Breaking Down the Breakdown: Biomechanical Contributions Towards ACL Injury

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Abstract

Injuries to the lower extremities are among the most common in sports due to the high strain placed on joints during intense movements. The Anterior Cruciate Ligament (ACL), particularly vulnerable during dynamic motions like jumping or sudden directional changes, is frequently injured in contact sports such as football, basketball, and soccer. This literature review explores biomechanical risk factors contributing to ACL injuries, specifically the impact of playing surfaces (grass vs. turf) and cleat design (stud patterns). The findings suggest that round-stud or turf cleats used on natural grass significantly reduce the likelihood of ACL injury. In addition to biomechanical causes, this paper reviews clinical diagnosis methods such as the Lachman and Anterior Drawer tests, outlines rehabilitation protocols, and discusses long-term implications like joint instability and arthritis. By understanding these biomechanical and clinical factors, athletes and practitioners can implement targeted prevention and treatment strategies. Further research should investigate how sport type, footwear, age, and evolving league rules affect injury risk and recovery.

Introduction

Anatomy and Function of the ACL

The Anterior Cruciate Ligament (ACL) is a key stabilizer within the knee joint. Alongside the posterior cruciate ligament (PCL), lateral collateral ligament (LCL), and medial collateral ligament (MCL), it helps control knee movement and resists excessive twisting, hyperextension, or valgus

forces. These ligaments work together to stabilize the knee during activities like running, pivoting, and jumping.

The ACL connects the femur (thigh bone) to the tibia (shin bone) and is responsible for limiting forward movement of the tibia relative to the femur. Composed primarily of fibroblasts, which generate collagen, the ACL has limited regenerative capacity. Collagen provides tensile strength and helps in forming scar tissue, though complete natural healing is rare without surgical intervention.

Studies suggest that females may have a higher risk of ACL tears due to differences in joint laxity, anatomy, and neuromuscular control. One study notes that women's joints typically exhibit more looseness and range of motion than men's (1). However, risk factors vary widely among individuals.

Although rare, some individuals are born with a congenital absence of the ACL (CAACL) or have an underdeveloped ligament (ACL hypoplasia). CAACL occurs in a very small amount of the general population, and symptoms often appear in adolescence or early adulthood due to knee instability. In these cases, individuals may be more prone to injury due to reduced joint stability.

Understanding the anatomy and function of the ACL—and how it differs from person to person—is essential to recognizing how and why injuries occur, and what unique recovery pathways may exist.

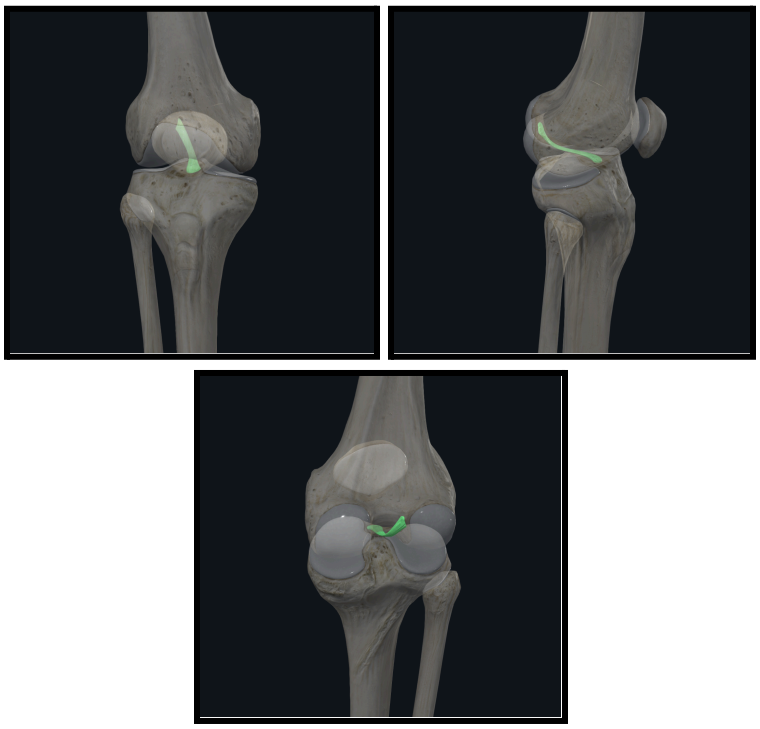

FIGURE 1. Anterior, medial, and posterior views of the ACL.

