalik JK, Gray AD, Djoko A, et al., The epidemiology of severe injuries sustained by national collegiate athletic association student-athletes, 2009-2010 through 2014-2015. *J Athl Train*. 2017;52(2):117-128.
6. Hrysomallis C, Relationship between balance ability, training and sports injury risk. *Sports Med*. 2007;37(6):547-556.
7. Dixon, C. (2017). When Student-Athletes Get Injured, Who Pays? Noodle. Available online at: https://www.noodle.com/articles/when-student-athletes-get-injured-who-pays134

8. Beynnon BD, Vacek PM, Murphy D, Alosa D, Paller D, First-time inversion ankle ligament trauma: the effects of sex, level of competition, and sport on incidence of injury. *Am J Sports Med*. 2005;33(10):1485-1491.

9. Beynnon BD, Vacek PM, Newell MK, Tourville TW, et al., The effects of level of competition, sport, and sex on the incidence of first-time noncontact anterior cruciate ligament injury. *Am J Sports Med*. 2014;42(8):1806-1812.

10. Vacek PM, Slauterbeck JR, Tourville TW, Sturnick DR, et al., Multivariate analysis of the risk factors for first-time noncontact ACL injury in high school and college athletes: a prospective cohort study with a nested, matched case-control analysis. *Am J Sports Med*. 2016;44(8):1492-1501.

11. Brant JA, Johnson B, Brou L, Comstock RD, Vu T, Rates and patterns of lower extremity sports injuries in all gender-comparable US high school sports. *Orthop J Sport Med*. 2019;7(10):232596711987305.

12. Montalvo AM, Schneider DK, Webster KE, et al., Anterior cruciate ligament injury risk in sport: a systematic review and meta-analysis of injury incidence by sex and sport classification. *J Athl Train*. 2019;54(5):472-482.

13. Uhorchak JM, Scoville CR, Williams GN, Arciero RA, et al., Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med.* 2003;31(6):831-842.

14. Hruby A, Bulathsinhala L, McKinnon CJ, Hill OT, et al., BMI and lower extremity injury in U.S. army soldiers, 2001-2011. *Am J Prev Med.* 2016;50(6):e163-e171.

15. Eagle SR, Kessels M, Johnson CD, Nijst B, et al., Bilateral strength asymmetries and unilateral strength imbalance: predicting ankle injury when considered with higher body mass in US special forces. *J Athl Train.* 2019;54(5):497-504.

16. Richmond SA, Nettel-Aguirre A, Doyle-Baker PK, Macpherson A, Emery CA, Examining measures of weight as risk factors for sport-related injury in adolescents. *J Sports Med.* 2016;article ID 7316947.

17. Ezzat AM, Schneeberg A, Koehoorn M, Emery CA, Association between body composition and sports injury in Canadian adolescents. *Physiother Can*. 2016;68(3):275-281.

18. Yard E, Comstock D, Injury patterns by body mass index in US high school athletes. *J Phys Act Health.* 2011;8:182-191.

19. Karnuta JM, Luu BC, Haeberle HS, Saluan PM, et al., Machine learning outperforms regression analysis to predict next-season major league baseball player injuries: epidemiology and validation of 13,982 player-years from performance and injury profile trends, 2000-2017. *Orthop J Sport Med.* 2020;8(11):1–10.

20. Luu BC, Wright AL, Haeberle HS, Karnuta JM, et al., Machine learning outperforms logistic regression analysis to predict next-season NHL player injury: an analysis of 2322 players from 2007 to 2017. *Orthop J Sport Med*. 2020;8(9):1–8.

21. Fulton J, Wright K, Kelly M, Zebrosky B, et al., Injury risk is altered by previous injury: a systematic review of the literature and presentations of causative neuromuscular factors. *Int J Sports Phys Ther*. 2014;9(5):583-595.

22. Hägglund M, Waldén M, Ekstrand J, Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *Br J Sports Med.* 2006;40:767-772.

23. Knowles SB, Marshall SW, Bowling MJ, Loomis D, et al., Risk factors for injury among high school football players. *Epidemiology*. 2009;20(2):302-310.

24. Waldén M, Hägglund M, Ekstrand J, High risk of new knee injury in elite footballers with previous anterior cruciate ligament injury. *Br J Sports Med.* 2006;40:158-162.

