COMMENTARY

TIME FOR A PARADIGM SHIFT IN CONCEPTUALIZING RISK FACTORS IN SPORTS INJURY RESEARCH

Kenneth L. Cameron, PhD, ATC, CSCS

Editor's note: Kenneth L. Cameron, PhD, ATC, CSCS, is the Director of Orthopaedic Research, John A. Feagin Sports Medicine Fellowship, Keller Army Hospital, West Point, NY.

Certified athletic trainers are positioned to play an integral role in sport-related, recreation-related, and exercise-related injury research and prevention efforts. The Centers for Disease Control and Prevention[1] have specifically identified certified athletic trainers and their potential to contribute to this important area of research in their recently published *Injury Research Agenda* for 2009–2018. From a public health perspective, identifying factors associated with injury is one of the initial steps in the injury prevention process. The ultimate goal of this line of research is to identify populations that are at greatest risk for subsequent injury and to develop effective screening and intervention strategies to reduce the incidence and burden of injury. Therefore, the manner in which risk factors are conceptualized in initial research has significant bearing on the development of subsequent screening and intervention strategies.

In the current issue of the *Journal of Athletic Training*, Reinking et al[2] examined the factors associated with exercise-related leg pain in high school cross-country athletes. After a discussion of modifiable and nonmodifiable risk factors, the authors conceptualized risk factors for exertional leg pain as intrinsic (within the body) or extrinsic (outside the body) factors; sports injury researchers have traditionally conceptualized risk factors associated with injury in this manner.[3–5] This study provides an opportunity to discuss how risk factors are conceptualized in the context of sports injury research. The seminal work by sports injury researchers such as van Mechelen et al[3] and Meeuwisse[5] provided a theoretic framework for sports injury research, and although these models have evolved since they were first described,[6–9] they have consistently characterized risk factors for injury as *intrinsic factors* and *extrinsic factors*. It is important to consider that injuries often result from the complex interaction of multiple factors[3,7,10] in a dynamically changing environment,[6] but the characterization of risk factors as intrinsic or extrinsic limits the clinical importance and usefulness of results in relation to future injury screening and prevention efforts. More importantly, characterizing risk factors in this manner provides limited insight into whether something can be done to intervene and mitigate the contributing influence of any given factor or combination of factors with regard to subsequent injury.[11] Injury epidemiologists and public health professionals, on the other hand, use a different approach to conceptualizing risk factors for disease or injury by focusing on those risk factors that are modifiable and those that are nonmodifiable.

Conceptualizing risk factors as *modifiable* and *nonmodifiable* is important from a clinical and injury prevention perspective, because modifiable risk factors are amenable to intervention.[11] Researchers[12,13] of chronic diseases, such as cardiovascular disease, hypertension, and type 2 diabetes, have conceptualized risk factors as modifiable and nonmodifiable. Some of these risk factors include physical activity, diet, smoking, and obesity, to name a few. Subsequent intervention efforts have been developed and evaluated to address these factors, with various degrees of success. Conceptualizing risk factors as modifiable and nonmodifiable aligns with the "Translating Research into Injury Prevention Practice (TRIPP)" framework described by Finch,[9] which applies a public health approach to sports injury prevention.

Clinicians and injury researchers are most interested in modifiable risk factors associated with injury because they provide the vector for developing injury prevention interventions. Although nonmodifiable risk factors may not be useful as targets for intervention, they are particularly important in identifying populations that are at greatest risk for injury, so that injury prevention strategies can be directed to those with the most pressing need. This information can be used to develop risk profiles for specific injuries, to screen athletes to identify those at greatest risk for injury, and to guide injury prevention interventions that target modifiable risk factors. This information can also be used to develop interventions and social marketing campaigns that are culturally and ecologically appropriate for the populations at greatest risk for injury.[14] When only nonmodifiable risk factors associated with injury are known, this information can be used to counsel athletes and parents about potential risks during the preparticipation screening process, so they can make informed decisions about participation.

Recently, researchers have conceptualized risk factors as modifiable and nonmodifiable in the sports medicine literature. Emerging research[10,15–17] into the risk factors associated with anterior cruciate ligament (ACL) injuries is one of the best examples in the sports medicine literature of how the conceptualization of risk factors has evolved. Early work[15] in this area conceptualized risk factors as *intrinsic* and *extrinsic*, while recognizing the importance of focusing on factors that are modifiable. Subsequent consensus statements[10,16] on the risk factors for ACL

Table. Modifiable and Nonmodifiable Risk Factors for Noncontact Anterior Cruciate Ligament (ACL) Injury Categorized as Intrinsic (I) or Extrinsic (E) and Using the Scheme Described in Several Consensus Statements[10,16,17]

