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CHALLENGES AND TRENDS IN INJURY RECOVERY AND PREVENTION IN HIGH-IMPACT SPORTS: A BIBLIOMETRIC APPROACH

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***ABSTRACT*:**

The practice of high-impact sports such as rugby, mountain biking, soccer, and gymnastics has increased significantly in recent decades, generating growing scientific interest in their physical and psychological consequences. Current studies reveal extensive but asymmetrically documented injuries associated with these disciplines, ranging from dental and joint trauma to concussions, muscle imbalances, and psychological disorders linked to pain or rehabilitation. This study seeks to address the research question: How can conceptual term co-occurrence network analysis identify the challenges in recovery and prevention of injuries in high-impact sports? To this end, a bibliometric co-occurrence network analysis was conducted based on 2,006 conceptual terms defined by 1,434 authors. The findings delineate four main clusters: Cluster 1: Prevention of bone and musculoskeletal injuries in high-impact sports—exercise, risk factors, and integral health; Cluster 2: Biomechanics, neuromuscular control, and prevention of lower-limb injuries in high-impact sports; Cluster 3: Concussions, neuroimaging, and cognitive sequelae in high-impact sports; Cluster 4: Knee injuries, tissue regeneration, and rehabilitation strategies in high-impact sports. These results highlight emerging research gaps that can be further explored through advanced quantitative techniques aimed at deepening conceptual structures and defining new constructs.

***Keywords**: Injury recovery, Injury prevention, High-impact sports, Bibliometrics, Python.*

INTRODUCTION

High-impact sports represent some of the most physically demanding activities today, both at the professional and recreational levels. Their popularity lies in the benefits associated with physical performance, cardiovascular health, and discipline; however, they also entail a high risk of injury due to the intensity of movements, physical contact, and biomechanical demands. Disciplines such as rugby, fencing, and mountain biking are characterized by a high prevalence of injuries that, in many cases, limit the continuity of athletic participation and affect athletes' quality of life [1].

Sports injuries encompass a wide spectrum of clinical manifestations. Musculoskeletal injuries, particularly anterior cruciate ligament (ACL) tears, stand out as one of the most extensively studied conditions due to their high recurrence and the complexity of return-to-sport processes [2]. Similarly, dental injuries constitute a frequent problem in contact sports, as reflected in reports of dental trauma and mandibular fractures. These injuries have fostered the widespread use of mouthguards as an effective preventive strategy [3].

Another area of concern involves neurological injuries resulting from repetitive head impacts, such as concussions and the cognitive decline associated with ball heading in soccer [4]. Adding to these risks are biomechanical variables such as inter-limb asymmetry, which has been identified as a predictor of recurrent injury [5]. These findings demonstrate that the etiology of injuries in high-impact sports is multifactorial and requires comprehensive approaches for both understanding and prevention.

The impact of such injuries extends beyond the individual clinical sphere. The costs associated with surgeries, prolonged rehabilitation programs, and loss of competitiveness affect clubs, federations, and healthcare systems, while simultaneously generating psychological consequences for athletes, including anxiety, depression, and loss

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of motivation. These factors can delay the recovery process and compromise adherence to rehabilitation programs [6].
In response to this issue, prevention and recovery strategies have evolved significantly. On the prevention side, advances include the incorporation of training methodologies aimed at correcting biomechanical imbalances [7], the use of mouthguards, and the implementation of sport-specific physical conditioning programs [8]. En el ámbito de la recuperación, In the recovery domain, progress has been marked by novel physiotherapy techniques, applications of functional magnetic resonance imaging to monitor tissue integrity, and the growing integration of digital technologies and wearable devices that enable personalized rehabilitation processes [2].

The growth of research in this field reflects a clear trend toward interdisciplinarity. Sports medicine, dentistry, physiotherapy, biomechanics, and psychology converge into a body of knowledge aimed at optimizing athlete safety and performance. Nevertheless, methodological limitations persist, including the scarcity of longitudinal studies and the underrepresentation of specific populations such as women and amateur athletes, which restricts the generalizability of findings [6], [9].

In this context, bibliometric studies emerge as a key tool for systematizing available information, identifying trends, and projecting future lines of research. Their application to the analysis of injury recovery and prevention in high-impact sports not only enables a better understanding of the evolution of scientific output, but also reveals collaboration patterns and the areas where academic efforts are concentrated [10], [11].

In summary, the rise of high-impact sports and the high incidence of associated injuries underscore the need for an analytical approach that integrates the fragmented evidence dispersed across the literature. Bibliometric analysis provides a map of accumulated knowledge, highlights the progress achieved, and at the same time points to the gaps that must be addressed in the future to ensure the safety, performance, and overall well-being of athletes.

Scientific Production and Field Evolution
The study of injuries in high-impact sports has shown sustained growth in scientific production over the past decades. The available literature demonstrates increasing interest not only in understanding the pathophysiology of injuries but also in identifying risk factors, developing prevention protocols, and designing recovery strategies adapted to the specific characteristics of each sport discipline. This rise in publications reflects the urgent need to address a problem that affects both professional and recreational athletes, as well as sports institutions and healthcare systems [12].

In terms of sports disciplines, rugby has emerged as one of the main objects of study due to its high rate of collisions and traumatic events, making it a key reference for analyzing injury incidence and prevention in high-contact contexts. Similarly, soccer has been extensively investigated for the cumulative effects of repeated head impacts, particularly regarding concussions and their association with cognitive decline. On the other hand, sports such as fencing and mountain biking have also begun to generate significant scientific output, reflecting the expansion of research areas beyond traditional contact sports [1], [5].

The types of injuries most frequently addressed in the scientific literature fall into three major categories. First, dental injuries, including trauma associated with contact sports and mandibular fractures documented across multiple disciplines. Second, anterior cruciate ligament (ACL) injuries, whose prevalence and high recurrence rates have motivated numerous studies on risk factors, preventive strategies, and recovery processes [13], [14]. Finally, research on functional asymmetries and inter-limb imbalances has revealed these to be significant predictors of subsequent injuries, which has stimulated the development of corrective training programs.

