applied sciences

MDPI

Review

Hamstrings on Morphological Structure Characteristics, Stress Features, and Risk of Injuries: A Narrative Review

Yinbin Shi [1,2], Gengsi Xi [1], Mengzi Sun [3], Yuliang Sun [2] and Li Li [4,*]

[1] College of Life Science, Shaanxi Normal University, Xi'an 710119, China
[2] School of Physical Education, Shaanxi Normal University, Xi'an 710119, China
[3] Biomechanics Laboratory, Beijing Sport University, Beijing 100084, China
[4] Department of Health Sciences and Kinesiology, Georgia Southern University, Statesboro, GA 30460, USA
* Correspondence: lili@georgiasouthern.edu

Abstract: Hamstring injury has been considered one of the most common exercise-induced injuries in sports. Hamstring injuries mostly occur proximal to the biceps femoris. However, the reasons and mechanisms remain unclear. To summarize hamstring morphological structure features and what the relationship is between their structure and risk of injury from the current literature, this review discussed the possible injury mechanism of hamstrings, from the morphological and connected pattern diversity, the mechanical properties, and the stress–strain performance, to probable changes in action control. Morphological and connected pattern diversity of hamstrings components show heterogeneous loads under muscle tension. Connections of gradient compliance between different tissues may lead to materials' susceptibility to detachments near the tendon–bone junction sites under heterogeneous load conditions. The hamstrings muscle's motor function insufficiency also brings the risk of injury when it performs multi-functional movements during exercise due to the span of multiple joints' anatomical characteristics. These structural features may be the primary reason why most damage occurs near these sites. The role of these biomechanical characteristics should be appreciated by exercise specialists to effectively prevent hamstring injuries. Future work in this research should be aimed at exploring the most effective prevention programs based on the material structure and motor control to enhance the properties of hamstring muscle materials to minimize the risk of injury.

Keywords: hamstrings; morphological structure; morphological diversity; stress features; manifestation of motor control

check for updates

Citation: Shi, Y.; Xi, G.; Sun, M.; Sun, Y.; Li, L. Hamstrings on Morphological Structure Characteristics, Stress Features, and Risk of Injuries: A Narrative Review. *Appl. Sci.* **2022**, *12*, 12713. https://doi.org/10.3390/app122412713

Academic Editors: Agnese Magnani and Alejandro Rodriguez Pascual

Received: 3 November 2022
Accepted: 9 December 2022
Published: 11 December 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Exercise-induced injuries frequently occur in sports. Hamstring injury is regarded as one of the most common and destructive damages due to the high incidence of the initial injury and frequent recurrence. Epidemiological investigations have shown that hamstring injury represents 37% of all muscle injuries [1]. It is common in competitive sports characterized by fast kicking and running [2,3], especially during non-contact sprinting activities, including gallops in ball games and sprints in track and field [1,3]. It also occurs in fitness exercises that involve extensive muscle lengthening-type maneuvers, such as yoga, and dancing [3,4]. Male athletes are 64% more likely to sustain an acute hamstring injury than female athletes [3,5]. These rates are similar in soccer, baseball, softball, and indoor track [6]. Injuries seriously affect athletes' performance in the arena, resulting in losing playing time, suffering from pain, and even threatening their professional career [7–10].

Hamstring injuries mostly occur proximal to the biceps femoris [3,11]. It has been reported that 57–72% of all hamstring injuries occur during sprinting. Nearly 94% of these injuries appear in the biceps femoris long head (BFLH) [12–16]. For example, in 17 subjects with single injuries or isolated re-injuries, 12 of these were injured on the proximal part [17].

This evidence supports the opinion that the biceps femoris is the major area of hamstring injuries and the injuries mostly occur in the proximal part of BFLH.

Researchers explored the underlying mechanism of hamstring injury through anatomical, kinematic, and kinetic analyses of sprinting [14,18–20]. The injury's timing, location and tissue involved are the discussions' foci due to the discordance of muscle–tendon length and force changes in leg swing progression throughout the gait cycle [15,21–24]. However, the reasons and mechanisms for why hamstring injuries tend to occur proximally remain unclear. In addition, injury details are equally unclear, e.g., parallel tearing, tissue becoming separated, misalignment of myofibrils, and others [25]. Thus, it is essential to explore further hamstring injuries.

