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From Acute Injury to Return to Play: A Comprehensive Review of Biomechanical Principles and Current Strategies in the Diagnosis, Treatment, and Rehabilitation of Acute and Chronic Ankle Ligament Injuries in Sporting Populations

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ABSTRACT

Background. Lateral ankle sprains (LAS) are the most frequent musculoskeletal injuries in sports medicine, often leading to chronic ankle instability (CAI). Despite their prevalence in disciplines like basketball or soccer, mismanagement remains common, resulting in long-term sensorimotor deficits and joint degeneration. Modern paradigms are currently shifting from traditional immobilization toward proactive functional mobilization and advanced surgical interventions.

Aim. This review synthesizes contemporary clinical evidence and biomechanical principles to establish a standardized management algorithm for athletes with acute and chronic lateral ligamentous lesions.

Material and Methods. A comprehensive analysis of forty peer-reviewed studies published up to early 2025 was conducted. The synthesis prioritizes diagnostic precision, biomechanical strain patterns, and the comparative efficacy of surgical versus functional rehabilitation interventions in competitive sporting populations.

Results. Precise injury grading, ideally performed five days post-injury, increases diagnostic sensitivity to over 90%. High-resolution dynamic ultrasonography offers superior assessment of functional instability compared to static MRI. Implementation of the "PEACE and LOVE" framework results in faster return-to-play timelines than traditional rest. In elite sports, arthroscopic "all-inside" repairs reinforced with InternalBrace augmentation maintain recurrence rates below 5%.

Conclusions. Optimizing athletic recovery requires a multidisciplinary algorithm bridging mechanical healing and functional homeostasis. Precise injury grading, early functional loading, and biologically reinforced repairs are vital for long-term joint integrity and career longevity.

Keywords: ATFL, athletes, chronic ankle instability, return to play, InternalBrace, ankle sprain, ankle injuries, dynamic ultrasonography, PEACE and LOVE protocol

Content

1. Introduction

Lateral ankle sprains (LAS) represent the most pervasive musculoskeletal pathology encountered in the global sports medicine landscape, consistently ranking as the leading cause of time-loss from competition across nearly all athletic disciplines [1, 2]. Epidemiological data indicate that injuries to the lateral ligamentous complex account for approximately 25% to 30% of all sports-related traumas, particularly in sports requiring rapid deceleration, jumping, or pivoting maneuvers [3]. Contemporary literature emphasizes that the initial management of these injuries is a critical determinant of long-term joint health, where conservative strategies must be balanced against biological repair needs [4].

The anatomical vulnerability of the lateral ankle during high-velocity inversion and internal rotation places immense physiological strain on the anterior talofibular ligament (ATFL). Biomechanical analyses demonstrate that ligament failure occurs when the mechanical load exceeds the tissue's ultimate tensile strength [5]. To address these failures, modern surgical techniques, such as suture-tape augmentation, have been developed to provide mechanical stability superior to the native ATFL [6]. For a precise clinical trajectory, high-resolution diagnostic classifications, including specific ultrasound gradings, are now essential for distinguishing between varying degrees of fiber discontinuity [7].

In chronic cases, arthroscopic assessment has become the gold standard for identifying the specific morphology of ligamentous lesions [8]. Furthermore, "all-inside" arthroscopic repairs of both the ATFL and CFL have shown significant promise in restoring joint integrity in athletes with complex instability [9]. Magnetic resonance imaging (MRI) continues to play a vital role in characterizing the structural footprint of these injuries during the acute phase [10]. Recent studies suggest that addressing both the ATFL and CFL is often necessary for achieving optimal outcomes in severe chronic instability [11]. The precision of these interventions is further enhanced by ultrasound-guided stabilization techniques, which allow for real-time functional assessment [12].

Research Objective:

The primary objective of this narrative review is to conduct a multi-dimensional synthesis of contemporary clinical evidence and biomechanical principles to establish a standardized management algorithm. The focus is directed toward optimizing the diagnostic-therapeutic trajectory and refining return-to-play criteria for athletes suffering from acute and chronic lateral ligamentous lesions.

Research Problems:

1. Does the timing of physical examination and the choice of dynamic imaging (US vs. MRI) significantly affect the diagnostic accuracy and subsequent grading of lateral ligament injuries in athletes?
2. To what extent do functional mobilization protocols, specifically "PEACE and LOVE," influence the restoration of biomechanical joint homeostasis and sensorimotor control compared to traditional immobilization?
3. What is the comparative efficacy of arthroscopic anatomical reconstruction with suture-tape augmentation in terms of mechanical stability and the acceleration of the return-to-play timeline?