Another key aspect of the field's evolution is the interdisciplinary character of scientific production. Sports medicine has led clinical and surgical studies on fractures and ligament injuries, while sports dentistry has focused its efforts on trauma prevention through the use of mouthguards [15]. Meanwhile, biomechanics and physiology have contributed knowledge on movement patterns, functional load, and fatigue as factors associated with injury [7]. This disciplinary convergence reinforces the need to integrate diverse perspectives to address a complex and multifactorial phenomenon.

The development of new technologies has also contributed to expanding the scope of research. Tools such as magnetic resonance elastography (MRE) have been applied in recent studies to monitor tissue status, facilitating

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more precise diagnoses and the personalization of rehabilitation programs [16]. These advances, combined with the use of wearable devices and digital technologies, demonstrate that the evolution of the literature goes beyond clinical analysis, incorporating technological innovations with direct impact on injury recovery and prevention.

Finally, it is important to emphasize that research in this field is not limited to the physical dimension of injuries. Recent studies have highlighted the psychological impact of recovery processes, showing that factors such as anxiety, motivation, and resilience play a decisive role in return-to-sport outcomes. This comprehensive approach confirms that scientific production on injuries in high-impact sports has shifted toward a holistic vision that integrates athletes' physical and mental health, as well as the need for multidisciplinary and sustainable strategies.

Challenges and Trends in the Recovery and Prevention of Injuries in High-Impact Sports

The scientific literature on injuries in high-impact sports highlights a series of challenges that limit the effectiveness of prevention and recovery programs, as well as trends that outline new opportunities for research and clinical practice. One of the main challenges identified is the heterogeneity of prevention protocols, which complicates the comparison of results across different sports disciplines. For example, studies in martial arts and contact sports show that despite the use of protective equipment, the incidence of craniofacial trauma remains high, underscoring the need to standardize safety measures [17], [18]. Similarly, in sports such as soccer and basketball, variability in preventive training programs has led to inconsistent results, representing a methodological limitation for the generalization of conclusions [19], [20].

In the field of recovery, another central challenge lies in the prolonged periods of inactivity that athletes face after surgery or severe injury. The literature indicates that, although advances have been made in physiotherapy and progressive readaptation programs, difficulties related to reinjury persist, particularly in the case of ligaments and joints subjected to high functional loads [21], [22]. Added to this are problems of adherence to rehabilitation programs, which are often undermined by the lack of psychological support and the pressure to return to competition prematurely [23], [24].

Nevertheless, emerging trends are redefining approaches to sports injuries. Among these is the integration of wearable technologies and biomechanical analysis systems that enable real-time monitoring of key variables such as load, speed, and movement symmetry, thereby reducing exposure to risk factors. Likewise, the use of artificial intelligence and big data tools in the analysis of injury patterns is an expanding trend, with promising applications in the personalization of training and recovery programs [25], [26]. Another emerging line of research is the incorporation of regenerative therapies, such as those based on growth factors and stem cells, which open new possibilities for shortening recovery times and improving tissue functional quality [27].

An additional aspect shaping the future research agenda is the need for multidisciplinary approaches. Recent studies emphasize the importance of combining physiotherapy, sports medicine, psychology, and nutrition to ensure sustainable rehabilitation processes [28], [29]. This integration reflects a trend toward comprehensive athlete care, where the physical dimension is not conceived in isolation but rather in interaction with the emotional and social factors that influence recovery.

Taken together, the challenges and trends identified in the literature demonstrate that research on high-impact sports is undergoing a process of transition. The challenges highlight gaps in standardization, adherence, and reinjury, whereas the trends point toward technological innovation, personalized medicine, and interdisciplinarity. This dual perspective reinforces the relevance of bibliometric analysis, as it not only maps current advances but also anticipates the directions that will guide future research on injury prevention and recovery.

Research Gaps and Future Perspectives

Despite the progress outlined above, bibliometric analysis reveals significant gaps that must be addressed to consolidate an effective framework for injury recovery and prevention in high-impact sports. One of the most relevant gaps is the absence of longitudinal studies that assess the long-term impact of preventive and rehabilitation programs, since most investigations focus on short periods and do not consider athletes' full sporting trajectories [30], [31]. This limitation prevents the determination of the true effectiveness of applied strategies and hinders the development of clinical guidelines based on robust evidence.

Another critical gap lies in the low representativeness of certain population groups. Despite the growing participation of women and youth in high-impact sports, research continues to focus primarily on adult male

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athletes, introducing biases in the results and limiting the applicability of recommendations [6]. This lack of diversity poses a challenge for future research, which must address the physiological and biomechanical particularities of underrepresented populations.

Methodological fragmentation also persists. Different disciplines employ heterogeneous criteria to define what constitutes an injury, how rehabilitation success is measured, and which indicators determine safe return-to-sport. This lack of standardization limits cross-study comparisons and obstructs the development of universal protocols [7]. Addressing this issue requires the promotion of international consensus to unify criteria and build a common language among researchers and sports professionals.

In terms of future perspectives, the literature points to the consolidation of personalized approaches supported by digital technologies, artificial intelligence, and specific biomarkers. These tools will enable the anticipation of risks, the design of prevention programs tailored to each athlete, and the optimization of rehabilitation through real-time monitoring of functional parameters. Likewise, the development of regenerative therapies, such as the use of platelet-rich plasma and stem cells, is projected as a promising line of research to accelerate recovery and improve the quality of injured tissues [31]. Finally, the integration of psychological and social components into rehabilitation protocols represents a trend aimed at ensuring not only physical recovery but also the comprehensive well-being of athletes [32].

In summary, the identified gaps and future perspectives demonstrate that the field of injury recovery and prevention in high-impact sports is at a transitional stage. Overcoming current limitations and capitalizing on emerging opportunities will depend on the capacity of scientific research to consolidate integral, inclusive, and technologically advanced models that meet the demands of athletes and coaches in highly competitive environments.