To understand the reason that hamstring injuries tend to occur in the proximal area and explore the relationship between the part and injury from the current literature, this review focused on discussing proximal structural features of the hamstrings, from morphological and connected pattern diversity to the tissue's mechanical properties under different loadings. Are injuries related to the structural features of BFLH? What is the risk factor of injury to the BFLH when hamstrings perform multi-functional movements? Although the discussion is focused on injuries to the proximal part of hamstrings, we also attempt to provide suggestions to prevent hamstring injury for sports participants.

2. The Morphological Structure of Hamstrings

Biceps femoris, semitendinosus and semimembranosus are colloquially termed the "hamstrings" [26]. They are the main distributed muscle group in the posterior thigh (see Figure 1) [26,27]. Like other normal skeletal muscles, hamstrings are composed of muscle fibers, nerve and vessel networks, and extracellular matrix that connects the tissue [26,27].

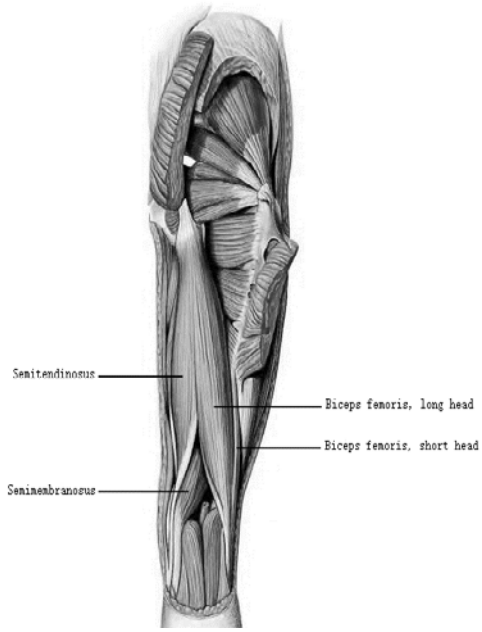


Figure 1. The posterior thigh muscles (with gluteus maximus and medius partially removed). Reprinted/adapted with permission from Ref [26]. Copyright 2016, Elsevier Health Sciences. (With a slight modified).

2.1. Morphological Diversity of the Tendons of Hamstrings

Detailed descriptions of the starting and ending points of the various components of the hamstrings can be learned in Standring's works [26]. Tendons of the hamstring components showed morphological diversity when they were attached to the upper and lower attachments, and each one has a unique shape [28,29], ranging from thin fascia shapes to long cord structures (see Figure 2) [28,30]. The long cord-like tendons prove advantageous

in compact structures for mechanical properties, transmitting a force quickly, and tensile properties [31]. The thin fascia-like structures of the tendons, also called aponeurosis, provide a roomy surface area. They is advantageous in dispersing force to quickly reduce the stress on the unit area [31]. Researchers indicated that this difference in shape results in different performances under muscle tension [32]. Using a three-dimensional model, they suggested that the aponeurosis morphology may play a role in determining stretch distribution on the hamstrings [32].

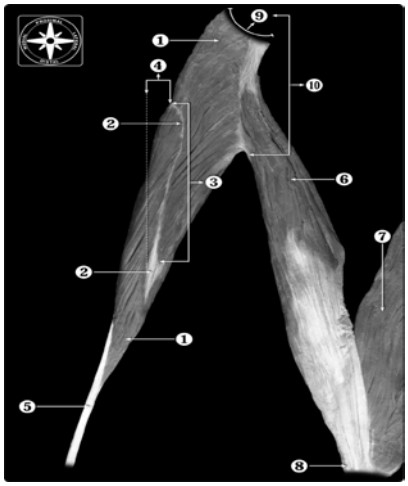


Figure 2. The morphological characteristics of the hamstrings (excluding semimembranosus). 1 Semitendinosus. 2 Raphe. 3 Length of the raphe (mean 9.0 cm). 4 Width of the raphe (3.0 cm maximum). 5 Semitendinosus tendon. 6 BFLH. 7 Short head of biceps femoris. 8 Biceps femoris tendon. 9 Ischial tuberosity. 10 Conjoint tendon (BFLH and semitendinosus). (Reprinted with permission from Ref. [33]. Copyright 2013, Springer.

