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Hamstring Injuries in Modern Sport and Society: Epidemiology, Biological Basis of Muscle Regeneration, and Emerging Treatment Strategies - A Narrative Review

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Abstract

Hamstring injuries represent one of the most common sports-related injuries, occurring at both professional and amateur level. They are also a primary cause of athlete exclusion from competitions, which presents consequences for both the athletes and their employers. Research conducted over recent years indicates an increasing incidence of this type of injury, leading to the development of science focused on modern treatment methods, shortening recovery time, and accelerating the return to activity. This article aims to review the literature related to the treatment of injuries to the biceps femoris, semimembranosus, and semitendinosus muscles, with reference to the pathomechanism of their occurrence and the impact of therapy on the time to return to activity.

Methodology. This review article was prepared based on scientific publications identified through the online databases PubMed and Google Scholar. The literature search was conducted using the following keywords and phrases: “hamstring injuries”, “muscle injury treatment”, “stem cells treatment in muscle injuries”, “platelet-rich plasma”, “muscle regeneration”, and “hamstring injuries in sports”. Relevant articles were selected and analyzed with a focus on the epidemiology, pathomechanisms, regenerative processes, and biological treatment strategies for hamstring injuries in athletes.

Keywords: hamstring injuries, muscle injury treatment, stem cells treatment in muscle injuries, platelet-rich plasma, muscle regeneration, muscle injuries in sport

1. Introduction

1.1 Epidemiology and Current Trends of Hamstring Injuries

During the 21st century, hamstring injuries have attracted increasing scientific attention due to their rising incidence and substantial impact on sports participation at both professional and recreational levels. The UEFA Elite Club Injury Study reported that hamstring injuries accounted for 20% of all injury-related time loss in professional football in 2022, compared with 10% in 2001. Regarding all injuries reported by players, their growing significance is also noteworthy – compared to 2001, when they constituted 12% of all injuries, their share doubled by 2022, reaching 22%. It should be noted that the studies discussed above focused exclusively on professional athletes training at the highest levels of intensity, who also had better access to physiotherapy, injury prevention strategies, and rehabilitation services.

The epidemiology of hamstring injuries in the general population was recently investigated in a large-scale American cohort study.. In 2024, researchers analyzed a database comprising more than 100 million individuals and identified over 118,000 patients diagnosed with hamstring injuries between 2015 and 2024. The analysis revealed an almost fourfold increase in injury incidence, rising from 11.6 cases per 100,000 individuals in 2015 to 42.8 cases per 100,000 individuals in 2024. Furthermore, statistical projections suggested that this upward trend is likely to continue through 2030, reaching over 56 cases per 100,000 individuals. The study also examined the age distribution of affected individuals - it demonstrated a bimodal pattern, with the highest incidence rates observed among adolescents and young adults aged 15-19 years, as well as among individuals older than 40 years, particularly those over 60 years of age. These findings indicate that hamstring injuries are no longer a problem confined to elite athletes but represent an increasingly important public health issue affecting physically active individuals across a wide age spectrum. [1,2,3,4]

1.2 Risk Factors for Hamstring Injuries

To minimize the risk of hamstring injuries, it is essential to identify and understand the factors associated with their occurrence. Previous hamstring injury is considered the strongest predictor of future injury, particularly during the early period following return to sport. Additional risk factors may be related to individual anatomical characteristics. In a prospective study published in 2016, Timmins et al. demonstrated a significant association between shorter fascicle length of the long head of the biceps femoris and an increased risk of hamstring strain injury. Among athletes with resting fascicle lengths of ≤10.56 cm, 33% sustained a hamstring injury during the study period, compared with only 8% of athletes whose fascicle lengths exceeded 10.56 cm. The authors further reported that reduced eccentric knee flexor strength was independently associated with a greater susceptibility to hamstring injury. The role of eccentric knee flexors strength asymmetry as a risk factor for hamstring injuries remains a subject of ongoing debate. In particular, it is unclear whether differences in eccentric and isometric knee flexor strength between the lower limbs contribute to an increased susceptibility to injury. Timmins et al. did not identify a significant causal relationship between those asymmetries and the occurrence of hamstring strain injuries. In contrast, several years earlier, Croisier et al. reported that athletes presenting with previously identified imbalances in hamstring muscle strength exhibited a substantially greater risk of injury. Furthermore, the authors demonstrated that correcting these strength deficits through targeted exercise interventions was associated with a reduction in injury incidence. These conflicting findings indicate that the influence of muscular strength asymmetries on hamstring injury risk remains incompletely understood and warrants further investigation. [2,6,7]