Mechanism of Injury

ACL and other ligament injuries can occur in various situations, including slips, falls, and sports-specific movements. The ACL is often injured when a foot is firmly planted and an external force or sudden directional change places strain on the knee. In sports, this may occur during jumping, cutting, pivoting, or contact with other players.

Forces and stresses often act together. A force may involve physical contact, such as a collision or tackle, while a stress may involve sudden twisting or lateral movement. Both mechanisms can cause ACL damage, either separately or in combination.

High-risk settings include competitive matches, high-speed drills, or training on poor-quality artificial turf. Players are more likely to sustain ACL injuries when fatigued, under pressure, or using improper technique.

Although everyday injuries and sports injuries can look similar, they differ in cause and context. Everyday injuries tend to result from slips or accidents during normal activity, whereas sports injuries usually involve greater intensity and physical demand. These include overuse, sudden deceleration, improper landing, or faulty movement patterns. To reduce injury risk, athletes should follow prevention programs focused on proper technique, neuromuscular training, strength building, and surface-specific cleat selection. Adequate warm-up, rest, and conditioning are also critical to injury prevention.

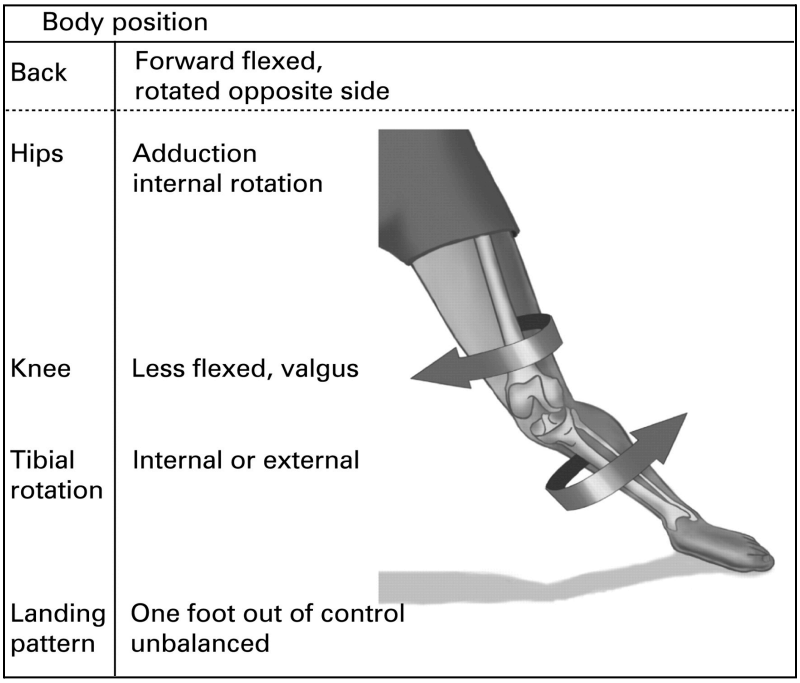

FIGURE 2. Example of a possible mechanism of injury.

According to University of Utah Health, ACL tears are among the five most common sports injuries (4). Contact sports like football and basketball show significantly higher rates of ACL injury than low-contact sports like swimming or cycling. This is due to frequent physical contact, jumping, and rapid changes in direction, all of which place additional stress on the knee.

Implementing training routines that focus on balance, agility, and strength may reduce these injury rates. Prevention programs tailored to sport and position have been shown to lower the incidence of ACL tears.

Diagnosis and Clinical Presentation

Upon ACL injury, patients typically experience a range of symptoms depending on the severity of the injury. Common signs include swelling, reduced range of motion, tenderness, difficulty walking, and an audible "pop" or snapping sensation at the time of injury.