Amazingly, parts in which the semitendinosus and the BFLH muscles form the common tendon show an apparent angle, similar to a pinnate angle. Its width is approximately divided into 2:1 [34], and a shift in the hip joint position changes the angle and length of the fascicle [35]. It was reported that the angle makes the muscle especially vulnerable to strain injuries during passive eccentric contractions (muscle contraction that occurs while the muscle is lengthening as it develops tension and contracts to control motion by an external force) [34]. In addition, the semitendinosus has a tendinous connective tissue in the spindle muscle belly, called raphe, running proximal to distal (see Figure 2) [33,36]. Whether this raphe strengthens the structure of the semitendinosus and thus protects it from injury is unclear, but this view has been suggested [33]. With abundant short unipennate and multi-pennate fibers, the number of muscle fibrils per unit area reaches its maximum in the semimembranosus [18].

2.2. Connected Pattern Diversity of Hamstring

Efficient interleaved fusion connection of muscle–tendon and tendon–bone is necessary to effectively transfer muscle force from muscle contraction to movement by pulling on the bone [29]. It is generally known that muscle, tendon, and bone exhibit dramatically distinct mechanical behavior [31,37,38]. At the level of tissue, tensile modulus of the tendon is on the order of 200 MPa in the direction of the muscle force. This results in easy bending when it is compressed [39]. In addition, tendons are tough and more extensible compared to bone and muscle [28,37]. Bone, however, has a modulus of 20 GPa in tension and compression, and it is hard and brittle versus tendon and muscle [29,38]. Muscle has approximately a modulus of 1 MPa in passive stretching, and it is more elastic and viscoelastic relative to tendon and bone [40]. An overview of the material properties of three kinds of tissue is presented in Table 1. Stress must be transferred among materials whose stiffness differs by two or more

orders of magnitude [29], as shown in the elastic modulus values in Table 1. Therefore, three kinds of different tissue elements among muscles, tendons, and bones are connected in series; the connected structure has to show specific structural characteristics in connection to transmit muscle force effectively and facilitate movement. Throughout musculoskeletal system assembly, both the muscle–tendon and tendon–bone attachment units form complex structures: the musculotendinous junction (MTJ) and entheses, respectively [29].

Table 1. Material properties at the level of tissue.

Tissue	Tensile Modulus	Material Properties
Bone	20 GPa (20,000 MPa)	Rigidity, hardness, toughness, extensible
Tendon	200 MPa	Tough, slightly elastic, flexible
Muscle	1 MPa	more elastic and viscoelastic

The musculotendinous junction, which connects muscles to the tendon, is mechanically and chemically coupled in its formation [9]. Reports from histological observations suggested that the muscle fibers are consecutively arranged, and end in a cone shape [41]. The membranes of terminal muscle fibers were deep invagination and formed finger-like processes with rich rugae [41]. The study of the human MTJ reported that the endotenon that wraps tendon collagen fibers is inserted into the deep recesses formed by muscle fiber membranes [42]. The myotendinous junction is formed with tendinous collagen fibers which are enclosed by the endotenon, which is bonded to muscle fibers near invaginated membrane by integrin, cohesive proteins, and fibronectin [42]. The finger-like processes with rich rugae between muscle fiber and tendon fiber implicate a greater surface area for connection; it was deemed to reduce the stresses of the tissue to some extent, and increase the load capacity of the MTJs [42,43].

In long cord-like tendons, distal of hamstrings, and proximal to the BFLH, each tendon fiber bundle is concentrated together by the endotenon and continues into the perimysium at the MTJs [38,44]. After leaving the musculotendinous junction, the collagen fibers in the endotenon align along the longitudinal axis of the tendon in a linear, spiral, or crossed fashion [31]. In comparison, the aponeuroses are fused with the tendon sheath's vascular mesangial or tendinous mesangial and covered with the tendon sheath to form a tendon with a dense structure [31]. At the concave side of the cross-joint action arc, there is often a tendinous sheath fiber pulley in the tendon to prevent the tendon from deflecting the center axis of motion when it contracts. It provides a greater range of motion and a more favorable torque [45].

In thin fascia-like tendons, such as the semimembranosus and the proximal part of biceps femoris short head, the proximal part of the tendon expands into an aponeurosis, which is inserted into the surface of muscle to form a junction on the side of the muscle, then directly enters the periosteum and attaches to the bone [26]. Therefore, these muscles are more wider and flatter than others [28].