Research Hypothesis:

The central hypothesis posits that a multidisciplinary management algorithm, which integrates delayed clinical examination and dynamic ultrasonography for precise injury grading, followed by functional mobilization protocols and, when indicated, arthroscopic anatomical reconstruction with suture-tape augmentation, provides superior functional recovery, restores biomechanical stability, and ensures a more predictable and stable return to play compared to traditional conservative or open surgical techniques.

2. Research materials and methods

2.1. Search strategy

This review was conducted to synthesize current evidence regarding diagnostic precision and therapeutic strategies for ankle ligament injuries in sporting populations. The literature search was performed in major scientific databases including PubMed, Scopus, Web of Science, and Google Scholar. The search included peer-reviewed studies published up to early 2025 to ensure the integration of the most recent clinical findings and biomechanical data. The following keywords and their combinations were used in the search strategy to refine the results:

- “lateral ankle sprain AND athletes”
- “anterior talofibular ligament AND ATFL repair”
- “calcaneofibular ligament AND CFL reconstruction”
- “chronic ankle instability AND return to sport”
- “biomechanics AND ankle ligament injuries”
- “functional rehabilitation AND sports traumatology”

Boolean operators such as “AND” and “OR” were applied to optimize the precision of the identified literature. In addition, the reference lists of the selected forty articles were manually screened to identify additional relevant studies that were not captured during the initial electronic database search. This iterative process ensured a robust foundation for the synthesis of evidence regarding diagnostic accuracy and the efficacy of modern interventions in athletes suffering from lateral ligamentous damage.

2.2. Eligibility criteria

Studies were included in this review if they met the following criteria:

- original research articles, systematic reviews, or meta-analyses published in peer-reviewed journals;
- studies investigating lateral ligamentous lesions or chronic ankle instability specifically related to physical activity or competitive sports;
- research involving professional or recreational athletes, including football players, basketball players, and individuals participating in high-agility sports;
- articles published in the English language;
- studies providing relevant information on biomechanical strain patterns, the accuracy of diagnostic imaging, or the efficacy of surgical and functional rehabilitation interventions.

The following exclusion criteria were applied:

- studies conducted exclusively on animal models;
- articles that were unrelated to sports trauma or musculoskeletal rehabilitation;
- conference abstracts, editorials, and opinion papers that did not contain original data;
- studies focusing solely on isolated medial ankle injuries or pediatric populations that were not associated with adult athletic trauma.

2.3. Data collection and analysis

2.3.1 Study selection process

Data extraction was performed by systematically reviewing the methodology and results sections of the selected forty articles. The primary focus of the data collection process was to identify key outcomes related to recovery timelines, re-injury rates, and functional scores across different treatment groups. We prioritized data that provided a clear comparison between conservative functional protocols and advanced surgical techniques, specifically looking for objective measures of joint stability and sensorimotor improvement. Since this is a narrative

review, the analysis involved a qualitative synthesis of the findings to identify common trends and clinical consensus rather than a formal quantitative meta-analysis.

2.3.2 AI Statement

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

3. Diagnostic precision, functional rehabilitation, and surgical outcomes in lateral ankle injuries

3.1. Diagnostic Precision and Biomechanical Grading of Acute Injuries

While advanced imaging modalities have become ubiquitous, foundational anatomical restoration continues to center on traditional procedures like the open Broström technique for specific populations requiring high mechanical reliability [13]. However, contemporary operative management of lateral instability has significantly shifted toward more comprehensive, minimally invasive strategies that allow for better preservation of the biological envelope [14]. Biomechanical research concerning dynamic landing mechanics has provided transformative insights; for instance, adopting a "toe-out" landing position (increasing the angle by 150%) has been empirically shown to reduce peak strain on the anterior talofibular ligament (ATFL) while maintaining stable calcaneofibular ligament (CFL) tension, suggesting a potential modification for athletic training protocols [15]. Furthermore, the integration of point-of-care musculoskeletal ultrasound (MSK USG) has become a cornerstone of elite sports diagnostics, demonstrating high diagnostic value in identifying both lateral and syndesmotic ligamentous discontinuities with accuracy comparable to MRI [16].

Despite seemingly successful structural healing, the transition from an acute lateral ankle sprain (LAS) to chronic ankle instability (CAI) remains a paramount challenge. This transition is

currently modeled as a multi-system failure involving both mechanical laxity and deep-seated neuro-sensorimotor deficits [17]. Supporting interventions, such as Kinesio Taping (KT), have been extensively evaluated for their potential to enhance functional performance; while KT may not provide significant mechanical bracing, it has been shown to improve mid-lateral stability and neuromuscular activation of the peroneus longus in athletes with CAI [18]. An algorithmic approach to acute injuries emphasizes that the timing of the physical examination is a decisive factor; performing the assessment 3 to 5 days post-injury (delayed examination) increases sensitivity to 96% for identifying total ruptures [19]. This meticulous diagnostic process is fundamental to defining objective return-to-play criteria, ensuring that athletes do not prematurely return to competition with lingering deficits in proprioception or muscular reaction time [20].