These symptoms often prompt the use of specific clinical tests to evaluate ACL integrity. One widely used test is the Lachman test, named after John Lachman. It assesses sagittal plane instability with the patient lying face-up and the knee flexed at 20–30 degrees (5). During the exam, the clinician stabilizes the thigh and pulls the tibia forward. An intact ACL will restrict forward movement, whereas a torn ACL results in greater anterior tibial translation. The Lachman test is most accurate when performed soon after injury, before swelling interferes with movement.

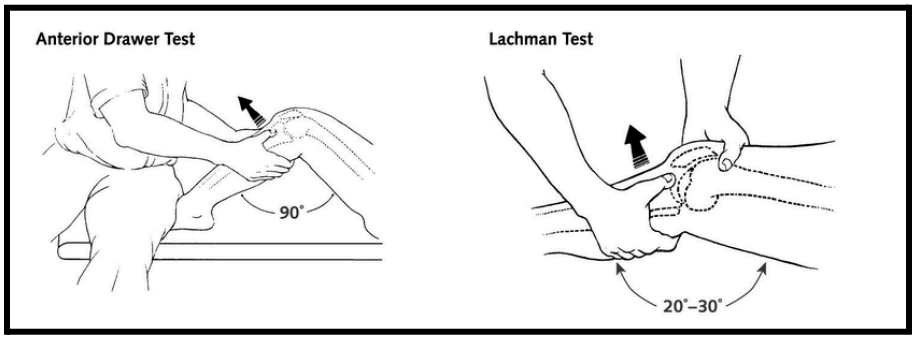

FIGURE 3. Examples of knee examinations.

Another diagnostic tool is the Anterior Drawer test. In this procedure, the knee is bent to 90 degrees, and the clinician pulls the lower leg

forward. A positive result—excessive forward movement or lack of a clear "end feel"—suggests ACL compromise (6).

ACL injuries vary in severity and are classified into three grades:

Grade I: The ligament is mildly stretched but retains joint stability (7).

Grade II: A partial tear of the ACL, resulting in some instability (7).

Grade III: A complete tear, where the ACL no longer stabilizes the knee (7).

This scale helps differentiate between minor sprains and complete ruptures, informing treatment and rehab planning.

Causes and Risk Factors of ACL Injury

Research suggests that athletes must take precautions, warm up properly, wear protective gear, and listen to their bodies to minimize the chances of sustaining injury. Dynamic stretching is recommended before activity to increase flexibility and readiness, while static stretching is more effective post-exercise to aid in recovery.

Tailored warm-up routines that combine both dynamic movements and static stretches can help improve muscle elasticity and joint stability. These routines are particularly important in sports requiring frequent cutting, pivoting, or jumping.

Studies suggest that artificial turf may increase the risk of ACL injuries due to its higher traction compared to natural grass, and wearing cleats on artificial turf may amplify this risk by creating an excessive grip. Instead of "giving out" and having the grass tear during a forceful impact with the ground, the turf remains firm. As a result, a higher percentage of the force due to contact will be distributed throughout the athlete's joint, increasing the risk for ACL injury. Furthermore, poor-quality artificial turf with holes could escalate injury rates by causing unpredictable foot interactions and potential instability during play.

Age can influence the susceptibility to ACL tears as well. Research indicates that while ACL injuries can occur at any age, younger individuals, particularly those involved in high-impact sports or activities, are more prone to ACL tears. This is due to factors like growth spurts, less developed muscles, and a higher level of participation in sports that involve high-risk movements. However, older individuals, especially those engaging in sports or physical activities, are also at risk due to decreased muscle strength, diminished joint flexibility, and general wear and tear on ligaments. Therefore, age plays an important role in the specific programs that are assigned to patients—"it is necessary to design [programs] taking the real world into account in terms of better considering both the context and the programmes' content" (8).

It is also important to note that there are many different positions that the knee can be in with respect to the rest of the body. Because of this, the knee can naturally be in more or less susceptible positions to obtaining an ACL injury. For instance, if the knee is bent at an unnatural angle, the ACL is initially under more stress than in the resting position. So, once an outside force is applied to the knee, it would be much easier for the ACL to be damaged because less force is required to injure it.

