Understanding and Preventing Noncontact ACL Injuries

American Orthopaedic Society for Sports Medicine

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Library of Congress Cataloging-in-Publication Data

Understanding and preventing noncontact ACL injuries / American Orthopaedic Society for Sports Medicine ; Timothy E. Hewett, Sandra J. Shultz, Letha Y. Griffin, editors.
p. ; cm.
Includes bibliographical references and index.
ISBN-13: 978-0-7360-6535-1 (hard cover)
ISBN-10: 0-7360-6535-0 (hard cover)
1. Anterior cruciate ligament--Wounds and injuries--Prevention. 2. Sports injuries--Prevention. 3. Knee--Wounds and injuries--Prevention. I. Hewett, Timothy E. II. Shultz, Sandra J., 1961- III. Griffin, Letha Y. IV. American Orthopaedic Society for Sports Medicine.
[DNLM: 1. Anterior Cruciate Ligament--injuries. 2. Athletic Injuries--prevention & control. 3. Knee Injuries--prevention & control. WE 870 U55 2007]
RD561.U53 2007
617.4'7044--dc22

2006038700

ISBN-10: 0-7360-6535-0
ISBN-13: 978-0-7360-6535-1

The Web addresses cited in this text were current as of January 12, 2007, unless otherwise noted.

Acquisitions Editor: Loarn D. Robertson, PhD; **Managing Editor:** Lee Alexander; **Copyeditor:** Joyce Sexton; **Proofreader:** Pam Johnson; **Indexer:** Nancy Ball; **Permission Manager:** Carly Breeding; **Graphic Designer:** Nancy Rasmus; **Graphic Artist:** Denise Lowry; **Photo Manager:** Laura Fitch; **Cover Designer:** Keith Blomberg; **Photographer (cover):** Richard Bergen; **Art Manager:** Kelly Hendren; **Printer:** Edwards Brothers

Printed in the United States of America 10 9 8 7 6 5 4 3 2 1

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Chapter 13

Sport-Specific Injury Mechanisms Associated With Pivoting, Cutting, and Landing

Mary Lloyd Ireland, MD

> The athlete jumps, then lands awkwardly in an upright position perhaps a million times, but that one unfortunate time—pop goes the ACL. It only takes 70 milliseconds. (Yasuda et al. 1992)

Almost 80% of ACL injuries result from a noncontact mechanism (Noyes et al. 1983). Common positions of injury have been determined from observation of injury tapes (Boden et al. 2000). Seventy percent of ACL injuries occur during landing from a jump. Most are in the deceleration phase, which includes landing from a jump, decelerating to a stop or a change of direction (McLean et al. 1999).

In a prospective study, Hewett and colleagues (2005) evaluated neuromuscular control for 205 athletes playing the high risk sports of soccer, basketball, and volleyball. Nine of the 205 females had ACL injuries and were noted to have a different knee posture with knee abduction angle increased by 8°, 2.5 times greater knee abduction moment, and higher ground reaction forces with stance times 16% shorter. The overall result was an increase in motion force and more quickly acquired moments. This increase in dynamic valgus and hip abduction loads increases risk of ACL injuries. Development and implementation of neuromuscular control programs are necessary to reduce risk of lower extremity injury (Hewett et al. 2005).

In a study analyzing sidestep maneuvers, the ACL-injured knee position was valgus and rotation. Females had significantly larger valgus angles (McLean et al. 1999). McNair noted that ACL injuries occur when the knee is in an almost fully extended position, with the tibia rotating on the femur. Schematically, the femur internally rotates on a fixed tibia (figure 13.1) (Olsen et al. 2004; McNair et al. 1990). In a cadaver study of 37 knees, internal tibial torque was greatest in extension or full flexion. In skiing, the most dangerous position for ACL tears is full extension or full flexion when internal tibial torque is at a maxium.

The quadriceps activity and rotated femoral tibial position with knee extended are typical in ACL tears. Typically the knee is in an extended position as the athlete lands from a jump or sidesteps or changes direction abruptly. It is difficult for reviewers of videotapes to agree totally on factors such as degrees of hip and knee flexion, knee angle, and valgus versus varus tibial rotation. However, the consensus of experts reviewing recorded ACL injuries was that the knee was in valgus relative to an extended knee and hip and that body momentum was backward. The consensus of the researchers reviewing the injury video was that the knee was most frequently less than 30° flexed in valgus, with external rotation of the foot relative to the knee. The center of gravity is behind the knee on landing a jump or stopping a run (Teitz 2001). The question remains: When does the ACL tear occur?