25. Murphy DF, Connolly DAJ, Beynnon BD, Risk factors for lower extremity injury: a review of the literature. *Br J Sports Med.* 2003;37:13-29.

26. Buckley TA, Howard CM, Oldham JR, Lynall RC, et al., No clinical predictors of postconcussion musculoskeletal injury in college athletes. *Med Sci Sport Exerc*. 2020;52(6):1256-1262.

27. Fino PC, Becker LN, Fino NF, Griesemer B, et al., Effects of recent concussion and injury history on instantaneous relative risk of lower extremity injury in Division I collegiate athletes. *Clin J Sport Med*. 2019;29(3):218–223.

28. Nielsen RO, Bertelsen ML, Ramskov D, et al., Time-to-event analysis for sports injury research part 2: time-varying outcomes. *Br J Sport Med*. 2019;53(1):61-68.

29. Nye NS, Carnahan DH, Jackson JC, Covey CJ, et al., Abdominal circumference is superior to body mass index in estimating musculoskeletal injury risk. *Med Sci Sports Exerc*. 2014;46(10):1951–1959.

30. Executive summary of the clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults. *Arch Intern Med.* 1998;158(17):1855-1867.

31. Schoenfeld AJ, Weiner BK, Treatment of lumbar disc herniation: evidence-based practice. *Int J Gen Med.* 2010;3:209-214.

32. Howell DR, Lynall RC, Buckley TA, Herman DC, Neuromuscular control deficits and the risk of subsequent injury after a concussion: a scoping review. *Sports Med.* 2018;48(5):1097-1115.

33. Sports Injury Research. Eds. Verhagen, Evert, and Willem van Mechelen. : Oxford University Press, 01. Oxford Scholarship Online. Date Accessed 6 Feb. 2022 <https://oxford.universitypressscholarship.com/view/10.1093/acprof:oso/9780199561629.001.0001/acprof-9780199561629>.

34. Collings TJ, Bourne MN, Barrett RS, du Moulin W, et al., Risk factors for lower limb injury in female team field and court sports: a systematic review, meta-analysis, and best evidence synthesis. *Sport Med*. 2021;51(4):759-776.

35. Ode JJ, Pivarnik JM, Reeves MJ, Knous JL, Body mass index as a predictor of percent fat in college athletes and nonathletes. *Med Sci Sports Exerc*. 2007;39(3):403-409.

36. Hearn DW, Kerr ZY, Wilkstrom EA, Goss DL, et al., Lower extremity musculoskeletal injury in US Military Academy cadet basic training: a survival analysis evaluating sex, history of injury, and body mass index. *Orthop J Sports Med.* 2021;9(10):23259671211039841.

37. Stern BD, Hegedus EJ, Lai YC, State dependence: does prior injury predict a future injury?. *Physical Therapy in Sport*. 2021;49:8-14.

38. Hegedus EJ, McDonough S, Bleakley C, Baxter GD, et al., Physical performance tests predict injury in national collegiate athletic association athletes: a three-season prospective cohort study. *Br J Sports Med*. 2016;50:1333-1337.

Table 1. Descriptive Frequency Data for All Predictor Variables

	Female N=159 (57%)	Male N=119 (43%)	Total N=278
BMI (>25 kg/m^2)	35 (22%)	24 (20%)	59 (21%)
Previous injury history (yes)	95 (60%)	76 (64%)	167 (60%)
Sport			
Soccer	47 (30%)	57 (48%)	104 (37%)
Volleyball	27 (17%)	0 (0%)	27 (10%)
Tennis	15 (9%)	18 (15%)	33 (12%)
Basketball	26 (16%)	21 (18%)	47 (17%)
Softball	25 (16%)	0 (0%)	25 (9%)
Cross-country	19 (12%)	23 (19%)	42 (15%)