Epidemiology and Prevalence

ACL injuries are common, with an estimated 100,000 to 200,000 cases occurring annually in the United States (9). Genetics also plays a role in ACL injury risk. Individuals with a family history of ACL injuries may have a significantly higher chance of sustaining one themselves (10). This highlights the need to consider inherited structural or neuromuscular factors during screening and prevention efforts.

Young athletes often face greater risk due to rapid physical development, increased participation in high-impact sports, and underdeveloped neuromuscular control. These factors place more strain on the knee and can contribute to non-contact ACL injuries.

Individuals who have previously injured their ACL are also more vulnerable to secondary injuries. Compensatory movement patterns can place excess stress on other joints or muscles, increasing the risk of injury elsewhere in the body.

Even after an ACL has healed, the risk of re-injury remains significant, especially if the individual returns to sport too early or skips proper rehabilitation protocols. Recovery timelines vary by injury severity, patient condition, and adherence to physical therapy.

Surgical intervention is often required for complete ACL tears (Grade 3), especially in athletes aiming to return to high-level activity. Without surgery, long-term instability may persist, leading to reduced function and a greater risk of joint degeneration.

Treatment and Rehabilitation

In the case that the knee is highly swollen after tearing the ACL, surgery may be delayed since the swelling can make it challenging for the surgeon to perform the surgery optimally. Additionally, receiving the surgery too early can contribute to the development of Arthrofibrosis, a condition where excessive scar tissue forms in the knee joint, limiting its range of motion (20, 21).

Using alternative therapies, such as cupping and acupuncture, can complement the rehabilitation process by promoting blood flow, reducing muscle tension, and alleviating pain. Additionally, incorporating cold

plunges and heat therapy aids in managing inflammation and promoting tissue healing throughout the different stages in rehabilitation.

The scheduling and timeline involved in physical therapy are carefully structured to allow the injured patient to progress at a personalized pace that supports them without causing further harm. Pushing too hard or advancing too quickly can lead to consequences like reinjury. Therefore, adhering to the recommended timeline and passing specific checkpoints before increasing workload is important.

Sports injuries often require specialized treatment and rehabilitation to get athletes back in the game. A primary component in the recovery process of an ACL injury is physical therapy. In the first stages, physical therapy focuses on restoring range of motion, reducing swelling, and regaining muscle strength. Specific exercises, ranging from simple leg raises to more complex movements, are slowly introduced with the intensity increasing over time. This progression is important to prevent overloading the healing ACL and surrounding ligaments. As the rehabilitation progresses, band work and weighted exercises are introduced, focusing not only on the injured knee but also surrounding muscles for a comprehensive recovery.

Zero to two weeks after one receives the surgery, it's crucial to focus on rest, icing, and elevating the area to manage pain and bring down the swelling. Following the surgeon's instructions, gentle exercises and physical therapy should be initiated to promote early mobility and begin the initial stages of rehabilitation. During the 3rd-5th weeks post-surgery, one would typically continue with physical therapy, gradually increasing the intensity of exercise to enhance knee strength and flexibility. At 6-8 weeks, one would focus on advancing their rehabilitation by incorporating more challenging exercises to continue improving muscle strength and joint stability. During weeks 9-12 after ACL surgery, one would continue with targeted exercises to build even more strength and stability. Rehabilitation will progress towards more dynamic movements and functional activities, preparing the patient to gradually return to normal daily tasks. Once one reaches the stage of 3-5 months post-surgery, patients begin to focus on more advanced exercises to enhance muscle coordination and joint control. Their physical therapy would become sports-specific to prepare them for a safe return (11). Lastly, 6+ months after surgery, the focus is to continue strengthening and proprioceptive exercises in order to safely progress to full sport. Proprioceptive exercises, which improve the body's sense of position, are important because they prevent the body from putting itself in potentially harmful situations that could lead to reinjury.