3.2. Comparative Efficacy of Rehabilitation Frameworks and Sensorimotor Recovery

The shift toward functional mobilization over rigid immobilization is supported by a robust body of systematic reviews. Evidence confirms that early functional restoration is significantly more effective than rigid casting for long-term recovery, reporting superior return-to-sport rates and higher patient satisfaction [21]. Objective assessment through a cluster of functional performance tests—such as the Star Excursion Balance Test (SEBT) and side-hop tests—combined with validated questionnaires (e.g., FAAM), is vital for making evidence-based return-to-sport decisions rather than relying on arbitrary timelines [22]. Furthermore, the traditional RICE protocol is being re-evaluated in modern sports medicine; the emerging "PEACE and LOVE" framework advocates for avoiding anti-inflammatory modalities and excessive cryotherapy in favor of early loading and vascularization to promote optimal tissue remodeling [23].

For athletes presenting with total mechanical disruption (Grade III), suture augmentation of both the ATFL and CFL using bone anchors has demonstrated exceptional success rates, providing immediate structural reinforcement that allows for early mobilization [24]. Systematic analyses confirm that surgical reconstruction of the lateral complex consistently yields positive functional outcomes in professional athletes, with approximately 89% returning to their pre-injury level of competition within a mean time of 16 weeks [25]. Monitoring this success requires the use of standardized psychological scales, such as the Ankle Ligament Reconstruction-Return to Sport after Injury (ALR-RSI) scale, which has proven reliable in predicting which patients are psychologically ready to resume high-intensity sports [26]. Currently, management remains a subject of ongoing debate, though the consensus is

increasingly favoring early, active functional restoration over passive rest to preserve muscle volume and evertor strength [27].

3.3. Surgical Outcomes and Advanced Augmentation Techniques

Technological advancements in arthroscopic repair have revolutionized the postoperative timeline. Accelerated rehabilitation protocols (AR) following arthroscopic lateral ligament repair have been shown to be safe and effective, often allowing for full weight-bearing by day 3 and a return to sport within 8 weeks [28]. Analysis of modified Broström techniques indicates that long-term patient satisfaction (up to 88%) is closely linked to anatomical restoration and the absence of residual instability, even if the pre-injury level of play is not always fully achieved [29]. Arthroscopic surgery for CAI has demonstrated excellent results, with high rates of return to competition and significantly improved AOFAS scores compared to open procedures [30]. Contemporary concepts in surgical management advocate for anatomical repair using suture anchors to maintain joint arthrokinematics and prevent the long-term progression of post-traumatic osteoarthritis [31].

The clinical course of acute sprains follows a predictable pattern of rapid pain reduction in the first two weeks, but without standardized care, the risk of recurrence remains as high as 34% over a 3-year period [32]. Simple clinical tests, such as the Single-Leg Loading (SLL) test, can quickly categorize the severity of acute LAS on the field, showing strong correlations with ultrasonographic findings of ATFL injury [33]. Ideally, operative stabilization should be combined with intra-articular inspection via ankle arthroscopy to address concomitant lesions, such as synovial impingement or chondral defects, which are present in over 90% of chronic cases [34]. This is particularly important because persistent muscle strength deficits, especially in plantar flexion and eversion, are major predictors of functional failure and recurrent injury [35].

High-resolution diagnostic ultrasonography provides a validated value for identifying both lateral and syndesmotic injuries, particularly the anterior inferior tibiofibular ligament (AITFL), offering a sensitivity of 100% when evaluated by experienced specialists [36]. In professional athletes (e.g., NHL players), specific MRI patterns—such as the presence of bone marrow edema—are primary tools for diagnosing high ankle sprains, although they do not always correlate perfectly with return-to-play timelines [37]. Understanding potential factors that worsen outcomes, such as supination trauma accompanied by persistent hematoma or pressure pain at 2 weeks, is essential for tailoring individualized recovery protocols [38]. Finally, the debate between single-anchor and double-anchor repairs has been addressed through meta-

analyses; the results suggest that double-anchor constructs may offer specific biomechanical advantages, particularly in achieving superior activity-related outcomes for patients participating in high-intensity sports [39, 40].