Applications of the PRISMA Methodology in Injury Recovery and Prevention in High-Impact Sports

The PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) has transformed the way systematic reviews are organized and reported, providing clarity, transparency, and rigor in the synthesis of scientific evidence. Its application in sports medicine specifically in the recovery and prevention of injuries in high-impact sports has become increasingly common, as it allows for the exhaustive filtering of information and ensures that clinical recommendations are grounded in high-quality studies.

In the case of maxillofacial injuries associated with sports activities, the use of PRISMA facilitated the identification of robust evidence among nearly two thousand articles reviewed. The process enabled the selection of sixteen relevant studies that provided specific data on mandibular fractures, zygomatic bone injuries, and temporomandibular joint damage, highlighting the importance of surgery combined with postoperative physiotherapy to achieve functional recovery and prevent complications such as infections or joint sequelae [33]. This methodological rigor allows professionals to adopt evidence-based treatment protocols tailored to the complexity of contact sports.

Complementarily, systematic reviews guided by PRISMA have analyzed return-to-sport (RTS) outcomes following orthopedic surgeries in athletes from high-impact disciplines. These studies indicate that approximately 82% of patients successfully return to their activity, although recovery times vary according to the intensity of the sport. While low-impact activities allow for a return within 4–7 months, high-demand sports such as soccer or tennis generally require 7–12 months to minimize the risk of relapses or new injuries [34]. These findings provide more reliable clinical criteria for designing secondary prevention programs and sport-specific readaptation strategies.

Taken together, the application of PRISMA methodology in this field not only enhances the quality of the evidence compiled but also translates into practical benefits: it enables the design of individualized rehabilitation protocols, the establishment of preventive strategies based on identified risk factors, and the promotion of a safe return to high-impact sports. Thus, PRISMA constitutes an indispensable tool for strengthening sports medicine and guiding decisions in both clinical practice and sports management.

Relevance of the Interquartile Range in Sports Studies

Interquartile analysis has gained prominence in contemporary sports research as a robust statistical tool for identifying variability and dispersion in data fundamental aspects for evaluating performance, injury prevention,

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and the validity of experimental results. Recent investigations show that the replicability of studies in sport sciences largely depends on the appropriate interpretation of effect sizes and the statistical tests applied, such as the *t*-test and ANOVA, where interquartile ranges allow researchers to assess the consistency of findings between original and replicated studies [35]. Moreover, the treatment of outliers, detected through interquartile range–based methods, has proven crucial for improving the accuracy of predictive models in sports such as rugby, reducing standard errors and strengthening the statistical inferences derived from longitudinal analyses [36].

Complementarily, applied research on physical fitness demonstrates that the use of quartiles and their intervals provides a clear view of the dose–response relationship between cardiorespiratory tests, muscle strength, and risks of overweight or obesity. In this regard, participants classified in lower quartiles exhibit a higher likelihood of overweight and obesity compared to those in upper quartiles, confirming the value of interquartile analysis as a predictor of risks in both athletic and recreational populations [37]. These findings underscore that, beyond its statistical utility, the interquartile range constitutes a methodological quality criterion that strengthens the reliability of studies and their applicability in the sports field.

Therefore, this study seeks to address the following research question: *How can conceptual term co-occurrence network analysis identify the challenges in injury recovery and prevention in high-impact sports?* From this question, the following hypothesis is proposed:

H1: Conceptual term co-occurrence network analysis will enable the identification of challenges in the recovery and prevention of injuries in high-impact sports.

The hypothesis suggests that co-occurrence network analysis of conceptual terms allows for the identification of challenges in the recovery and prevention of injuries in high-impact sports. This proposition is justified insofar as the scientific literature on the subject is characterized by a wide diversity of approaches, disciplines, and sporting contexts, which necessitates a method capable of synthesizing and revealing hidden patterns among the most frequently studied concepts.

The literature illustrates how research ranges from biomechanical and performance-related factors, such as inter-lateral asymmetry in runners or kinematics in combat sports, to clinical and therapeutic dimensions, including the treatment of traumatic dental injuries or surgical interventions for joint damage. Likewise, studies highlight high-impact sports such as rugby, mountain biking, and fencing, where physical demands and exposure to impacts increase the risk of trauma. These findings show that the problem is not confined to a single category of injury but spans multiple areas, including physiotherapy, orthopedics, sports psychology, and community-based prevention.

In this sense, the co-occurrence technique enables a rigorous mapping of the relationships among key concepts—for example, “biomechanics,” “injury prevention,” “rehabilitation,” “performance,” and “trauma”—and facilitates visualization of how they evolve over time and in which sports or contexts they are concentrated. By integrating thousands of keywords and descriptors, the analysis generates a structure of thematic clusters that helps identify cross-cutting challenges, such as the prevention of recurrent injuries, functional rehabilitation in young athletes, or the design of sport-specific training programs to mitigate risks.

Consequently, the hypothesis is supported because co-occurrence analysis not only organizes the vast body of scientific production but also provides a strategic tool to anticipate trends, identify research gaps, and guide intervention policies in high-impact sports, where injury prevention and recovery are decisive for both athletes’ health and their professional careers.

METHODOLOGY

Document Selection

The selection of documents was carried out in accordance with the best practices of the PRISMA methodology (see Figure 1). Based on the selection of databases, tailored search equations were designed for each source, resulting in the retrieval of a total of 746 articles (see Table 1).