The increasing incidence of hamstring injuries observed in both professional and recreational sports may be partially explained by the growing demands of high-intensity physical activity. Barnes et al. reported in 2014 that professional football has become progressively more physically demanding, with the number of sprinting actions performed during matches increasing by approximately 35% over a seven-year period. Such changes expose athletes to greater eccentric loading and repeated high-speed running. These conditions are known to place substantial mechanical strain on the hamstring musculotendinous unit, particularly during the terminal swing phase of sprinting. A similar trend can be observed at the recreational level, where increasing public awareness of the health benefits of regular physical activity and the role of exercise in the prevention of chronic diseases has led to greater participation in sport and exercise. Consequently, hamstring injuries should be viewed not only as a problem affecting elite athletes but also as an increasingly relevant issue among recreationally active individuals. [4,5]

2. Anatomy, Biomechanics and Pathophysiology of Hamstring Injuries

2.1 Functional Anatomy of the Hamstring Muscle Group

The hamstring muscle group consists of three muscles: the biceps femoris, which is composed of a long head and a short head, the semimembranosus muscle, and the semitendinosus muscle. The semitendinosus, semimembranosus, and long head of the biceps femoris originate from the ischial tuberosity, whereas the short head of the biceps femoris originates from the lateral lip of the linea aspera of the femur. Their distal insertions are located on the bones of the lower leg: the biceps femoris inserts onto the head of the fibula, whereas the semimembranosus and semitendinosus insert onto the tibia. [24]

The primary functions of the hamstring muscles include knee flexion and hip extension. Owing to their biarticular nature, these muscles play a crucial role in coordinating lower-limb movement during locomotion, particularly during running, sprinting, jumping, and changes of direction. In addition to generating movement, the hamstrings contribute significantly to dynamic stabilization of both the hip and knee joints and are essential for controlling eccentric loading during high-speed athletic activities. [24]

2.2 Biomechanics of Sprinting-Related Hamstring Injuries

Numerous researchers have attempted to identify the specific phase of movement during which hamstring injuries most commonly occur. These investigations have been conducted through both biomechanical analyses of athletes sprinting on treadmills and computational models designed to simulate the forces and mechanical stresses acting on the muscles of the lower extremity during high-speed running. One of the seminal studies in this field was conducted by Thelen et al., who sought to determine the phase of sprinting associated with the greatest risk of hamstring injury. Their findings demonstrated that the period of highest vulnerability occurs during the terminal swing phase, when the lower limb is advanced forward immediately prior to foot contact with the ground. During this phase, simultaneous knee extension and hip flexion result in maximal elongation of the hamstring musculotendinous unit while the muscles continue to generate substantial force, thereby exposing them to considerable mechanical stress. Subsequent studies conducted by Chumanov et al. expanded upon these observations by examining the behavior of individual muscles within the hamstring group during sprinting. Their analyses revealed that the long head of the biceps femoris undergoes greater elongation during the swing phase than either the semimembranosus or semitendinosus muscles. This finding provides a biomechanical explanation for the disproportionately high incidence of injuries involving the long head of the biceps femoris compared with other components of the hamstring complex. Further advances were achieved by Schache et al., who developed one of the most sophisticated biomechanical models of hamstring function to date. Their work enabled a comprehensive analysis of hamstring mechanics during sprinting and not only confirmed the conclusions of previous studies but also highlighted the critical role of force generation within the hamstring muscles. Specifically, the authors demonstrated that the hamstrings are required to produce substantial eccentric forces in order to decelerate the swinging lower limb during the terminal swing phase. The combination of marked musculotendinous elongation and high eccentric loading is now considered a fundamental component of the pathophysiology underlying hamstring strain injuries. [8,9,10]