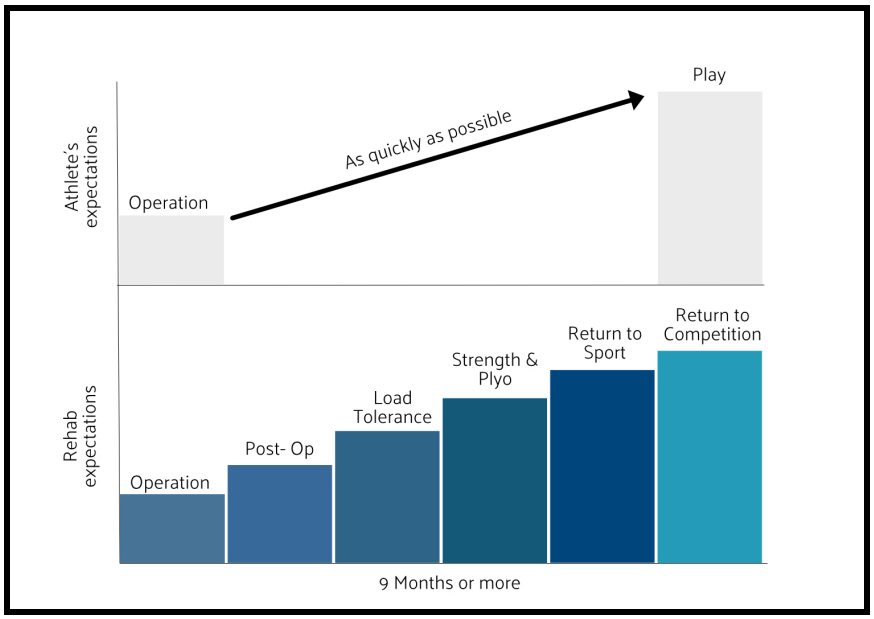

FIGURE 4. Athlete vs. Rehabilitation progress expectation visual.

Rehabilitation must be gradual, as rushing the process can lead to reinjury. Passing clinical strength and stability tests is essential before returning to sport. Modern technology supports recovery by offering movement analysis, load monitoring, and biofeedback through wearable sensors. These tools can help customize programs, identify weaknesses, and reduce reinjury risk.

Examples of sport-specific rehab include lateral bounding for basketball players or deceleration training for soccer athletes. These exercises prepare the athlete for movements they may encounter during live gameplay. At the same time, complementary therapies—like cold plunges, heat therapy, acupuncture, or cupping—may also help manage inflammation, promote blood flow, and reduce pain throughout recovery.

Long-Term Effects

ACL injuries can lead to long-lasting consequences that affect physical performance, joint health, and quality of life. Even after surgical reconstruction and rehabilitation, some individuals never fully return to their prior level of athletic function.

Surgery does not guarantee a complete recovery (13). Some patients experience residual instability, reduced strength, or limited range of motion even after a successful procedure. These deficits can impact daily activities, especially in sports that require cutting, pivoting, or explosive movement.

Long-term complications include early-onset osteoarthritis, especially in individuals with concurrent meniscal damage (14). The altered joint mechanics following ACL injury—whether or not surgery is performed—can contribute to cartilage degeneration and chronic pain over time.

In some cases, persistent swelling, stiffness, or muscle imbalance may limit mobility permanently. These outcomes are more common in patients who delay treatment, skip rehab stages, or return to play too quickly.

Athletes who experience a second ACL injury, either on the same or opposite knee, face even greater long-term risk. Reinjury can cause compounding damage to ligaments, cartilage, and bone, leading to irreversible joint deterioration (15). This underscores the importance of both surgical precision and disciplined rehabilitation protocols. Managing long-term effects involves continued strength training, joint protection strategies, and periodic clinical monitoring. These steps can help reduce symptom progression and preserve function over time.

Research

Research Question

How does sports infrastructure contribute to the risk of ACL injuries in athletes?

This research question allows us to examine the different aspects of ACL injuries, and their connection to risk factors like playing facilities and equipment. Playing facilities, meaning the surfaces being played on (synthetic turf or natural grass), have been proven to have significant effects on injury rates. Equipment differences, such as stud type or pattern in cleats, have also been optimized to better grip different playing surfaces; however, when matched with the wrong cleat type, players could instead increase their risk of injury.