Table 2. Descriptive Data of Prospective Injuries Gathered

Variable	Levels	N (%)
Occurrence	First-time	116 (84.7%)
	Recurrent	19 (13.9%)
	Complication of previous injury	0 (0%)
	Concurrent with another injury	2 (1.5%)
Side	Left	60 (43.8%)
	Right	65 (47.4%)
	Midline	12 (8.8%)
Body part	Ankle	32 (23.4%)
	Foot	13 (9.5%)
	Head (concussion)	9 (6.6%)
	Knee	22 (16.1%)
	Lower leg	15 (10.9%)
	Patella	5 (3.6%)
	Pelvis, hip, buttocks	10 (7.3%)
	Upper leg	31 (22.6%)
Type	Bursitis	1 (0.7%)
	Concussion	9 (6.6%)
	Disc pathology	2 (1.5%)
	Dislocation/subluxation	2 (1.5%)
	Dysfunction (SI joint, facet joint, spondylolysis, spondylolisthesis)	6 (4.4%)
	Fracture	2 (1.5%)
	Intra-articular derangement (meniscal tear, labral tear, femoroacetabular impingement)	6 (4.4%)
	Overuse syndromes	22 (16.1%)
	Sprain	31 (22.6%)
	Strain	40 (29.2%)
	Stress fracture	2 (1.5%)
	Synovitis	1 (0.7%)
	Tendinitis	12 (8.8%)
	Other	1 (0.7%)
Onset	Acute	90 (65.7%)
	Chronic	47 (34.3%)
Surgery	No	131 (95.6%)
	Yes	6 (4.4%)
Total prospective injuries		137

Table 3. Results of All Athletes Univariate Cox Regression Predicting Prospective Injury Risk

Variable	HR	95% CI	P value
Sex *(ref: male)*	1.29	(0.91, 1.83)	0.16
BMI *(ref: <25 kg/m²)*	1.23	(0.84, 1.82)	0.29
Previous injury *(ref: no)*	1.09	(0.76, 1.54)	0.64
Reference sport: cross-country			
Basketball	3.12	(1.51, 6.44)	0.002
Softball	3.49	(1.61, 7.54)	0.002
Soccer	2.78	(1.46, 5.31)	0.002
Tennis	1.70	(0.77, 3.76)	0.19
Volleyball	1.78	(0.75, 4.19)	0.19

Table 4. Results of Sex-Stratified Univariate Cox Regression Predicting Prospective Injury Risk

Variable	Female			Male		
	HR	95% CI	P value	HR	95% CI	P value
BMI *(ref: <25 kg/m²)*	0.80	(0.48, 1.36)	0.41	2.21	(1.20, 4.07)	0.01
Previous injury *(ref: no)*	0.82	(0.53, 1.28)	0.39	1.74	(0.95, 3.19)	0.07
Reference sport: cross-country						
Basketball	3.07	(1.09, 8.64)	0.03	3.20	(1.13, 9.03)	0.03
Softball	3.44	(1.26, 9.42)	0.02	NA	NA	NA
Soccer	3.21	(1.24, 8.32)	0.02	2.48	(1.03, 5.99)	0.04
Tennis	2.26	(0.74, 6.91)	0.15	1.25	(0.40, 3.91)	0.70
Volleyball	1.79	(0.61, 5.25)	0.29	NA	NA	NA

Table 5. Results of the Multivariate Cox Regression Predicting Prospective Injury Risk

Variable [a]	HR	95% CI	P value
Sex *(ref: male)*	1.55	(1.00, 2.39)	0.05
BMI *(ref: <25 kg/m²)*	1.56	(0.83, 2.94)	0.17
Reference sport: cross-country			
Basketball	2.91	(1.37, 6.18)	0.005
Softball	3.30	(1.47, 7.42)	0.003
Soccer	2.76	(1.44, 5.32)	0.002
Tennis	1.82	(0.82, 4.04)	0.14
Volleyball	1.61	(0.66, 3.89)	0.29
Sex * BMI interaction	0.44	(0.19, 1.00)	0.05

[a] Multivariate model included all univariate predictors that displayed a p-value <0.3.

Figure 1. Kaplan-Meier survival curve depicting sex differences in sustaining prospective injury.

Figure 2. Kaplan-Meier survival curve depicting the risk for prospective injury between individuals with and without previous injury history.

Figure 3. Kaplan-Meier survival curve depicting prospective injury risk between sports.

Figure 4. Kaplan-Meier survival curve depicting prospective injury risk between males (A) and females (B) with BMI <25 kg/m^2 and BMI >25 kg/m^2.

