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AAOS recognizes Barry P. Boden, MD, FAAOS for research into the epidemiology, mechanisms and prevention of sports injuries

ROSEMONT, Ill. (February 12, 2021)—Barry P. Boden, MD, received the Orthopaedic Research and Education Foundation (OREF) Clinical Research Award, which recognizes outstanding clinical research related to musculoskeletal disease or injury.

For over 20 years, Dr. Boden has studied the epidemiology and causes of severe sports injuries to develop preventive strategies, with a focus on anterior cruciate ligament (ACL) ruptures and catastrophic sports injuries. Along with his collaborators, Dr. Boden's research determined that an axial compressive force is the predominant cause of non-contact ACL injuries (NC-ACLI) and uncovered the science behind catastrophic injuries in certain high-risk sports, leading to legislation and fundamental changes that have saved lives and prevented numerous injuries.

Non-Contact ACL Injuries
In the mid-1990s, having observed the devastating outcomes of ACL injuries, Dr. Boden was inspired to go beyond traditional explanations and find new ways to explore the mechanisms of ACL injuries.

"Observing the high number of athletes whose careers were disrupted by ACL injury motivated me to explore the fundamental causes in order to support the development of prevention programs," said Dr. Boden, an orthopaedic surgeon at The Orthopaedic Center, a division of Centers for Advanced Orthopaedics in Rockville, Md., and clinical adjunct professor at the Uniformed Services University of the Health Sciences in Bethesda, Md.

Utilizing athlete interviews and videotapes that captured the moment of injury, his early research revealed that nearly 70% of ACL injuries involve minimal to no contact (subsequently referred to as NC-ACLI) and occurred as the athlete either abruptly stopped or landed from a jump, both on one leg.

"In sports, you can simply be running down the field or court—most of the time with the ball or defending the ball—stop abruptly or land from a jump, and tear your ACL," said Dr. Boden.

As the research progressed, Dr. Boden advanced his analysis of the videos captured at the moment of NC-ACLI, using 2D analysis of body mechanics. By pinpointing the precise measurements of the ankle, knee and hip angles, and trunk position at initial foot contact, he was able to study whole body dynamics at the time of injury. This provided insights into the likely forces causing the NC-ACLI. A key finding uncovered by Dr. Boden was that injured athletes either landed flat-footed or heel first. For injured athlete's, the foot became

completely flat twice as fast as the uninjured, control group athletes who landed on their forefoot or toes. This indicated a difference in how the body was absorbing the high forces that occur when the foot hits the ground while landing.

“Similar to how airbags dissipate the impact forces of a crash before they reach the passenger, the calf muscles slow the impulsive ground reaction forces,” said Dr. Boden. “In essence, athletes need to land like an accordion, so as the joints bend, the muscles contract and absorb those forces. Landing flat-footed or nearly flat-footed with the knee almost straight renders the calf muscles ineffective at dissipating the ground reaction forces and the impulsive forces are transmitted directly to the knee. When these forces aren’t absorbed properly, something has to give, often resulting in an axial compression injury with ACL rupture.”

With this knowledge, Dr. Boden’s findings revealed that the primary force responsible for the NC-ACLI is the impact force with the ground which is directed through the tibia (shinbone) to the soft tissue of the knee. A mentor of Dr. Boden’s, Dr. Joseph Torg, originally proposed the concept that this impact force upon landing or “axial compressive force” is responsible for the NC-ACLI. Dr. Torg, an orthopaedic surgeon, is known to many as the “Father of Sports Medicine” for his decades of work in athlete injury prevention.

Dr. Boden then partnered with co-investigator Frances T. Sheehan, PhD, a researcher at the National Institutes of Health, to further prove the mechanical principles of NC-ACLI and the engineering behind this axial compression injury. They conducted an MRI study of 25 subjects, collecting images of the subjects’ knees in a safe position and the dangerous ACL injury position to determine how landing posture, especially hip flexion, might affect the alignment of the femur (thighbone) and tibia given that the ACL connects both bones.