Modifiable Risk Factors	Nonmodifiable Risk Factors
Environmental	Environmental
Meteorologic conditions (E)	*Playing situation (E)*
Playing surface (E)	*Opponent behavior (E)*
Footwear (E)	*Unanticipated events during play (E)*
Knee braces (E)	Anatomical
Rules (E)	*Q angle (I)*
Referees (E)	*Navicular drop (I)*
Coaching (E)	*Knee valgus (I)*
Anatomical	*Postural alignment (I)*
Foot pronation (I)	*Notch size, ACL geometry and properties (I)*
Body composition and body mass index (I)	*Tibial slope angle (I)*
Neuromuscular	*Generalized joint hypermobility or laxity (I)*
Muscle strength (I)	Hormonal
Muscle activation patterns (I)	*Menstrual cycle and hormone concentrations (I)*
Muscle stiffness (I)	Demographic
Physical fitness and muscle fatigue (I)	*Age (I)*
Skill level (I)	*Injury history (I)*
Hormonal	*Familial history and genetics (I)*
	Sex (I)
	Height (I)
	Race (I)

injury conceptualized risk factors by categorizing them into environmental, anatomical, hormonal, neuromuscular, and familial-tendency factors. Although these consensus statements[10,16,17] did not categorize risk factors as modifiable and nonmodifiable, they did recognize the importance of neuromuscular factors, primarily because of their modifiable nature. Risk factors from several consensus statements related to understanding and preventing ACL injuries are conceptualized as modifiable or nonmodifiable in the Table. It is important to note that some risk factors categorized as nonmodifiable may be modifiable through surgical (eg, tibial slope angle) or pharmacologic (eg, menstrual cycle and hormone concentrations) interventions, but such interventions may not be feasible or ethical. Conversely, risk factors categorized as modifiable (eg, meteorologic conditions, playing surface, rules) may not be financially or socially feasible to change, which would affect the successful implementation of subsequent injury prevention initiatives.[9]

Researchers[10,17] have recently been focusing more on modifiable risk factors for ACL injury, such as neuromuscular control and biomechanical factors, dynamic loading, movement variability, muscle strength, fatigue, and alignment during landing and cutting maneuvers. This information has been used to develop promising injury prevention programs to reduce the incidence of noncontact ACL injuries among athletes.[18,19] The JUMP-ACL project, led by Dr Stephen Marshall at the University of North Carolina at Chapel Hill and funded by the National Institute of Arthritis and Musculoskeletal and Skin Diseases, is an example of a research initiative that has conceptualized risk factors as modifiable and nonmodifiable in the context of noncontact ACL injuries.

The JUMP-ACL project is a prospective, multicenter cohort study designed to identify the modifiable and nonmodifiable risk factors for noncontact ACL injuries within the high-risk population attending the nation's 3 largest military academies. The project was initiated in the summer of 2005 and is nearing completion. During the first several weeks of their academy career, incoming freshmen were asked to provide informed consent and, subsequently, to complete a baseline questionnaire (eg, injury history, age, activity history, menstrual history) along with a battery of anatomical (eg, height, weight, Q-angle, navicular drop, knee valgus) and neuromuscular (eg, muscle strength, kinetics and kinematics during a jump landing task) assessments. Participants were tracked through the closed health care systems at the academies, and regular injury surveillance activities aided in identifying all ACL injuries within the cohort until graduation. Participants who subsequently sustained an ACL injury were asked to complete a follow-up injury questionnaire that documented proximal factors associated with the injury. Injury information was also abstracted from the medical record. As of August 2008, 5686 participants had been enrolled in the study and had fully completed baseline testing.

The initial results of this project confirm that individuals who eventually tear their ACLs jump and land differently than those who are at low risk for subsequent ACL injury. This finding indicates that incoming cadets could be screened upon arrival, and those determined to be at greatest risk could be placed into a training program designed to correct their movement deficits. Previous authors[18–22] have reported that exercise programs could reduce the incidence of ACL injuries. Data from the JUMP-ACL project are being used by the research team to develop and validate risk profiles and field assessments to efficiently identify individuals at greatest risk of injury.[23] Using the scientifically validated risk profiles, the research team has also begun to further develop, refine, and evaluate the effectiveness of injury prevention interventions to target modifiable neuromuscular risk factors associated with noncontact ACL injury. Preliminary data indicate that based on an individual's neuromuscular risk profile, a targeted exercise program performed 2 to 3 times per week

(for 10 minutes at a time) may reduce the incidence of ACL injuries by as much as 70% and the incidence of lower extremity injury in general by as much as 50%. However, it is clear that close supervision is required in order to attain maximum benefit from such programs; intervention programs with higher levels of supervision appear to show stronger effects.[24] The future goals of the research team are to validate the effectiveness of these injury prevention programs, to better understand the role of the dose-response relationship, and to identify the factors affecting intervention fidelity as they try to transition their work from injury prevention research to injury prevention practice, consistent with the TRIPP framework described by Finch.[9]