Figure 1

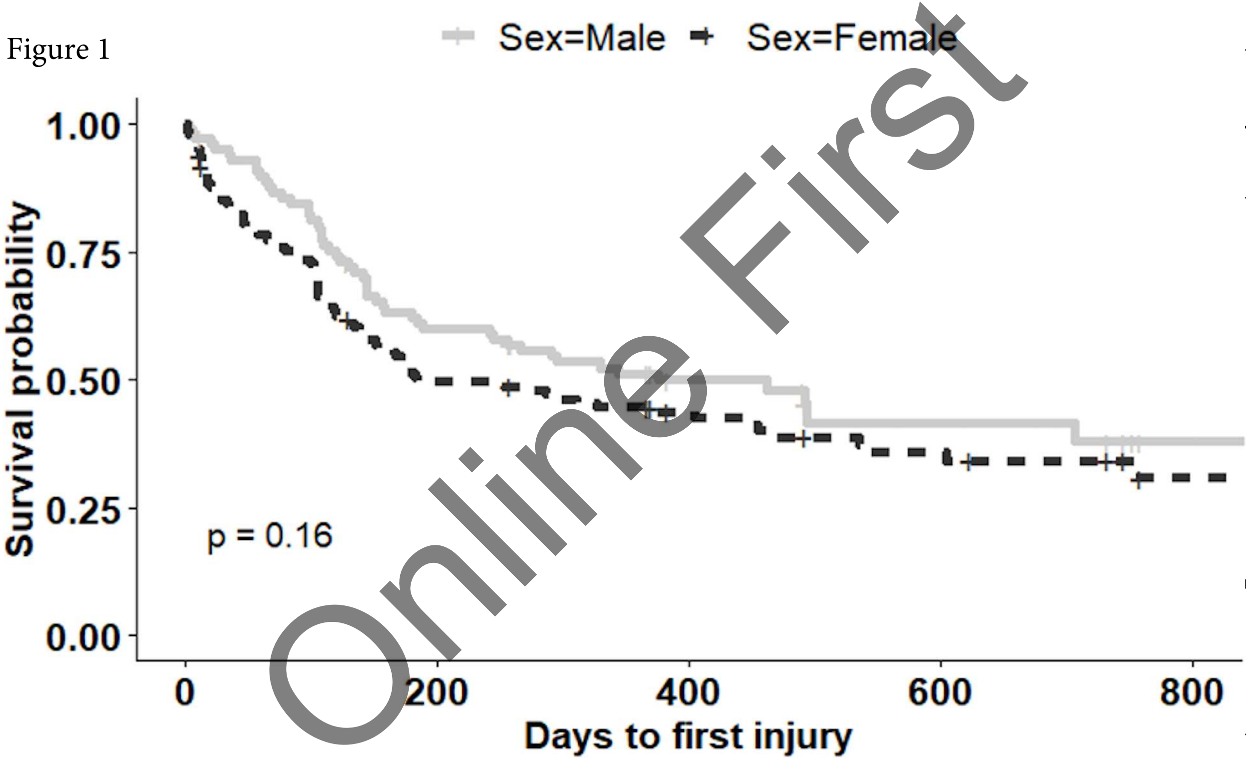