2.3 Sprinting-Type and Stretching-Type Hamstring Injuries

In 2007**, Askling et al.** demonstrated through a series of studies that hamstring injuries should not be regarded as a homogeneous group of disorders. Their research distinguished between injuries sustained during sprinting or high-speed running, referred to as **sprinting-type injuries**, and a separate category of injuries resulting from excessive muscle elongation, known as **stretching-type injuries**. The authors showed that these injury patterns differ not only in their underlying mechanisms but also in their clinical presentation, anatomical location, magnetic resonance imaging (MRI) findings, and recovery characteristics. Furthermore, substantial differences were observed in the time required for athletes to return to sport and regain their pre-injury level of performance. These findings provided important evidence that hamstring injuries comprise distinct clinical entities with different pathophysiological mechanisms and prognostic implications.

	Sprinting-type injury	**Stretching-type injury**
Injured muscle	Long head of the femoris biceps	Semimembranous muscle (87%)
Time of symptoms occurance	Acute onset	Gradual onset
Corelation between MRI findings and time of recovery	The bigger changes in the MRI, the longer time of recovery	No relation between MRI changes and time of recovery
Time of recovery	~16 weeks	~ 50 weeks

In their investigations of sprint-related hamstring injuries, researchers reached several important conclusions. First, a significant relationship was identified between the anatomical location of the injury and the expected duration of recovery. More proximally located lesions, as determined both by tenderness on clinical palpation and by findings on magnetic resonance imaging (MRI), were associated with longer rehabilitation periods. In particular, involvement of the proximal tendon was recognized as a strong negative prognostic factor, significantly prolonging the time required to return to full athletic participation. Second, follow-up MRI examinations performed several weeks after injury revealed an association between the rate of resolution of imaging abnormalities and functional recovery. Proximal involvement of the tendon, particularly at the musculotendinous junction, was associated with prolonged rehabilitation and delayed return to sport. These findings suggest that serial MRI assessment may provide valuable prognostic information regarding the healing process and expected recovery timeline following sprint-related hamstring injuries. [12]

Subsequent studies demonstrated that not all hamstring injuries occur through the same mechanism. In professional dancers, injuries were observed not as a consequence of high-speed movements requiring substantial force production, such as sprinting, but rather as a result of slow, excessive elongation of the hamstring muscle group caused by simultaneous maximal hip flexion and knee extension. These findings highlighted the existence of a distinct injury mechanism characterized primarily by extreme musculotendinous stretch rather than high mechanical loading. Several important differences between the two injury mechanisms were identified. In stretching-type injuries, although the injury occurred at a clearly identifiable point in time, the initial symptoms were frequently mild in severity, allowing continued participation in athletic activity, while symptom intensity gradually increased over the subsequent days, which frequently led to an initial underestimation of its severity. The semimembranosus muscle was the structure most commonly affected, particularly its proximal portion, often involving the tendinous structures attaching the muscle to the ischial tuberosity. Furthermore, the time required to return to full athletic performance was substantially longer than that observed following sprinting-type injuries. Unlike sprint-related hamstring strains, the extent of abnormalities detected on MRI showed limited correlation with the severity of clinical symptoms and appeared to have relatively little prognostic value regarding the expected duration of recovery. Collectively, these findings support the concept that sprinting-type and stretching-type hamstring injuries represent distinct clinical entities with different mechanisms, anatomical involvement, and prognostic profiles. [11]

3. Diagnosis of Hamstring Injuries

Hamstring injuries typically present with the sudden onset of localized posterior thigh pain occurring during high-speed running, sprinting, or other activities involving rapid muscle elongation. A thorough clinical history is essential and should include information regarding previous episodes of similar injury as well as the patient's age, both of which are recognized risk factors for hamstring strains. Physical examination should include an assessment of muscle strength, range of motion of the lower extremity, and careful palpation to identify the precise location of maximal tenderness. These findings may provide an initial indication of whether the proximal tendinous structures are involved and, consequently, may offer valuable prognostic information regarding the expected time required for return to full athletic performance. Furthermore, they serve as an important reference point for monitoring recovery throughout the rehabilitation process.