The mechanism of ACL injury is caught with video during live action and not in gait labs live action. On the field, movement patterns can be planned or reactive and influenced by external forces, including time left in the game, score, playing offense versus defense, fear or anticipation of someone coming in to block or steal

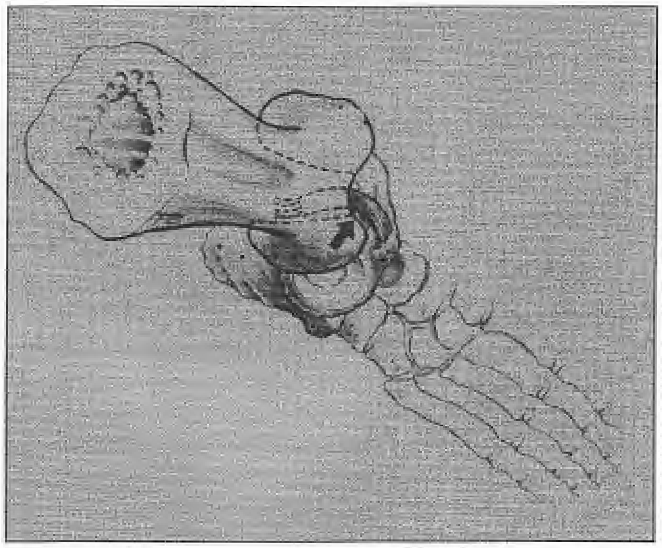

FIGURE 13.1 Possible mechanism of ACL rupture. Tibial rotation added to forceful quadriceps contraction in a valgus position may cause impingement of the ACL on the femoral condyle.

Illustration by Tommy Bolic. Reprinted, by permission, from R. Bahr, S. Maehlum, (eds.), *Idrettsskader* (Oslo, Norway: Gazette Bok.)

the ball. Attempts to combine athlete's recollection of ACL injury and video analysis are helpful. Bahr advocates a multifactorial approach to understand all factors contributing to an ACL injury (Bahr and Krosshaug 2005). This includes player interview, inciting events, and description of body and joint alignment. Thirty-five healthy high school basketball athletes (18 males and 17 females) underwent analysis of knee during planned and reactive jump start tasks in three different directions (Sell et al. 2006). Lateral jumps were found to be more dangerous than stop jumps. Compared to males, female subjects in reactive jumps had less knee flexion, greater maximum knee valgus, and greater shear forces and knee moments. Reactive jumps were different than planned jumps, suggesting problems in comparison of basic gait lab situations to playing field scenarios. In the design of research projects, the appropriate tasks as done in the sport must be included, for example directional reactive versus planned tasks (Sell et al. 2006).

Gender Comparisons

Athlete interviews should be detailed and should employ the standard vocabulary of assessment of sport injuries. This includes external and internal factors and history of the specific conditions experienced by the athlete at the time of the ACL tear. Specifically, the athlete describes the playing situation, field position, player and opponent behavior, whole-body joint kinematics, and kinetics of the injury (Olsen et al. 2004). In sports demanding rapid direction change, the mechanism of injury by athlete description or observation is predictable. The athlete is not hit directly on her knee but is perturbed or agitated as she goes to do a complex task, usually in a game. Even the other athletes on the court or field know the ACL injury drill—rapidly decelerate, feel or hear a pop, fall down on back, grab knee to chest, then scream.

The 70 millisecond time frame for tearing the ACL, as well as the unlikelihood that video is running in a frontal sagittal plane to allow analysis of body and leg position and subsequent forces, makes it difficult to determine the exact time at which the ACL tears and the position of the upper body, lumbar spine, hip, knee, ankle, and foot. Coaches teach athletes to stay in a get-down or flexed knee, hip position in basketball for guarding or for jumping. Landing lighter in a more flexed hip and flexed knee position protects the ACL. In video analysis of athletes tearing their ACL, in basketball the athlete is typically upright, with all weight on the injured limb, and the foot is fixed typically in pronation, resulting in limb malrotation. In extension, the knee dislocates, and the tibia is anteriorly translated and internally rotated, then self-reduces as the athlete flexes the knee. This standing pivot shift maneuver correlates well with the magnetic resonance imaging bone bruise pattern of the midlateral femoral condyle and posterolateral tibial plateau. The concept of position of safety and position of no return is based on observation of mechanism of injury (Ireland, Gaudette, and Crook 1997) (figure 13.2).