While kinds of insertions exist between tendons and bones, for example, described as fibrous or fibrocartilaginous, indirect, or direct according to the character and mode of the tissue at the bone-tendon interface, the most common anatomical structure is the insertion of the tendon into the bone across a fibrocartilaginous transition by entheses [30,38]; this is a typical structural region of adult tendons. The enthesis is a site where the ligament, tendon, or muscle attaches to a bone. It is equipped with a unique and intricate structure, including the end of the tendon next to the bone, the transitional zone across which the tendon inserts into a bone, and the mineralized side of the attachment [29]. At the tendon–osseous junction, the collagenous fibers of endotenon enter the bone as perforating fibers and attach to the periosteum [44].

The entheses connect the tendon to bone through gradations of composition, structure, and mechanical properties as a specialized organ on the tendon-to-bone interface [46]. Starting at the subterminal of the tendon next to the bone, the zone shows tendon properties, such as aligned type I collagen fibers and proteoglycan decorin [46]. The transitional

zone where the tendon inserts into a bone comprises fibrocartilage. The fibrocartilage contains type II collagen, with a little bit of type I collagen. The extracellular matrix of the part contains type III collagen, decorin, and aggrecan [47–49]. At the mineralized zone of entheses, there is mineralized fibrocartilage, which includes type II and type X collagen, and aggrecan [46–49]. The entheses exhibit numerous types of shapes and sizes on bone surfaces under the effect of muscle tension [29]. This is important because the adaptive entheses can absorb a greater amount of energy by increasing local deformation at the interface. Related experiments exhibited measurable local strains above 7%. This deformation usually ensures that it is not broken between dissimilar materials, thus maintaining its integrity [39].

3. Transfer of Force among Muscles, Tendons, and Bone

3.1. The Transfer of Force between Muscle Fibers and Tendons

Muscle fibers and their innervation work together to achieve muscle contraction, whereas the extracellular matrix comprises the frameworks which bind the individual muscle fiber together [46]. The extracellular matrix forms a daedal and dynamic network that consists of collagens, non-collagenous glycoproteins, elastin, and proteoglycans [47], and laterally binds the individual element of muscle fibers together by three levels of sheaths: the epimysium (enveloping muscle), perimysium (enveloping muscle bundle), and endomysium (enveloping muscle fibers) [48,49]. At the end of the fibers, muscle is attached to its tendon, and the collagen fibrils of muscle and tendon fuse or interdigitate [47].

The endomysium structure by scanning electron microscopy and surface topology of the perimysium suggests that the shape and structure of the extracellular matrix of muscle are considerably intricate compared to the tendon [48]. A highly ordered extracellular matrix network surrounds individual muscle fibers and forms a load-bearing network [48]. Perimysium collagen fibers extend along and across muscle fibers. The lengthwise extension perimysium collagen fibers form a dense series of bands along muscle fibers, and transverse collagen fibers interconnect muscle fibers at discrete points. Epimysium is composed of abundant collagen bundles with a similarity to the structure seen in tendon [48]. The structure of the epimysium no longer resembles the network of endomysium and perimysium.

In addition, the muscle fibers are usually shorter than the bundle they are in, so the distance between the tendons of the two ends of the bundle must be crossed by several muscle fibers connected in series in sequence. In that case, a portion of the end of the epimysium and/or perimysium would have appeared as an extension of the tendon. It means that the extracellular matrix plays a key role in muscle fiber force conduction [48,50,51], because it aggregates the contraction of individual muscle fibers into a collaborative effect. That is to say, the longitudinal force produced by the tandem fibers and the transverse force between the bundles of fibers of different lengths is rapidly polymerized via shear forces and transmitted into the tendon by the extracellular matrix [48].

Although each muscle is an anatomical entity, it is not always a functional unit [52], especially in a complex such as the hamstrings. The different parts of muscles may have significantly different functions because muscle is made up of individual motor units comprised of muscle fibers [52]. The amount of muscle fiber controlled by a specific motor unit is the same under normal circumstances, but the amount of muscle fiber controlled by different motor units is different [31,52]. The muscle fibers in a particular motor unit always contract in the same way when they are working as a unit, more or less independently of the other motor units in the same muscle [52], such as the innervation of two separate nerves in different parts of the biceps femoris.