Imaging studies may constitute an important component of the diagnostic process, with ultrasonography being one of the most commonly used modalities. Ultrasound can identify muscle edema, hematoma formation, and disruptions of normal muscle architecture following injury. For a more detailed assessment, magnetic resonance imaging (MRI) is frequently employed. In addition to detecting edema and hemorrhage, MRI enables precise evaluation of the injured tissues, including the exact location and extent of the lesion as well as the involvement of tendinous structures. These findings may provide useful prognostic information, particularly regarding tendon involvement and injury location, although imaging findings should always be interpreted in conjunction with the clinical presentation.

4. Physiological Mechanisms of Muscle Healing

4.1 Degenerative and Inflammatory Phase

Following muscle injury, the healing process begins with a degenerative phase, during which damaged portions of muscle fibers are removed. This phase is initiated by disruption of the cell membrane, intracellular calcium overload, disruption of cellular homeostasis, and subsequent myofiber necrosis. These events trigger an inflammatory response involving leukocytes, which are responsible for the phagocytosis of necrotic tissue and the release of inflammatory cytokines that facilitate the recruitment of additional cells to the site of injury. During the first hours following trauma, this process is mediated primarily by neutrophils, whereas macrophages subsequently become the predominant inflammatory cell population. Initially, the inflammatory response is dominated by M1 macrophages, which are responsible for the phagocytosis of necrotic tissue and the maintenance of a pro-inflammatory environment. Over time, these cells are gradually replaced by anti-inflammatory M2 macrophages, whose primary role is to stimulate satellite cell activation and muscle regeneration. M2 macrophages also secrete cytokines and growth factors that regulate tissue repair and remodeling, thereby maintaining a balance between muscle fiber regeneration and fibrotic processes. This balance limits excessive connective tissue deposition and pathological scar formation at the site of injury, ultimately reducing the risk of impaired muscle function and strength loss. Concurrently, several growth factors are released, including hepatocyte growth factor (HGF), fibroblast growth factor (FGF), and insulin-like growth factor 1 (IGF-1), thereby promoting the transition from the degenerative to the regenerative phase of muscle healing. [13,14,15]

4.2 Satellite Cells and Muscle Regeneration

Muscle regeneration is primarily enabled by the presence of satellite cells, which represent tissue-specific stem cells located between the sarcolemma and the basal lamina of skeletal muscle fibers. In response to the aforementioned signaling molecules, satellite cells become activated and undergo extensive proliferation. Their activation is accompanied by the up-regulation of the myogenic regulatory factors MyoD and Myf5, which play a central role in satellite cell proliferation and commitment to the myogenic lineage. A proportion of these cells subsequently differentiate into myoblasts, which migrate to the site of injury, where they fuse with one another to form multinucleated myotubes. These structures progressively mature into functional muscle fibers, thereby restoring the structural integrity of the damaged tissue. [13,14,15]

4.3 Angiogenesis and Tissue Remodeling

Simultaneously, angiogenesis occurs within the regenerating muscle, improving the delivery of oxygen and nutrients required for tissue repair. Upon completion of the regenerative process, a subset of activated stem cells returns to a quiescent state, re-establishing the satellite cell pool. This self-renewal capacity ensures the long-term maintenance of the muscle's regenerative potential and allows satellite cells to participate in future repair processes following subsequent injuries. The coordinated interaction between inflammatory cells, growth factors, satellite cells, and vascular remodeling ultimately determines the quality and efficiency of skeletal muscle regeneration following injury. [13,14,15]