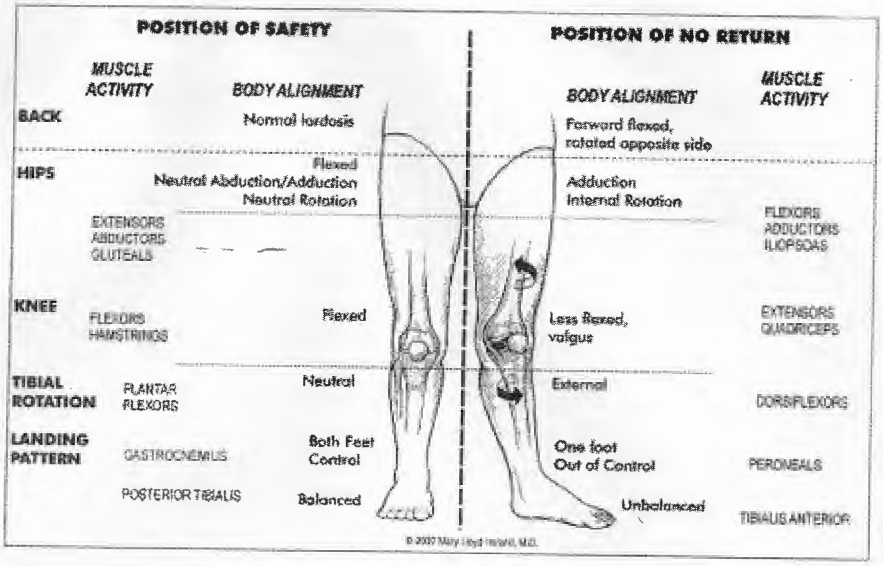

FIGURE 13.2 This diagram shows the "position of no return." This term refers to an awkward out-of-control landing with the leg pronated in valgus angulation, the body more upright and the leg in pronation and external rotation, and the knee in valgus angulation, which places the ACL at risk of tearing. In the high-risk landing position, the trunk is upright; the pelvis is more anteriorly rotated and subsequently the lower extremity is malrotated, the knee is in valgus, and ACL injury is more likely. The safety position is more flexed, with the body over the knees and knees over feet with greater balance and control.

The knee is the victim of poor proximal position of the lumbar spine and hip in sports demanding rapid stops and momentum changes. In an upright posture, the awkward landing drives more distal limb malrotation (femur internal and adducted, knee valgus). Due to the joint position and 70 milliseconds time to tear the ACL, the muscles which work to protect the ACL fail and anterior tibial translation occurs. The ACL protective muscles are the two joint hamstrings and hip abductors and external rotators. The two joint muscle quadriceps and hip adductors and flexors contribute to ACL tear. ACL injuries rarely occur in weak lower extremity muscled individuals.

Definitions of Mechanism of Injury

There are four ACL injury mechanisms: noncontact-perturbated, totally noncontact, contact, and skiing. In skiing, the mechanism is unique to that sport, typically involving falling backward after landing from a jump, with quadriceps contraction causing anterior tibial translation (Ettlinger, Johnson, and Shealy 1995; Johnson and Ettlinger 1982; McConkey 1986; Speer et al. 1995). The tail of the ski points in the direction of the foot (phantom foot ACL injury mechanism). The position is hips below knees, upper body downhill, and weight on inside edge of downhill ski (figure 13.3) (Ettlinger, Johnson, and Shealy 1995).

The contact mechanism and sudden ACL tear in an athlete, out-of-the-blue, running-downfield noncontact are more common mechanisms of ACL

FIGURE 13.3 "Because this injury involves the tail of the ski, a lever that points in a direction opposite that of the human foot, we have termed this mechanism of injury the phantom-foot ACL injury mechanism and believe it to be the most common and insidious ACL injury scenario in alpine skiing today. In all the cases we have observed in our video analysis, the skier is off balance to the rear, with all his or her weight on the inside edge of the tail of the downhill ski and the uphill ski unweighted. The hips are below the knees with the upper body generally facing the downhill ski. The uphill arm is back and the injury is sustained in each case by the downhill leg."

Illustration courtesy of Vermont Safety Research.

tear. Anterior cruciate ligaments are most commonly torn in a noncontact way with perturbation or agitation from an external or internal force. Athlete description is key. Someone is guarding the athlete, going to block him, run down the ball—and awkward movement results in an ACL tear. The perturbation is an agitation or distraction from some external or internal influence. If mechanisms are documented, specific instruction on movement in the sport and strengthening and proprioception preparation programs can be designed for each sport.