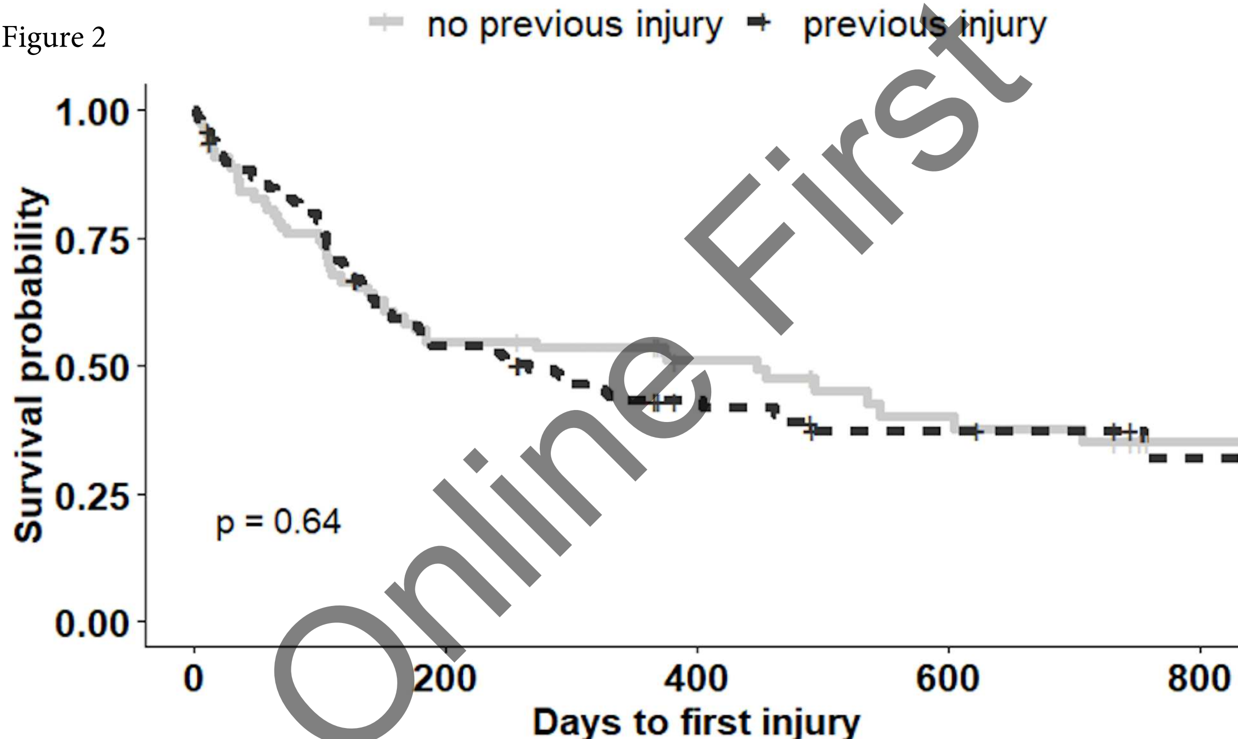
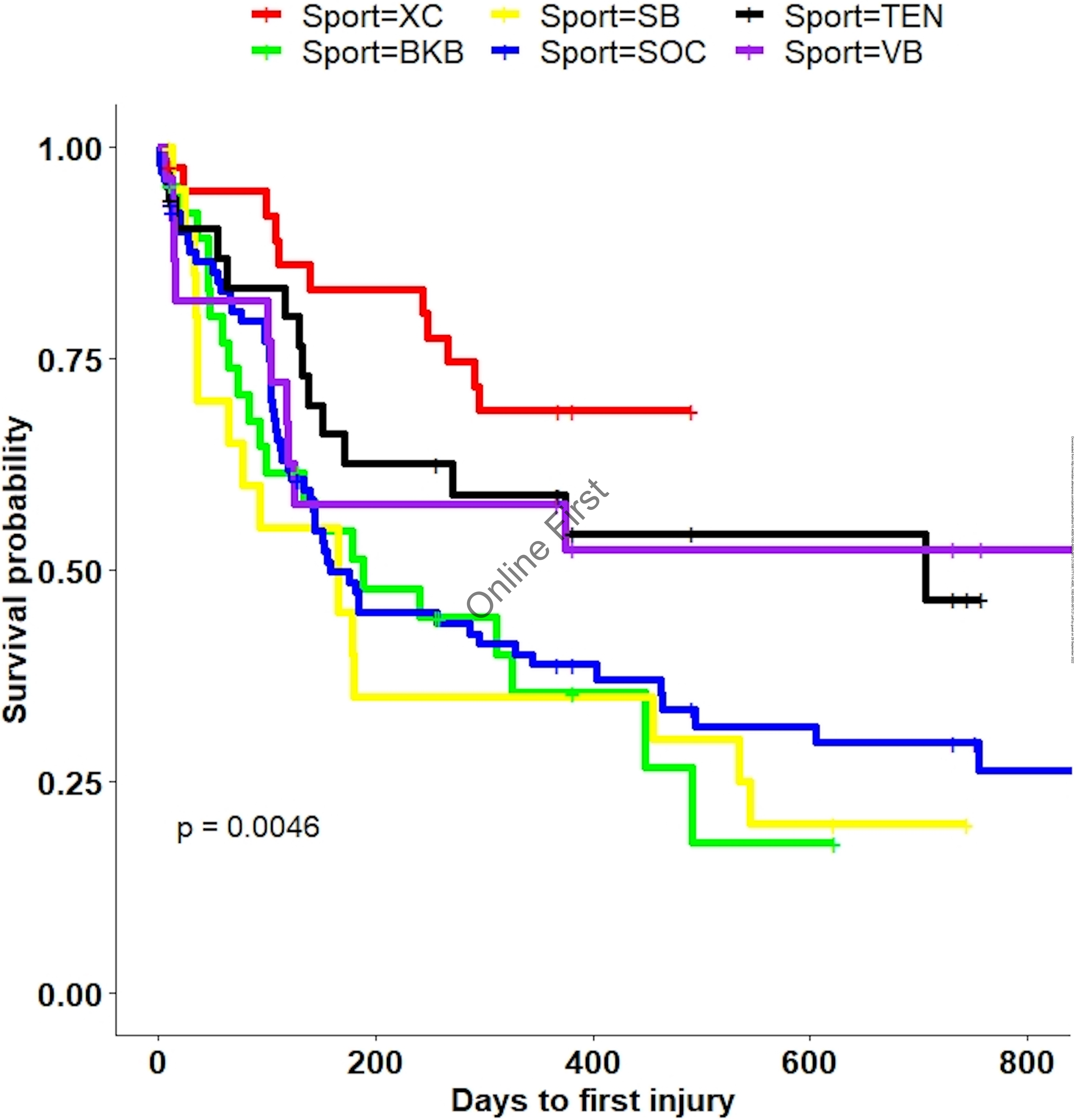