Methods

A 2018 study by Christina Mack et al. examines whether NFL players get injured more often on synthetic turf compared to natural turf (also referred to as “real grass”). On natural grass, the dirt layer underneath is relatively softer and often allows the ground to "give out" when there is too much force distributed throughout the knee joint (16). This cannot be done as effectively on turf, because the underneath layer consists of rubber, which is much stiffer and resists making divots. This makes players’ joints bear the entirety of the force during sudden changes in direction when playing on turf, therefore leading to more injuries. Similarly, the researchers hypothesized that “Incidence of lower body injury is higher on synthetic turf than on natural turf among elite NFL athletes playing on modern-generation surfaces” (17). They aimed to determine whether field

type has a direct correlation with how often players get hurt. This study helps us understand if the kind of field can make a difference in keeping players safe during football games.

Their experiment analyzed NFL injury data from 2012 to 2016 to investigate the relationship between playing surfaces and lower extremity injuries. Data were collected prospectively from medical staff for all 32 teams and under the NFL's injury surveillance system (17). Additional data sources included the NFL Game Statistics and Information System (GSIS) and field surface hardness measurements recorded by the NFL Taskforce for Game Day Surfaces (17). The study focused on injuries that caused players to miss time, with a particular emphasis on non-contact injuries related to shoe-surface interaction (17).

The researchers categorized playing surfaces as either natural or synthetic and analyzed injury rates across different field types. They conducted statistical analyses to compare injury incidence while adjusting for factors like game-day field conditions and surface hardness, measured using a Clegg Impact Soil Tester (17). The study used Poisson models to calculate incidence state ratios (IRRs) to determine how surface type influenced injury risk (17). To ensure accuracy, independent inspectors randomly tested field conditions before games.

The researchers found that the players were indeed more likely to get injured on synthetic turf than on natural grass (17). They calculated that there was a 16% increase in leg injuries per play on turf compared to grass, meaning that for every play in a game, there were more injuries on turf (17). By looking at different types of leg injuries (like ones to the knee or ankle), researchers found that the risk was higher on turf for all of them (17). It was also discovered that the risk was even higher for injuries that didn't involve direct contact with another player, like when a player slips or trips on the field (17). However, when players tore their ACL due to contact with another player, the field type had less impact on injury severity, according to athletic trainers (17). This shows that the type of field surface can affect how likely it is for a player to get injured during a game or practice.

The second paper used (Mansfield and Bucinell) investigates why there has been a large increase in knee injuries, especially among athletes, focusing on Anterior Cruciate Ligament (ACL) tears. These injuries have gone up a lot, from about 80,000 in the year 2000 to 150,000 in the year 2011 (18). They were curious about whether or not the shoes one plays in cause more ACL tears (19), and investigated how these factors affect the risk of getting injured.

In the study, an experiment was performed that measured how much force different soccer shoes could take before slipping on different natural and artificial surfaces using standards set by the American Society of Testing and Materials (ASTM) (19). It was designed to replicate the forces a player experiences while pivoting, using a servo-hydraulic bi-axial load frame (19). The Actuator Interface Plate (AIP) connected the mounting

box to the hydraulic actuator, transferring torque to the playing surface (19). A prosthetic foot was mounted in soccer shoes and attached to the load frame to ensure accurate load transmission through the forefoot (19).

Natural grass was grown in controlled boxes, while artificial turf was secured in custom frames for accurate testing (19). Additionally, the grass boxes were turned after each test (so that different areas could be tested), while artificial turf was placed on layers of crushed rock to make it feel like a real field (19). The artificial turf was attached to wooden frames, and metal was used to keep the rubber pieces in place (19).

Four types of soccer shoes were tested on five different surfaces to see how they affected movement (19). The surfaces tested included grass and different types of artificial turf with different amounts of rubber padding (19). Every shoe and surface combination was tested five times, making a total of 100 tests (19). The grass was tested first, and artificial tests were done in a random order to keep the trials fair (19). Artificial turf was tested in two groups based on how much rubber padding it had, with random shoe and surface pairings (19). A machine pressed down on the shoes while the surface turned, and the force was measured very quickly by a device called an axial actuator (19).