4. Therapeutic dilemmas and biomechanical considerations in elite athletic recovery

The synthesis of evidence from the analyzed forty sources confirms that the management of lateral ankle ligament injuries in athletes has transitioned from a passive, immobilization-based approach to a proactive, functional, and often biologically augmented surgical strategy. The most critical finding regarding diagnostic protocols in competitive sports is the superiority of delayed clinical examination combined with dynamic imaging. As indicated in the results, the high rate of false-negatives in the ultra-acute phase [1, 5, 12] suggests that early assessment might lead to an underestimation of the injury severity or a failure to recognize complete ligamentous disruption. A five-day delay, however, allows for a much more accurate evaluation of the athlete's structural integrity, as the reduction in acute edema and muscle guarding enables more reliable stress testing of the ATFL and CFL footprints [10, 13, 21]. This supports the hypothesis that for a professional athlete, where a precise prognosis is essential for season planning, timing is as crucial as the diagnostic modality itself. The strategic use of dynamic ultrasonography further enhances this process, allowing clinicians to visualize the ligament under functional load, which static MRI, despite its high resolution, cannot effectively replicate in terms of assessing functional joint laxity [16, 36, 37].

A significant point of discussion is the biological and clinical superiority of the "PEACE and LOVE" framework over the traditional RICE protocol in high-performance sports environments. While cryotherapy and compression were once the undisputed gold standard, contemporary biomechanical data suggest that excessive reliance on ice may hinder the metabolic markers and cellular signaling necessary for optimal collagen remodeling [4, 19, 23, 27]. The observed 14% faster return-to-play timeline in athletes utilizing functional mobilization [20, 21, 32] highlights a crucial competitive advantage. However, it is imperative to emphasize that clinical "clearance" for sport is not synonymous with complete biomechanical stability. The high prevalence of Chronic Ankle Instability reported in the analyzed literature [2, 17, 32] indicates that many athletes return to high-intensity training with lingering sensorimotor deficits.

The persistence of delayed peroneal activation and impaired proprioception even after mechanical ligament healing [17, 18, 35, 38] suggests that the modern gold standard must integrate intensive neuromuscular perturbation drills to bridge the gap between structural repair

and functional joint homeostasis. Furthermore, incorporating progressive eccentric loading of the peroneal muscles is essential to restore the dynamic eversion torque required to counteract sudden inversion stresses during competition. This is particularly vital in sports requiring explosive jumping and landing maneuvers, where the joint is most vulnerable to re-injury.

Moreover, advanced surgical interventions, particularly suture-tape augmentation (InternalBrace), represent a transformative paradigm shift for high-demand athletes in sports such as basketball, association football, and volleyball. Traditional anatomical repairs, while successful in the general population, often necessitate prolonged protected mobilization that results in significant muscle atrophy and a loss of explosive power [13, 14, 31]. The ability of suture-tape to act as a "secondary restraint" [6, 24, 39] provides the mechanical confidence required for immediate weight-bearing and early initiation of sport-specific agility drills. This acceleration of the return-to-play timeline, combined with recurrence rates remaining below 5% [6, 37, 40], confirms that biological reinforcement effectively addresses the biomechanical demands of elite performance. For an athlete, this integrated approach does not merely repair a ruptured ligament; it preserves their career trajectory by ensuring a more predictable, stable, and rapid reintegration into peak competition levels.

5. Multi-dimensional conclusions for standardized athletic ankle management

he synthesis of contemporary clinical evidence and biomechanical principles analyzed in this narrative review allows for the formulation of several key conclusions regarding the optimization of the recovery trajectory for athletes. Firstly, the traditional approach to immediate clinical assessment must be revised; a delayed physical examination, ideally on the fifth day post-injury, provides significantly higher diagnostic sensitivity, reducing the risk of misgrading ligamentous lesions. Secondly, high-resolution dynamic ultrasonography should be integrated into the primary diagnostic pathway in elite sports, as it provides a real-time functional assessment of ligamentous laxity that static MRI fails to capture.

Furthermore, the transition from the RICE protocol to the "PEACE and LOVE" framework is essential for modern sports medicine, as early, pain-free vascularization and controlled loading are critical for the biological restoration of ligamentous tensile strength. However, mechanical healing alone is insufficient for a stable return to play; the persistence of sensorimotor deficits underscores the necessity of intensive neuromuscular and proprioceptive training within the early stages of rehabilitation. Finally, for high-demand athletes, arthroscopic anatomical reconstruction reinforced with suture-tape augmentation (InternalBrace) represents the current gold standard. This approach effectively addresses the biomechanical demands of explosive

agility sports, providing immediate stability that allows for an accelerated and safe return to peak competition. Adopting this integrated multidisciplinary algorithm is vital for ensuring long-term joint integrity and career longevity in the athletic population.

Disclosure

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In preparing this work, the authors used ChatGPT (OpenAI) for the purpose of improving language and readability as well as translating specific terms. After using this tool, the authors have reviewed and edited the content as needed and acceptfull responsibility for the substantive content of the publication.

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