The researchers discovered that in the dangerous position the tibial plateau (top of the tibia articulating with the femur to create the knee joint) is in a more vertical position, relative to gravity. This allows the femur to shift backwards on the tibia. As the ACL is designed to prevent this backwards shift, this creates excessive ACL stretching, enhancing the likelihood of a tear. Additionally, the point where the tibia and femur touch (joint contact) moves between the dangerous and safe positions. In the safe position the point is located on the round, posterior (rear) portion of the femur. However, in the dangerous position the contact point moves to the flat, anterior (front) portion of the femur. When the flat ends of the femur and tibia at the knee are in contact, sliding of the femur on the tibia is favored instead of the normal rolling.

When the femur and tibia collide with a significant axial compression force in this dangerous leg position (vertical tibial plateau and two flat surfaces making contact), the risk of an ACL injury is increased. In the safe landing position, the tibial plateau is in a more horizontal, stable position, and the tibia contacts the round posterior aspect of the femur, favoring rolling as the knee flexes, rather than sliding. In this position, the muscles around the knee can absorb the forces.

To further substantiate their hypothesis that axial compressive forces are the primary force responsible for NC-ACLI, Dr. Boden and his colleagues conducted cadaver studies which

replicated ACL injury by applying an axial compression force to the knee. The cadaver study found that the addition of a quadriceps force increases the compressive force on the joint, thereby lowering the axial force necessary to injury. Similar to the quadriceps force, Dr. Boden's videotape studies, as well as the work of other researchers, demonstrated that valgus (knee buckling inward) is not a primary component of the injury, but can be a contributing factor by lowering the axial force necessary for injury.

"While we can't prevent all ACL injuries in athletes, the more we learn about the mechanics of NC-ACLI, the better we can help athletes understand the dynamics and train them accordingly," said Dr. Boden.

Catastrophic Sports Injuries

The second part of Dr. Boden's research focused on catastrophic athletic injuries. Through a series of studies using data from the National Center for Catastrophic Sports Injury Research (NCCSIR) and other databases, he was able to determine the epidemiology, mechanisms of injury, diagnoses and outcomes in sports with high rates of catastrophic events.

With insight into the causes of injury, Dr. Boden's research, along with advocates, sports associations and legislators, has led to policy and rule changes, equipment redesign, training programs and education.

Catastrophic Pole-Vaulting Injuries

A 16-year review of the data showed pole vaulting had the highest incidence of catastrophic injuries in male high school and collegiate athletes. Dr. Boden's initial research demonstrated that the most common cause of injury was the vaulter missing the back or side of the landing pad (70%), followed by landing in the vault box. This work helped establish a collective effort to significantly enlarge the minimum dimensions of the landing pad in 2003, leading to an annual reduction in pole vault fatalities from 0.90 before to 0.13 after the rule change or an estimated 12-13 saved lives to date. Biomechanical research on existing vault boxes has demonstrated the risks of landing in this area due to poor shock absorption characteristics. A new vault box with improved padding has been developed which reduces the force impacts by 90%. Dr. Boden and his colleagues continue to study the injury epidemiology to determine the clinical effect of the new padded vault boxes.

Catastrophic Football Injuries

Of all high school and college sports, football is associated with the highest number of fatalities, but there was limited data to explain the causes. Dr. Boden reviewed traumatic and non-traumatic fatalities over the past few decades, and identified cardiac arrest, brain injury, heat illness and sickle cell trait (SCT) as the most common causes.