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Figure 1. PRISMA Flow Diagram

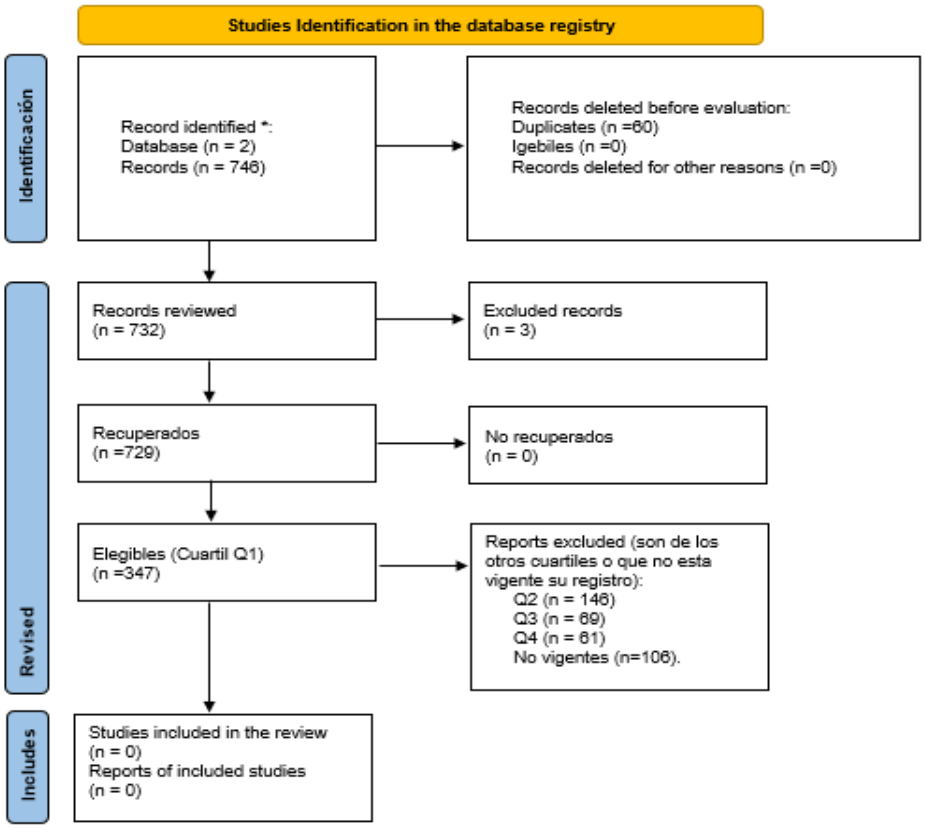

Table 1. Search equation

Data Base	Search Equation	Total Doc
Scopus	TITLE-ABS-KEY ((recovery OR prevention OR injuries) AND ("high-impact" AND sports)) AND (LIMIT-TO (DOCTYPE , "ar"))	356
Web Of Science	(recovery OR prevention OR injuries) All Field And ("high-impact" AND sports) All Field Document Type: Article	390
Summary		746

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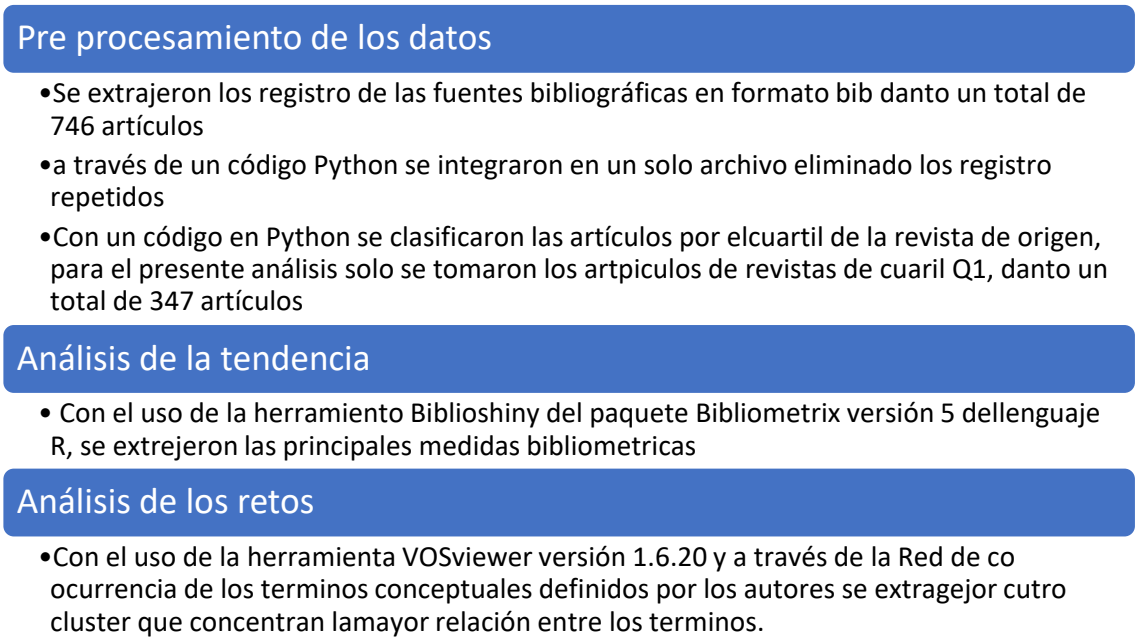
Analysis Process

The following workflow was developed to perform the bibliometric analysis (see Figure 2):

Figure 2. Bibliometric workflow



RESULTS

Analysis of Trends in Bibliometric Measures

The bibliometric analysis on injury recovery and prevention in high-impact sports covers a period of nearly five decades (1977–2025), evidencing the progressive consolidation of this field as a specialized line of research within sport sciences and applied medicine (see Figure 3). Within this timeframe, 256 documents were identified across a total of 110 academic sources (see Figure 4C), reflecting a moderate level of dispersion and a diversity of dissemination channels. The annual growth rate (6.44%) confirms steady, though not exponential, progress, suggesting sustained and growing interest in the subject (see Figure 4A).

In terms of academic influence, the documents exhibit an average of 21.32 citations per publication (see Figure 4B), a significant figure that denotes the relevance of this field in the scientific literature and its capacity to generate impact on subsequent studies. The average age of documents (9.55 years) indicates that, although there are recent contributions, much of the relevant production originates from the last decade and remains current. Collectively, the reviewed works cite 7,238 references, demonstrating a solid theoretical and methodological foundation.