5. Treatment of Hamstring Injuries

5.1 Current Standards of Treatment and Rehabilitation

Conventional treatment and rehabilitation protocols for hamstring injuries aim to restore the patient's pre-injury level of physical activity while minimizing the risk of recurrence. The high recurrence rate is thought to result from persistent deficits in eccentric muscle strength, reduced musculotendinous extensibility, and residual scar tissue formation following injury. Furthermore, strengthening of the quadriceps femoris muscle group, as well as the lumbopelvic stabilizing musculature, may contribute to reducing the likelihood of subsequent injury. The first days following injury are particularly important for pain management and for limiting excessive scar tissue formation, which may adversely affect the long-term functional properties of the injured muscle. During the initial phase of rehabilitation, exercises should be performed only within a pain-free range of motion Cryotherapy is frequently used during the acute phase of injury to reduce pain and facilitate early rehabilitation, although its influence on long-term healing remains uncertain. Rehabilitation remains the cornerstone of treatment and follows a progressive, milestone-based approach, allowing progression to subsequent stages only after specific functional goals have been achieved. Early rehabilitation focuses on activation of the stabilizing and postural musculature, together with low-intensity isometric exercises. Subsequent stages involve the gradual reactivation of the injured muscles through both progressive strengthening exercises and the controlled restoration of range of motion. The final phase of rehabilitation requires the implementation of sport-specific activities performed at maximal or near-maximal intensity, as well as exercises involving rapid acceleration, deceleration, and changes of direction. The primary objective of this stage is to prepare the athlete for a safe return to unrestricted sports participation while minimizing the risk of reinjury. Return-to-sport decisions should ideally be based on functional performance, restoration of strength, and the absence of pain rather than on time elapsed since injury alone. [13,16]

5.2 Platelet-Rich Plasma Therapy

Due to the high incidence of hamstring muscle injuries and their substantial impact on athletic performance, particularly among professional athletes, considerable efforts have been made to develop novel treatment strategies, many of which are based on biological therapies. One of the most extensively investigated approaches involves injections of platelet-rich plasma (PRP).

Owing to its high concentration of growth factors and bioactive molecules, PRP has attracted attention for its potential ability to stimulate satellite cell activation and enhance skeletal muscle regeneration, thereby shortening the time required for return to sport. [17,18,19]

However, the available evidence remains inconclusive. In 2014, Hamid et al. demonstrated a significant reduction in return-to-play time following a single PRP injection combined with a conventional rehabilitation program. In contrast, one year later, Reurink et al. conducted a double-blind randomized controlled trial in which participants received either two PRP injections or placebo injections containing sodium chloride solution. Their study failed to demonstrate any beneficial effect of PRP on recovery time or clinical outcomes. [17,18]

In 2024, Tollance et al. investigated the effects of platelet-rich plasma (PRP) on the population of skeletal muscle satellite cells. Their study focused primarily on the biological mechanisms underlying PRP activity and suggested that PRP may exert a beneficial effect on the long-term regenerative capacity of skeletal muscle. Exposure to PRP resulted in increased expression of Pax7, one of the most important molecular markers of muscle satellite cells, in the analyzed cell cultures. Furthermore, these cells demonstrated a greater tendency to remain in a quiescent state and exhibited delayed re-entry into the cell cycle following activation. Consequently, PRP contributed to the expansion of the pool of quiescent satellite cells, which may serve as a reserve population available for future regenerative processes. However, it should be emphasized that this study was conducted using in vitro cell cultures rather than human subjects, and therefore did not allow direct assessment of the clinical effects of PRP therapy on rehabilitation outcomes or return-to-sport time. [19]

These findings highlight the inconsistent evidence regarding the efficacy of platelet-rich plasma in the treatment of muscle injuries. Consequently, further well-designed studies are required to determine the precise role of PRP in skeletal muscle healing and to establish whether its use provides clinically meaningful benefits beyond those achieved with conventional rehabilitation alone. [17,18,19]

5.3 **Stem Cell-Based Therapies**

Given their central role in skeletal muscle regeneration, satellite cells have become an attractive target for regenerative therapies. For this reason, they have long attracted considerable interest as potential targets for therapies aimed at accelerating and improving muscle regeneration. However, most studies conducted to date remain at the preclinical stage. [20,21,22]