Soccer

The typical soccer mechanism of injury involves a rapid change in direction, the cleat rapidly engaging the field, and valgus knee rotation at the hip. Obviously no jumping is involved (Heidt et al. 2000). More often than in basketball or team handball, the athlete may be just running downfield and tear the ACL without any external perturbation forces. Certainly in soccer there is a foot dominance, and specific athlete description of the mechanism of injury should include the planted foot, the kick foot, and the perturbating factors in that particular play.

Three hundred female soccer athletes underwent a seven-week preseason conditioning program and then were followed for injuries during the season. Although there were not enough ACL injuries to reach statistical significance, lower extremity injuries were significantly reduced in the trained versus the untrained group ($P = 0.0085$) (Heidt et al. 2000). Anterior cruciate ligament injuries in soccer are reported to occur due to several factors: equipment (type of shoe and shin guards), playing surface (grass vs. artificial turf), rules (sportspersonship and adherence to rules), and player factors (joint instability, muscle tightness, conditioning, and rehabilitation) (Ekstrand and Gillquist 1983). Assessment of these factors should be documented in preparticipation physicals, as well as injury mechanism, to allow better analysis of causes of lower extremity injuries.

Team Handball

In studies by Myklebust on mechanisms of ACL injury in 115 male and female handball athletes, 95% and 89% of players reported that no player-to-player contact was associated with their injuries (Myklebust et al. 1997, 1998). Injuries occurred in a movement that they had done numerous times before. We need a standardized, more detailed questionnaire for the athletes regarding the perceived mechanism and playing conditions in order to stratify the factors contributing to ACL injury, at least from the athlete perspective.

Detailed video analysis of injury mechanisms for 20 athletes sustaining ACL injuries in team handball was reported by Olsen and colleagues (2004). The evaluators were three physicians and three national team coaches. The injury mechanism was forceful valgus collapse with the knee close to full extension, combined with external or internal rotation of the tibia. The variables assessed in the video were foot and knee position at foot strike, time of ACL rupture, movement direction at the time of injury, and weight distribution of percentage body weight on injured leg. The two main injury situations were plant and cut (12 cases); four of these were two-footed and eight were one-footed push-offs and one-legged landing from a jump (four cases). The proposed mechanism of ACL rupture was foot planted ~~with~~ tibia in external rotation and femoral internal rotation with quadriceps contraction (see figure 13.1). In fewer degrees of flexion, the quadriceps and knee moments can result in anterior tibial translation and hence the mechanism of standing pivot shift. The question posed by Olsen is whether the valgus collapse observed in the videos is actually the cause of the injury or whether it occurs after the ACL is torn. Most likely when the knee is in extreme valgus, in an action much like that of a whip, the femur internally rotates on a planted foot, and the tibia externally rotates. Whether the quadriceps musculature causes the tear or the biomechanical forces (including tibial slope and anterior shear) cause the pivot shift remains controversial.

Basketball

The incidence of ACL injuries in female compared to male basketball athletes at the collegiate level from 1989 to 2002 was 3.38 (female-to-male ratio) and for soccer was 2.75 (NCAA 2002). At Kentucky Sports Medicine, over a 14-year period of ACL reconstructions performed on basketball players, 67% of the females were high school age and 39% of the males were high school age. In the postcollege age group (>23 years), 41% were males and only 6% were females (Crook and Ireland 2005). In basketball athletes, there is a 3% failure rate and a 6% rate of ACL injury on the opposite side (personal communication, unpublished Kentucky Sports Medicine data).

The easiest sport in which to capture ACL tears on video is basketball. Unfortunately, the cameras on courts and fields do not show frontal and sagittal planes as in the laboratory. The athlete in figure 13.4 rebounds from a shot and comes down awkwardly, thinking about turning back to put up another shot, and is perturbated by the defender. Injury has definitely occurred by the fourth frame and possibly already by the third frame. In the “position of no return,” a combination of moments in torque with the hip adducted and internally rotated, foot planted in a rapid stop in this poor body position creates the situation for ACL injury. Neuromuscular control cannot occur rapidly enough to prevent ACL tear (Ireland, Gaudette, and Crook 1997). The relationship of hip strength, specifically abduction, external rotation to lower extremity injuries and patellofemoral pain has been reported (Ireland et al. 2003).