Sex=Male
Sex=Female
Survival probability
1.00
0.75
0.50
0.25
0.00
p = 0.16
0
200
400
600
800
Days to first injury

Figure 2



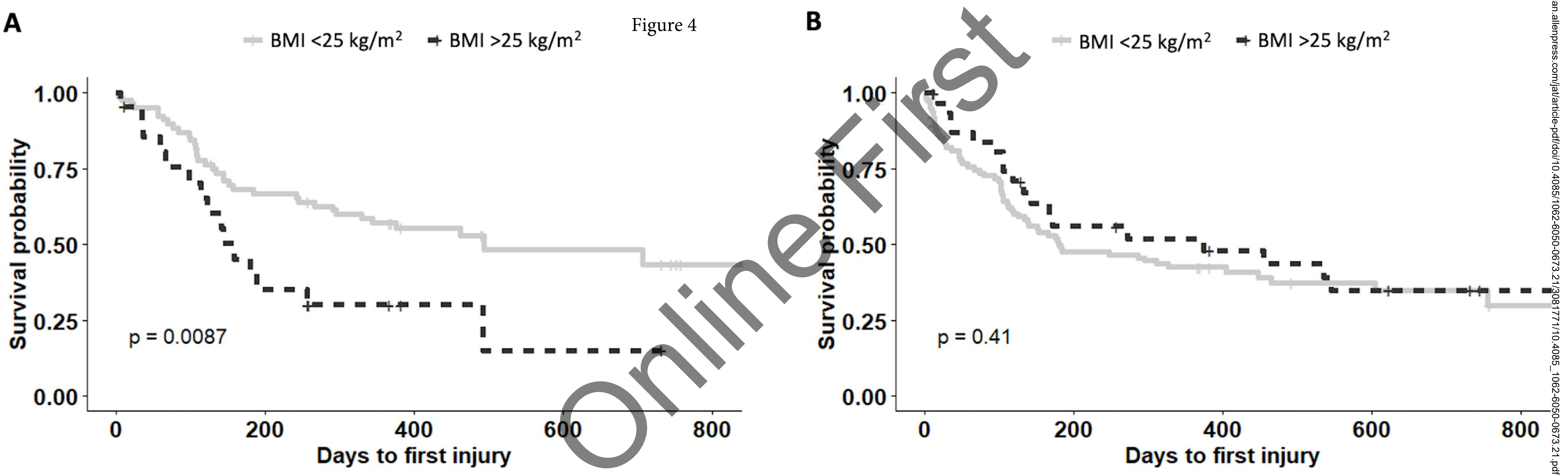
no previous injury
previous injury
1.00
0.75
0.50
0.25
0.00
Survival probability
p = 0.64
0
200
400
600
800
Days to first injury

Figure 3



Sport=XC
Sport=SB
Sport=TEN
Sport=BKB
Sport=SOC
Sport=VB
1.00
0.75
0.50
0.25
0.00
Survival probability
p = 0.0046
Online First
0
200
400
600
800
Days to first injury

Figure 4


A
BMI <25 kg/m²
BMI >25 kg/m²
Survival probability
1.00
0.75
0.50
0.25
0.00
p = 0.0087
0
200
400
600
800
Days to first injury
B
BMI <25 kg/m²
BMI >25 kg/m²
Survival probability
1.00
0.75
0.50
0.25
0.00
p = 0.41
0
200
400
600
800
Days to first injury