Although the published sports medicine literature provides precedence for conceptualizing risk factors associated with injury as intrinsic and extrinsic or as grouped by domains, sports injury researchers should reexamine the utility of these conceptual models in light of the overarching goals of sports injury epidemiology, which are to reduce the incidence and mitigate the burden of preventable injuries among athletes. Within the sports medicine literature, research related to the understanding and prevention of ACL injuries has provided one of the most robust examples of how conceptualizing risk factors as modifiable and nonmodifiable has led to advances in injury prevention efforts. Conceptualizing risk factors as modifiable and nonmodifiable provides a framework that is more aligned with the overarching goals of injury prevention and one that has been used to develop and evaluate the effectiveness of intervention strategies. Considering the overarching goals of sports injury research, a paradigm shift in how risk factors are conceptualized seems justified in the context of sports injury research.

REFERENCES

1. Centers for Disease Control and Prevention. CDC Injury Research Agenda, 2009–2018. National Center for Injury Prevention and Control. http://www.cdc.gov/ncipc/pub-res/research_agenda/agenda.htm. Accessed August 24, 2009.
2. Reinking MF, Austin TM, Hayes AM. Risk factors for self-reported exercise-related leg pain in high school cross-country athletes. *J Athl Train*. 2010;45(1):51–57.
3. van Mechelen W, Hlobil H, Kemper CG. Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Med*. 1992;14(2):82–99.
4. Jones BH, Knapik JJ. Physical training and exercise-related injuries: surveillance, research, and injury prevention in military populations. *Sports Med*. 1999;27(3):111–125.
5. Meeuwisse WH. Athletic injury etiology: distinguishing between interaction and confounding. *Clin J Sport Med*. 1994;4(12):171–175.
6. Meeuwisse WH, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sports injury: the recursive nature of risk and causation. *Clin J Sport Med*. 2007;17(3):215–219.
7. Gissane C, White J, Kerr K, Jennings D. An operational model to investigate contact sports injuries. *Med Sci Sports Exerc*. 2001;33(12):1999–2003.
8. Van Tiggelen D, Wickes S, Stevens V, Roosen P, Witvrouw E. Effective prevention of sports injuries: a model integrating efficacy, efficiency, compliance and risk-taking behaviour. *Br J Sports Med*. 2008;42(8):648–652.
9. Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport*. 2006;9(1–2):3–9.
10. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *Am J Sports Med*. 2006;34(9):1512–1532.
11. Bahr R, Holme I. Risk factors for sports injuries: a methodological approach. *Br J Sports Med*. 2003;37(5):384–392.
12. Elisaf M. The treatment of coronary heart disease: an update, part 1: an overview of the risk factors for cardiovascular disease. *Curr Med Res Opin*. 2001;17(1):18–26.
13. Cannon CP. Cardiovascular disease and modifiable cardiometabolic risk factors. *Clin Cornerstone*. 2007;8(3):11–28.
14. Storey JD, Saffitz GB, Rimon JG. Social marketing. In: Glanz K, Rimer BK, Viswanath K, eds. *Health Behavior and Health Education: Theory, Research, and Practice*. San Francisco, CA: Jossey-Bass; 2008:435–461.
15. Ireland ML. Anterior cruciate ligament injury in female athletes: epidemiology. *J Athl Train*. 1999;34(2):150–154.
16. Griffin L, ed. *Prevention of Noncontact ACL Injuries*. Rosemont, IL: American Academy of Orthopaedic Surgeons; 2001.
17. Shultz SJ, Schmitz RJ, Nguyen AD. Research Retreat IV: ACL Injuries—The Gender Bias, April 3–5, 2008, Greensboro, NC. *J Athl Train*. 2008;43(5):530–537.
18. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med*. 2005;33(7):1003–1010.
19. Gilchrist J, Mandelbaum BR, Melancon H, et al. A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med*. 2008;36(8):1476–1483.
20. Olsen OE, Mykelbust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ*. 2005;330(7489):449.
21. Pfeiffer RP, Shea KG, Roberts D, Grandstrand S, Bond L. Lack of effect of a knee ligament injury prevention program on the incidence of noncontact anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2006;88(8):1769–1774.
22. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*. 2003;13(2):71–78.
23. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE, Beutler AI. The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. *Am J Sports Med*. 2009;37(10):1996–2002.
24. Padua DA, Marshall SW. Evidence supporting ACL-injury–prevention exercise programs: a review of the literature. *Athl Ther Today*. 2006;11(2):11–23.