From a thematic content perspective, 558 terms were identified in Keywords Plus and 2,006 author keywords (see Figure 4D), reflecting considerable conceptual richness and the existence of multiple associated lines of research. This high volume of descriptors highlights both the diversity of approaches employed (physiotherapy, sports medicine, rehabilitation, injury prevention, biomechanics, among others) and the evolution of key concepts over time.

Regarding scientific production, a total of 1,434 authors were identified, evidencing a broad and active academic community working on this topic. However, single authorship is rare (only 4 single-authored documents), while the average of 6.28 co-authors per publication reflects a strong collaborative character, likely linked to the need for multidisciplinary teams in studies on sports injuries.

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Figure 3. Bibliometric Measures

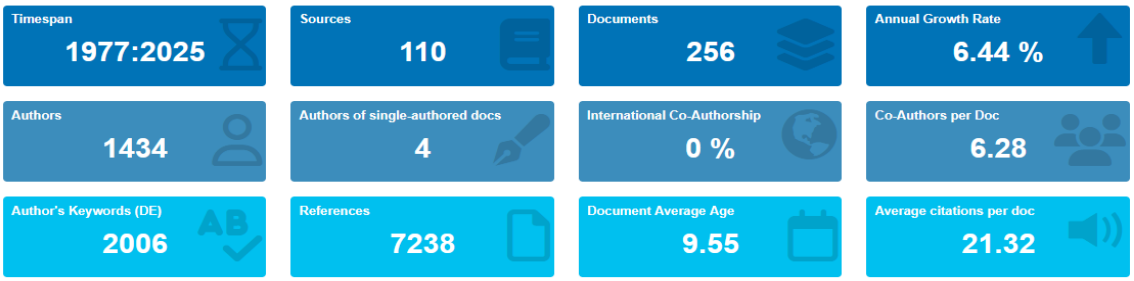
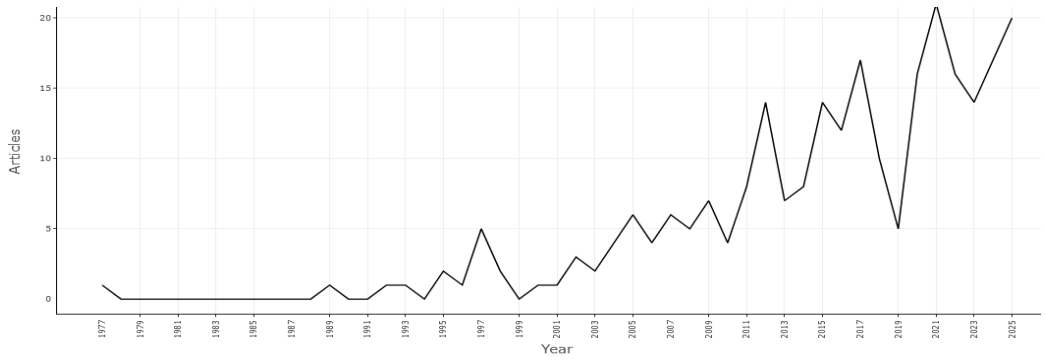
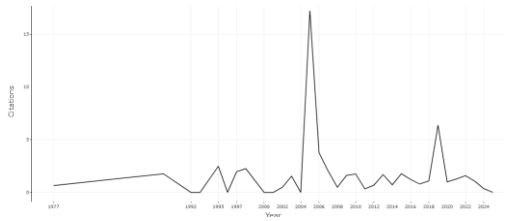


Figure 4. Bibliometric trend

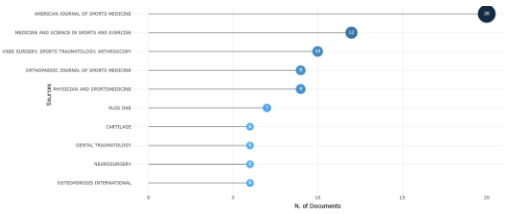
A)



B)



C)



D)

Note: A) Annual Scientific Production B) Average Citations Per Year C) Most Relevant Sources D) WordCloud

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Conceptual Term Co-Occurrence Network Analysis

Based on the 2,006 conceptual terms defined by the 1,434 authors, a co-occurrence network graph was designed (see Figure 5). From this analysis, four clusters were identified that concentrate the strongest relationships among conceptual terms. The first cluster was labeled **"Prevention of Bone and Musculoskeletal Injuries in High-Impact Sports: Exercise, Risk Factors, and Integral Health."** The second cluster was associated with the theme **"Biomechanics, Neuromuscular Control, and Prevention of Lower-Limb Injuries in High-Impact Sports."** The third cluster was defined as **"Concussions, Neuroimaging, and Cognitive Sequelae in High-Impact Sports."** The final cluster was designated as **"Knee Injuries, Tissue Regeneration, and Rehabilitation Strategies in High-Impact Sports."** The following section provides a literature review of each cluster and the corresponding conceptual definitions.

Cluster 1: Prevention of Bone and Musculoskeletal Injuries in High-Impact Sports Exercise, Risk Factors, and Integral Health.

Cluster 1, *Prevention of Bone and Musculoskeletal Injuries in High-Impact Sports*, brings together a body of research focused on identifying risks, exercise strategies, and integral health measures aimed at reducing the incidence of fractures, sprains, and recurrent trauma in athletes (see Figure 6A). This cluster is characterized by the integration of evidence on predisposing factors for injuries and practices that strengthen bone and muscular structures, highlighting the importance of an interdisciplinary approach that considers not only athletic performance but also the overall health of the athlete [26], [38].

The prevention of bone and musculoskeletal injuries in high-impact sports represents a central priority in contemporary research, as the constant practice of activities such as soccer, basketball, or athletics generates intense mechanical loads that, while strengthening bone structure, also increase the risk of fractures and cumulative microtrauma. Several studies indicate that the nature of injuries varies depending on the sport, with knee, ankle, and spinal injuries being particularly common, which necessitates the design of sport-specific prevention protocols [26]. Among the most prominent strategies are muscle strengthening and improved flexibility, both of which contribute to impact absorption and the reduction of joint strain. Likewise, the analysis of playing surfaces, footwear, and equipment has been shown to be a determining factor in the incidence of injuries, since the interaction between body and environment can either mitigate or exacerbate risks [39].