After analyzing their results, there were many interesting findings. The shoe with round studs or turf shoes provides the best grip on all surfaces without allowing the foot to slip, proving that the type of shoe matters when it comes to preventing an ACL tear (19).

Discussion

Our research aimed to understand how sports infrastructure and footwear contribute to ACL injury risk. After reviewing the two studies, it's clear that both surface type and cleat design play critical roles—each study approaches this from a different angle, providing complementary insights.

Christina Mack et al. (2018) analyzed NFL injury data and found a 16% higher rate of leg injuries on synthetic turf, especially for non-contact injuries. This shows that environmental conditions, like surface hardness and traction, significantly influence injury rates. Meanwhile, Mansfield and Bucinell (2016) took a controlled experimental approach to examine cleat design. Their tests showed that round-stud and turf cleats produced lower torque on both grass and turf, reducing the likelihood of an ACL tear.

Both studies agree that high-traction surfaces and cleats that "stick" too much increase injury risk, especially during cutting or pivoting motions. However, their methods differ: Mack's study used epidemiological data from real NFL games, offering real-world injury patterns but with limited control over confounding variables like fatigue, cleat (footwear) choice, and weather. In contrast, Mansfield & Bucinell's study used a servo-hydraulic bi-axial load frame for precise torque testing,

offering clarity on mechanics but no direct measurement of actual injury rates.

This contrast, therefore, makes them complementary. One explores biomechanics; the other explores consequences. Together, they suggest that both fields and footwear need regulation. Administrators should invest in safer surfaces—meaning natural grass whenever possible. Players must also choose cleats matched to surface type, as improper footwear increases risk.

Furthermore, each paper had methodological strengths. Mack's study used injury surveillance data from all 32 NFL teams, field condition ratings, and IRRs calculated from thousands of plays. This gives strong external validity because of the wide range of datapoints. Mansfield's lab design controlled for field type, cleat type, and repeated trials, offering precise torque comparisons across 100 surface–cleat pairings. Both papers contributed uniquely to the research question and helped offer a holistic understanding of the topic.

At the same time, both papers have limitations. Mack's data did not include cleat type, warm-up routine (if any), or fatigue levels of the athletes, which may influence injuries. Mansfield's study only tested soccer cleats and surfaces under lab conditions, which lack real-game unpredictability. Neither study addressed movement quality or strength conditioning, which are factors known to influence ACL risk.

Overall, it can be concluded that the type of field and cleats used can significantly increase the risk of ACL injuries. This is consistent across both studies, despite having used very different methods. More research is needed to explore how field maintenance, footwear trends, and individual biomechanics intersect in real time. Future studies should consider wearable tech to monitor force and torque during actual gameplay. The findings support a call to action between players, coaches, leagues, and shoe designers. Evidence-based policy and smart design could significantly reduce ACL injuries across multiple sports. These findings don't just apply to elite athletes—they have broader implications for youth sports, physical therapy, and public awareness.

Future Questions

Future research should explore how cleat design and stud configuration affect joint torque across a wider range of sports, not just soccer. Mansfield and Bucinell's study tested only four cleats, leaving questions about how other models and brands perform in football, lacrosse, or rugby. In addition, factors like fatigue, movement mechanics, and muscle imbalance during real gameplay should be studied more closely—Mack et

al.'s findings didn't account for these variables, even though they likely influence non-contact injury risk. Expanding research to assess how players' cleat choices (which are often influenced by sponsorships or regulations) impact injury rates could also be valuable. Weather conditions deserve more attention as well: field traction can vary drastically when wet, cold, or poorly maintained, and current studies didn't examine how this may impact injury mechanisms. Another important direction is the use of machine learning and wearable tech to predict ACL injury risk by combining gameplay footage, surface data, and player biomechanics. Lastly, behavioral research is needed to understand what influences athletes' decisions regarding footwear and surface use—even with clear injury risks, many still opt for less safe equipment. Together, these questions push beyond lab results and toward real-world, athlete-centered prevention.

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