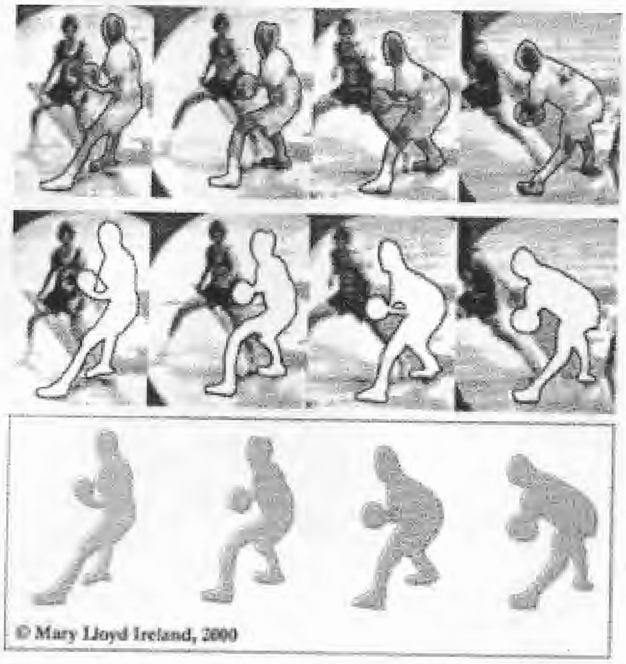

FIGURE 13.4 Analysis by videotape—basketball athlete. Injury to the left knee as observed from the back and left side of the athlete. She has just rebounded and stops to change direction to avoid the defending player. She lands in an upright position with less knee and hip flexion, and forward-flexed lumbar spine. After the ACL fails, she falls forward and knee valgus rotation and flexion increase. She is unable to upright herself and regain pelvis control to avoid ACL injury.

Gender Differences

Collegiate athlete numbers continue to rise (table 13.1). Unfortunately, the rate of noncontact ACL injury in females remains significantly higher in sports demanding rapid stops, cuts, and change in direction (basketball, soccer, team handball; Ireland 2005). When one looks at the NCAA participants and includes football, ratios are 1.3:1. If football is excluded, ratios are 1:1.

Conclusions

The work of Hewett's group (1999) was instrumental in our understanding of knee injury patterns. Further research needs to be done so that coaches can better understand the cues players need to hear during practice (jumping straight as an arrow, landing light as a feather). Analysis of injury must include

TABLE 13.1 2003-2004 NCAA Participants[a]

	Women	M:W ratio	Men	Men playing football	M (football): W ratio	Men w/o football	Total
Div I	69,768	1.2	86,826	25,363	0.9	61,463	156,594
Div II	31,725	1.5	46,662	14,206	1.0	32,456	78,387
Div III	61,259	1.4	83,821	20,411	1.0	63,410	145,080
Total	162,752	1.3	217,309	59,980	1.0	157,329	380,061

[a]Overall numbers and gender ratios—with and without men's football.

body position, momentum, joint position, activity on court or field, and joint angles of flexion-extension and rotation.

The question remains: What are the risk factors for ACL injury? Until the risk factors can be determined and ranked, prevention programs, although they do appear to be working, remain the black box. If the factors responsible for ACL tears are unknown, then we cannot state what has changed. Prospective studies on risk factors are necessary to answer this question.

The literature on risk factors with prospective study designs has been reviewed (Murphy, Connolly, and Beynnon 2003). The risk factors for lower extremity injury were divided into extrinsic and intrinsic. The extrinsic factors evaluated were level of competition, skill level, shoe type, ankle bracing, and playing surface; the intrinsic factors were age, days of the menstrual cycle, previous injury and inadequate rehabilitation, aerobic fitness, body size, limb dominance, flexibility (generalized joint laxity and ankle and knee joint laxity, muscle tightness, range of motion), muscle strength, imbalance, reaction time, limb girth, anatomic alignment, and hand and foot morphology. Regarding ACL injuries, the risks are being female, having had a previous ACL injury followed by inadequate rehabilitation, having a narrow femoral intercondylar notch width, competing in games compared to practice sessions, and wearing edge-type cleats compared to other cleat designs. More multiple-center prospective studies are needed to determine the risk factors.

A better understanding of ACL mechanisms will allow specific strengthening and proprioception programs to be analyzed for relative risk. A risk ratio from ranking of risk factors can then be established. Coaches can then better understand positions of safety and implement strengthening programs to avoid the risky positions and situations leading to ACL injury. Several ACL research retreats have been held. In these retreats, researchers present their work and participate in a think tank to assess the present knowledge base—what we know and what we don't know (McClay-Davis and Ireland 2001, 2003). These ACL research retreats have focused on the gender bias. Hunt Valley I and II have helped elucidate factors involved in ACL injuries from the basic science to the clinical level (Griffin and Gael 2000; Griffin et al. In press-a).