In contact sports, dental and craniofacial injuries also form part of the spectrum of associated risks, reinforcing the need to integrate protective devices, such as mouthguards, into sports safety programs [15]. At the same time, the literature emphasizes that training programs based on resistance and balance exercises not only enhance athletic performance but also optimize overall health by reducing the likelihood of sprains, dislocations, and stress fractures [27]. Factors such as age, medical history, and prior sporting experience significantly influence vulnerability to injury, which means that prevention programs should be designed with an individualized focus and take into account the athlete's developmental trajectory [40].

The component of integral health plays a central role, since injury prevention cannot be limited to the physical dimension alone. Factors such as proper nutrition, hydration, rest, and mental health contribute to maintaining body homeostasis and facilitating recovery processes following repetitive exertion. Likewise, educating athletes in self-care techniques and in the early recognition of symptoms associated with joint overload emerges as a fundamental preventive resource [41]. Accumulated evidence supports that interdisciplinary programs combining sports medicine, physiotherapy, psychology, and nutrition provide a more comprehensive perspective on prevention and the maintenance of musculoskeletal health [42].

In summary, Cluster 1 reflects the convergence of multiple factors for preventing bone and musculoskeletal injuries in high-impact sports: from the design of sport-specific exercise programs to the consideration of contextual risks and the holistic approach to athlete health. This multifactorial perspective not only reduces the incidence of injuries but also promotes safer, more sustainable sports practice aimed at long-term well-being.

Cluster 2: Biomechanics, Neuromuscular Control, and Prevention of Lower-Limb Injuries in High-Impact Sports.

Cluster 2 focuses on the interaction between biomechanics, neuromuscular control, and strategies for preventing lower-limb injuries, particularly in high-impact sports where repetitive loads and technical movements demand an adaptive response from the musculoskeletal system (see Figure 6B). Scientific evidence demonstrates that the

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study of these dynamics is crucial to understanding the incidence of injuries and proposing measures that enhance athletic performance while safeguarding long-term health [43], [44].

In this context, it has been demonstrated that increased vertical impact loading during running is a determining factor in the onset of musculoskeletal injuries, as ground reaction forces generate cumulative microtrauma that compromises joints such as the knee and ankle. At the same time, postural control and dynamic balance play a fundamental protective role, as they compensate for asymmetries and improve stability during high-demand movements, thereby reducing the risk of sprains and overloads [45]. These findings reinforce the need for training programs focused on proprioception and neuromuscular stability.

The literature also indicates that age, joint anatomy, and history of previous injuries condition athletes' vulnerability. In disciplines involving frequent twisting and impacts, such as running or contact sports, these variables are associated with the development of early-onset osteoarthritis and an increased risk of relapses if biomechanical factors are not adequately controlled. Indeed, runners with prior injuries present distinct tibial and sacral acceleration patterns, suggesting a reduced capacity to attenuate loads and, consequently, a greater propensity for recurrent injuries [44], [46].

Similarly, research on postpartum female runners has identified multiple risk factors associated with pain and injury, including accumulated fatigue, incontinence, sleep disturbances, and biomechanical changes resulting from childbirth. These findings highlight how neuromuscular demands may be exacerbated in specific physiological contexts [47]. In the clinical setting, the analysis of functional tests has proven critical in determining the need for anterior cruciate ligament reconstruction, emphasizing that quadriceps strength and response to progressive training are predictors of improved outcomes and lower reinjury rates [48].

Finally, studies on inter-limb asymmetries reveal that even small differences between limbs generate significant overloads on joints, challenging traditional thresholds used for return-to-sport decisions and proposing stricter criteria to prevent relapses [13]. This risk is particularly high in contact sports such as rugby, where lower-limb fractures represent a considerable proportion of severe injuries treated in hospital settings [49].

Taken together, the evidence from Cluster 2 underscores that the prevention of lower-limb injuries must be approached from an integral perspective, combining biomechanical analysis, neuromuscular strengthening, correction of asymmetries, and adaptation of training loads. These measures not only reduce the incidence of injuries but also help prolong the athletic career of individuals participating in high-impact disciplines.

Cluster 3: Concussions, Neuroimaging, and Cognitive Sequelae in High-Impact Sports

Cluster 3 encompasses a line of research that has gained significant relevance in recent decades due to growing concerns about the short- and long-term effects of head trauma in both professional and amateur athletes (see Figure 6C). This cluster emphasizes that concussions, frequent in disciplines such as American football, boxing, and rugby, not only cause immediate symptoms such as dizziness, headaches, or disorientation, but are also associated with persistent neurological and cognitive sequelae that may affect athletes' quality of life even after retirement [50].

A range of studies have employed advanced neuroimaging techniques to evaluate the structural and functional alterations resulting from these traumatic events. Evidence has shown that contact sport athletes exhibit significant changes in critical brain regions, demonstrating a direct association between prolonged participation in high-impact sports and the emergence of neurocognitive deficits [51]. Magnetic resonance imaging, in particular, has enabled the detection of microlesions and alterations in white matter, which are not always visible in conventional clinical assessments but correlate with impairments in functions such as memory, attention, and processing speed [52].

Research also highlights the importance of addressing concussions from both clinical and preventive perspectives. Early diagnosis is essential, as multiple studies agree that athletes who experience repeated concussions face a higher risk of developing neurodegenerative diseases such as chronic traumatic encephalopathy, which is characterized by slowly progressing behavioral and cognitive impairments [53]. In this regard, the literature stresses that concussions are not merely transient injuries but events with a potential cumulative impact on brain health [54].