Dunn et al. confirmed the crucial role of satellite cells in the regeneration of damaged muscle fibers, while also highlighting the substantial challenges associated with translating this biological significance into targeted clinical therapies. Major obstacles include difficulties in harvesting sufficient numbers of cells, their limited survival during ex vivo expansion, inefficient migration and engraftment following intramuscular transplantation, and immune responses that may compromise the survival of transplanted cells. [21]

The authors also discussed another population of stem cells, namely mesenchymal stem cells (MSCs), which can be obtained from bone marrow. Unlike satellite cells, MSCs do not directly differentiate into mature muscle fibers. Instead, their therapeutic potential appears to be largely mediated through paracrine mechanisms. By secreting a variety of growth factors and signaling molecules, MSCs may reduce fibrosis, promote angiogenesis, and facilitate the recruitment and activity of endogenous satellite cells within the injured tissue. [20,21,22]

Despite the growing body of experimental evidence supporting these biological effects, the actual clinical impact of stem cell-based therapies on the treatment of muscle injuries has not yet been clearly established, and further clinical studies are required to determine their efficacy and safety. [20,21,22]

5.4 Biomaterials and Tissue Engineering Approaches

Biomaterials have emerged as a promising component of regenerative strategies for skeletal muscle injuries. Dunn et al. emphasized their potential role in skeletal muscle regeneration, particularly as scaffolds for tissue repair and as delivery systems for exogenous stem cells. Hydrogels and biological scaffolds composed primarily of collagen and fibrin have attracted considerable interest due to their ability to mimic the native extracellular matrix. These materials may promote satellite cell migration, enhance cell survival, and facilitate the controlled delivery of growth factors and other bioactive molecules to the site of injury. An additional potential advantage of these biomaterials is their ability to facilitate the integration of transplanted cells with host tissues. Although their clinical impact on muscle injury treatment remains largely undefined, the authors concluded that combining biomaterials with stem cell-based therapies and growth factor delivery may represent a promising strategy for future regenerative approaches. [21]

5.5 Exosome-Based Therapies

Exosomes have recently attracted considerable attention as potential cell-free regenerative therapies. These small extracellular vesicles are released by cells and mediate intercellular communication through the transport of proteins, lipids, RNA, and microRNA. Experimental studies conducted in cell culture models have demonstrated that exosomes may positively influence satellite cell activity, including their proliferation and regenerative potential. Wang et al. proposed that exosome-based therapies could represent a potential alternative to stem cell-based approaches. However, the clinical effects of exosomes remain largely unexplored and require further investigation. Nevertheless, current evidence suggests that exosomes may possess considerable therapeutic potential, both as a standalone treatment and in combination with other biological therapies described in the literature. Further research is also needed to determine whether exosome-based therapies could eventually replace stem cell therapies by providing comparable regenerative benefits while being associated with fewer complications and safety concerns. [23]

	Stem cells	**Exosomes**
Biological nature	Living cells	Cell-derived extracellular vesicles
Post-transplant survival	Limited	High
Immunogenicity	Potentially possible	Low
Risk of uncontrolled proliferation	Potentially possible	Minimal
Manufacturing and storage	Complex	Relatively straightforward

6. Conclusions

Hamstring injuries represent one of the most common musculoskeletal injuries encountered in sports, regardless of the level of athletic participation. Given the growing number of individuals engaging in physical activity and the increasing intensity of competitive sports, their clinical and socioeconomic significance is likely to continue to rise in the coming years. Despite the availability of well-established treatment protocols based primarily on appropriate load management and progressive rehabilitation, there is still a lack of therapeutic interventions with unequivocally proven efficacy in accelerating return to sport and full functional recovery.

Consequently, future research should focus on the development and evaluation of biological treatment strategies. Advances in the understanding of the cellular and molecular mechanisms underlying skeletal muscle regeneration have already provided valuable insights into the healing process and identified multiple potential therapeutic targets. Further elucidation of these pathways may enable the development of targeted interventions aimed at specific stages of muscle repair, ultimately improving the quality of tissue regeneration, reducing recovery time, and facilitating a safer and more efficient return to physical activity.

DISCLOSURES

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