While traumatic fatalities have declined 4-5-fold since the 1960s as a result of rule changes and improved equipment, non-traumatic fatalities have remained constant, with approximately 10 deaths per year. Dr. Boden's research showed that 87% of non-traumatic football fatalities occur during practice or conditioning sessions, mostly in obese players who are participating in

intense workouts and/or punishment drills (e.g., 350-pound lineman required to run 36, 50-yard sprints for perceived poor performance). With a large spectrum of baseline aerobic fitness in football, Dr. Boden and his coauthors have concluded that most of these fatalities are due to a lack of adequate exercise science applied to conditioning. The research revealed that most non-traumatic fatalities, once thought to be caused by inherent medical problems, instead are mostly caused by overexertion and irrational exercise programs during conditioning sessions and are preventable.

"Our goal with these findings is to inject more exercise science into training regimens; require baseline aerobic fitness assessment in order to develop safe, individual exercise regimes; hold coaches accountable for ensuring appropriate conditioning regimens; and establishing independent medical care to empower trainers to advocate on behalf of the players," said Dr. Boden.

The research also demonstrated:

- The NCAA 2003 Acclimatization Bylaw has not been effective at reducing heat-related fatalities since it focuses on weather conditions instead of exertion.
- The sickle cell trait (SCT) Screening Bylaw, adopted by the NCAA in 2010, has effectively prevented SCT fatalities in NCAA Division I football. Since implementation in 2010, the Bylaw has spared an estimated five to seven Division I, football players and has reduced the risk of death in NCAA Division I African American athletes with presumed SCT nine-fold. Dr. Boden recommends similar guidelines at all levels, especially high school where the rate of fatalities has tripled since 2010.

In addition to football fatalities, a review of catastrophic brain injuries in football players revealed the increased risk of injury in younger athletes, especially those who return to football prior to full recovery from a prior concussion. Due to the efforts of many health care advocates and the scientific support of the brain injury study, the Lystedt Law has been adopted by all 50 states and the District of Columbia. The law requires any youth demonstrating signs of a concussion to be examined and cleared by a licensed health care provider before return to play.

Catastrophic Cheerleading Injuries

At the high school and college levels, cheerleading accounts for two-thirds of the catastrophic athletic injuries in female athletes.[i] A review of catastrophic cheerleading injuries documented the risk of severe brain injuries to cheerleaders during the pyramid and basket toss stunts due to factors such as poor spotting or landing on the hard gym floor. Dr. Boden's report made numerous recommendations for preventing injuries such as mandating floor mats, limiting transitions between complex stunts and only performing stunts during halftime or postgame in an area free of obstruction. Since the 2006 rule changes, there has been a 70% (high school) and 66% (college) reduction in the annual number of all catastrophic cheerleading injuries. There have been no catastrophic basket toss injuries over the last nine years of data collection (2010–2019).

About the OREF Clinical Research Award.
The OREF Clinical Research Award was established in 1995 to recognize outstanding clinical research related directly to musculoskeletal disease or injury. All submitted manuscripts are reviewed, graded, and selected by the AAOS Research Development Committee. The award provides $20,000 to recipients. For more information about the manuscript submission process, please visit aaos.org/kappadelta.

About the OREF
The Orthopaedic Research and Education Foundation (OREF) is an independent, 501(c)3 non-profit organization that raises funds to support research on diseases and injuries of bones, nerves and muscles and to enhance clinical care leading to improved health, increased activity and a better quality of life for patients. To further its mission, OREF is committed to exploring ways to partner with others to move the field of musculoskeletal research forward. For more information, visit http://www.oref.org and follow us on Twitter.

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With more than 39,000 members, the American Academy of Orthopaedic Surgeons is the world's largest medical association of musculoskeletal specialists. The AAOS is the trusted leader in advancing musculoskeletal health. It provides the highest quality, most comprehensive education to help orthopaedic surgeons and allied health professionals at every career level best treat patients in their daily practices. The AAOS is the source for information on bone and joint conditions, treatments and related musculoskeletal health care issues and it leads the health care discussion on advancing quality.

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[i] Boden BP. 2005. Direct catastrophic injury in sports. J Am Acad Orthop Surg 13:445-454.