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Subtle cognitive manifestations have also been identified as potential early indicators of these sequelae. For example, a documented reduction in oral language complexity among professional American football players has been proposed as an early marker of neurocognitive decline, reinforcing the need to combine clinical assessments with linguistic and psychological tools for timely detection [50]. Complementarily, evidence shows that the incidence of concussions in mass sports such as soccer and mountain biking requires greater attention, as the mechanisms of impact differ and generate sport-specific injury patterns that must be studied in greater detail [1], [55].

Taken together, this cluster presents both a scientific and social challenge: to understand and mitigate the consequences of concussions in sport. The integration of neuroimaging with cognitive outcome analysis has enabled substantive progress, yet the accumulated evidence also reveals research gaps regarding prevention, interdisciplinary management, and the longitudinal monitoring of athletes exposed to these injuries. Consequently, a more rigorous and multidimensional approach is required—one that considers not only the medical dimension but also the psychological, social, and ethical implications associated with participation in high-impact sports.

Cluster 4: Knee Injuries, Tissue Regeneration, and Rehabilitation Strategies in High-Impact Sports
Cluster 4 encompasses research that delves into the high incidence of knee injuries and the therapeutic advances aimed at restoring athletes' functional capacity (see Figure 6D). Due to its complex biomechanical structure, the knee is particularly vulnerable in disciplines involving jumps, pivots, and sudden changes of direction, which explains its frequent involvement in high-performance sports [38]. In this regard, the literature consistently shows that increased participation in intense activities has multiplied cases of ligament, meniscal, and cartilaginous injuries, generating a broad field of study that integrates prevention, tissue repair, and rehabilitation [56].

Several studies have documented that knee injuries not only limit immediate athletic participation but may also lead to long-term effects such as joint degeneration or early-onset osteoarthritis. Consequently, particular attention has been devoted to tissue repair and regeneration techniques, including grafts, stem cell therapies, and biomaterials that promote the restoration of structural and functional integrity of the joint [39]. These innovations have opened new opportunities for elite athletes to return to competition with a lower risk of reinjury, while also establishing reference models in regenerative medicine applied to sport [57].

At the same time, rehabilitation has evolved beyond traditional physiotherapeutic processes toward comprehensive strategies that include neuromuscular control, progressive functional readaptation, and individualized relapse-prevention programs. It has been demonstrated that the combination of strengthening exercises, proprioceptive training, and safe return-to-play protocols significantly reduces the risk of reinjury and optimizes subsequent performance [58]. These approaches have established that successful recovery from a knee injury depends not only on surgical or regenerative interventions but also on the quality of the rehabilitation program implemented [59].

Finally, bibliometric research reveals that this cluster has consolidated as a strategic core of contemporary sports medicine. The emphasis on the knee as a key joint, the integration of regenerative technologies, and the design of multidimensional rehabilitation programs demonstrate a clear trend toward the pursuit of sustainable, evidence-based solutions [50]. In conclusion, Cluster 4 not only represents the concern for reducing the incidence and severity of knee injuries in high-impact sports but also reflects the commitment to integral recovery, where tissue regeneration and advanced rehabilitation converge to ensure joint health and extend athletes' sporting careers.

Figure 5. term co occurence Network

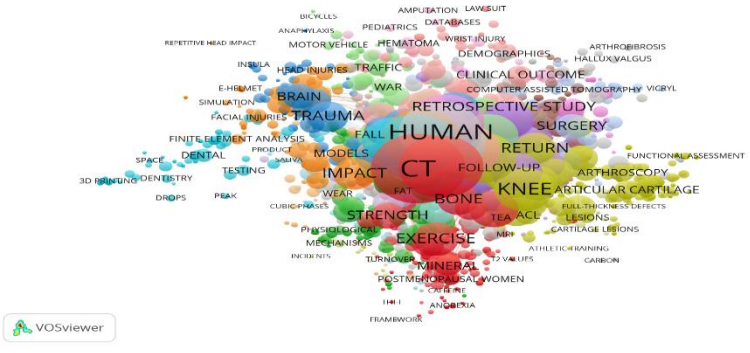

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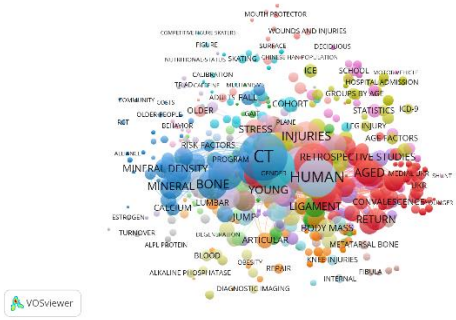
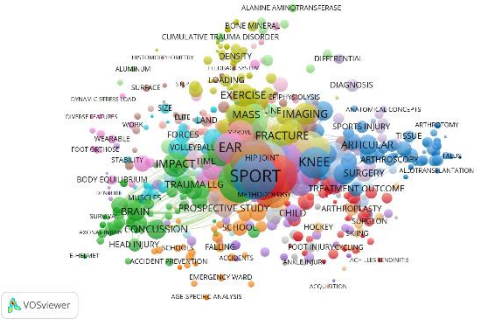
Figure 6. Clústeres

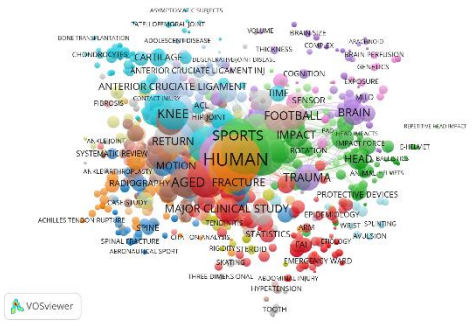
A)



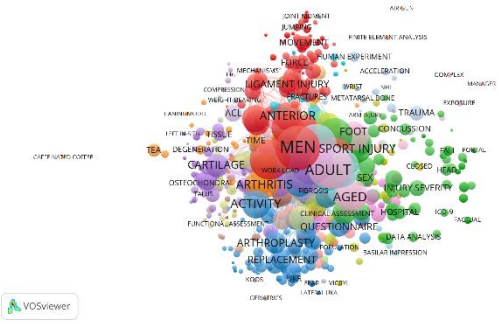
B)



C)



D)



Note: A) Prevention of bone and musculoskeletal injuries in high-impact sports: exercise, risk factors, and integral health. B) Biomechanics, neuromuscular control, and prevention of lower-limb injuries in high-impact sports. C) Concussions, neuroimaging, and cognitive sequelae in high-impact sports. D) Knee injuries, tissue regeneration, and rehabilitation strategies in high-impact sports.

DISCUSSION

The bibliometric analysis conducted on injury recovery and prevention in high-impact sports reveals a consolidating field, characterized by steady scientific production from the late 1970s to the present. The annual growth rate (6.44%) reflects constant interest in the topic, though not an exponential surge of publications. This suggests that research on sports injuries, while showing progressive development, has responded more to practical needs arising from professional and competitive practice than to temporary academic trends. The average of 21.32 citations per document confirms the relevance of the contributions made and the impact they have had on shaping new lines of inquiry.

The diversity of sources (110 in total) and the breadth of identified keywords (2,006 author keywords and 558 Keywords Plus) demonstrate the conceptual richness of the field and underscore its multidisciplinary nature, which integrates medicine, physiotherapy, biomechanics, sports psychology, and rehabilitation. This dispersion also poses a challenge, as researchers must navigate multiple dissemination channels, which can fragment accumulated knowledge. Nevertheless, the existence of well-defined thematic clusters mitigates this dispersion and helps organize knowledge into priority areas.

Cluster A, focused on the prevention of bone and musculoskeletal injuries, highlights the importance of designing exercise, nutrition, and self-care programs that integrate an overall health perspective. Evidence indicates that risk factors are not limited to training itself but are also linked to contextual conditions such as playing surfaces,

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footwear, or cumulative load. In this sense, the consolidation of interdisciplinary strategies confirms that prevention requires both biomechanical measures and educational and psychological interventions.
In **Cluster B**, the centrality of biomechanics and neuromuscular control underscores the need to address the lower limbs as a critical area for impact absorption and functional stability. Findings that inter-limb asymmetries or postpartum changes alter neuromuscular response capacity show that prevention programs must be adapted to athletes' particular conditions. This personalized approach, supported by scientific evidence, aligns with the trend toward training protocols based on functional testing and objective return-to-sport criteria.

Cluster C introduces an emerging component of high social relevance: concussions and their cognitive sequelae. The integration of neuroimaging techniques has made it possible to document structural and functional brain damage that previously went unnoticed, shifting the perception of concussions from transient events to cumulative risk factors for neurodegenerative diseases. This presents ethical and clinical challenges in managing contact sports, where balancing spectacle, performance, and long-term athlete health remains controversial.

Finally, **Cluster D**, centered on knee injuries, confirms that this joint continues to be one of the most vulnerable in high-impact sports. Advances in tissue regeneration using grafts, stem cells, and biomaterials have opened promising horizons, but their success depends on comprehensive rehabilitation programs that combine strengthening, neuromuscular control, and relapse prevention. At this point, the discussion illustrates how sports science is moving toward a more holistic model, where surgery or regenerative treatment alone is insufficient without progressive and multidimensional readaptation.

Taken together, the results suggest that research in this field is structured around a balance between prevention and recovery. Prevention, represented in Clusters A and B, seeks to reduce the initial incidence of injuries through integrated and biomechanical programs. Recovery, addressed in Clusters C and D, focuses on mitigating neurological sequelae and on joint regeneration and rehabilitation. Thus, the discussion reveals a landscape in which sports science aims not only to prolong athletes' careers but also to safeguard their long-term well-being, reinforcing the need for multidisciplinary and collaborative approaches.

CONCLUSIONS

The bibliometric analysis on injury recovery and prevention in high-impact sports demonstrates that this field has reached a significant level of consolidation, with sustained scientific production spanning nearly five decades and a clear orientation toward multidisciplinary approaches. The reviewed literature shows that, although sports injuries have diverse etiologies ranging from bone and musculoskeletal to neurological and articular there is a common trend toward integrating preventive, rehabilitative, and regenerative strategies aimed not only at ensuring competitive performance but also at safeguarding athletes' overall well-being.

The four identified clusters synthesize the main lines of research. **Cluster 1** underscores the importance of exercise, nutrition, and self-care programs to prevent bone and musculoskeletal injuries, while **Cluster 2** highlights the role of biomechanics and neuromuscular control in reducing risks to the lower limbs. **Cluster 3** provides compelling evidence on concussions and their cognitive sequelae, positioning neuroimaging as a key tool in the detection and monitoring of such injuries. Finally, **Cluster 4** confirms that the knee is one of the most vulnerable joints in high-impact sports and that advances in tissue regeneration, together with comprehensive rehabilitation programs, represent a strategic axis of contemporary sports medicine.

Taken together, the findings indicate that the balance between prevention and recovery is the defining feature of scientific progress in this area. Prevention aims to reduce the initial incidence of injuries through sport-specific and discipline-adapted protocols, while recovery seeks to mitigate neurological sequelae and optimize functional regeneration for a safe return to competition. Furthermore, the application of methodologies such as PRISMA and statistical tools like interquartile analysis strengthens the robustness of research, ensuring greater transparency, rigor, and replicability.

Nonetheless, important gaps remain that must be addressed in future studies. The scarcity of longitudinal research, the underrepresentation of women and amateur athletes, and the lack of methodological consensus in defining and evaluating injuries all constitute limitations that restrict the generalizability of results. In this regard, future perspectives point to the consolidation of personalized approaches supported by artificial intelligence, big data,

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wearable technologies, and regenerative therapies, which will allow for risk anticipation, individualized program design, and accelerated rehabilitation processes.

In summary, research on injury recovery and prevention in high-impact sports is advancing toward a holistic, interdisciplinary, and technologically sophisticated model. The evidence analyzed confirms that ensuring safety, prolonging athletic careers, and securing athletes' overall well-being requires overcoming current challenges through the integration of science, innovation, and international collaboration.

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