When different parts of a muscle perform different functions, or different motor units that are involved in the same function fail to synchronously coordinate, significant differences in tensions among fibers/bundles will cause a change of the internal conformation, i.e., tear damage will occur between the muscle fibers/bundles [31]. This type of injury occurs along the direction of the muscle fibers/bundles, a lengthwise direction or verge towards to tear in the clinical images [53].

Research had shown that the part which resembles a pinnate angle between the semitendinosus and the tendon of the long head of the biceps femoris is more frequently torn [54]. A laceration at the fusion of the short and long heads of the biceps femoris is another injury of the proximal hamstrings during the eccentric contraction of muscles. [18]. This type of injuries is thought to occur due to the differential contraction of the two muscles, which increases susceptibility to tearing [18]. To be specific, the BFLH is innervated by the tibial portion of the sciatic nerve, while the biceps femoris short head is innervated by the peroneal division [26]. The duality of innervation of the biceps femoris may lead it to be desynchronized in the coordination or intensity of stimulation of the two heads. This is deemed as a reason for the muscle being torn a lot [55]. In addition, the angles between the BFLH and the semitendinosus and between the BFLH and the short head of biceps femoris are also postulated as a cause for their susceptibility to be torn. The angles are formed due to the oblique trended distribution of the biceps femoris from the inside out and from the top down [18].

The intricate architecture of MTJ buffers the tensile stress exerted on tendons when muscles contract. However, MTJs are still regarded as the weakest part of the muscle–tendon unit [41]. It is reported that acute muscle strain caused by sudden eccentric contraction usually occurs at or near MTJs [56]. This kind of injury occurs almost perpendicular to the direction of the muscle fibers/bundles. Incomplete avulsion injury or root avulsion injury of the muscle from the tendon is exhibited in the clinical images [18]. In reality, though, the myotendinous junction is rarely injured [57]. It is reported that the MTJ is not a briefly involved area but a complex part of the transition from muscle to tendon, where myofibrils widely intersect with the tendon collagen fibers or ligamentous collagen fibers [36].

3.2. The Transfer of Force between Tendons and Bone

The attachment of tendons to the skeleton is unique to vertebrates [28]. The development of entheses is essential for musculoskeletal functionality, because they provide flexible, robust, and resilient anchor points for muscles, and transmit force by muscle generated to the skeleton [28]. Mineral content and collagen fiber orientation combine to provide the entheses a unique grading in mechanical properties [29]. The linear increase in accumulation of minerals on collagen fibers causes significant stiffening of the partially mineralized fibers, while expanding dispersion in the orientation distribution of collagen fibers from tendon to bone is another major determinant of tissue stiffness. Combining the two factors leads to be the non-monotonic variation of stiffness over the entheses [38]. When two materials with different physical properties and a compliant interface are exposed to external loads, they will display non-uniform deformation [39]. The incongruity in the deformation between the two parts will cause a stress singularity to arise locally; this will increase the risk of crack propagation and failure [39].

When the tendon is acted upon by the muscle force, the directionally distributed collagen fiber bundles show force compliance, rapidly following the direction of tension, transferring tension along the extremely tenacious tendon to the entheses [58]. During this process, tendons exhibit different rigidity due to the dependence on stress repetition and stress rate [31]. Specifically, the stress–strain curve of tendon tissue material will be offset to the right along the horizontal axis after being stretched repeatedly [59]. The tissues will exhibit a greater elasticity due to the certain plastic deformation of the tendon tissue [58]. It means that the tendon can store more energy when under high stress, and be used to buffer possible fractures by large strain [58]. Additionally, the slope of the linear part of the tendon stress–strain curve increases under an increasing load rate [59]. The tendon tissue shows greater stiffness under a greater load rate [31]. This means that tendons will exhibit brittleness rather than elasticity when they subjected to more sudden stresses. In this case, the tendon tissue may be broken due to stress concentration [31]. A rupture of the Achilles's tendon is a typical case of this type of injury. However, this rupture rarely occurs in hamstrings. This might be because of the flexibility of the muscle [6,60,61].

4. Possible Performance of Motor Control during Hamstrings Acute Strain

From the hamstring muscles' starting and ending position, one can observe that the semimembranosus, semitendinosus, and the biceps femoris long head are biarticular. They go across the hip joint and knee joint, and the biceps femoris short head is monoarticular; t spans just across the knee joint [9,62]. As essential muscles for hip joint extending and knee joint flexing in the gait cycle, the biarticular muscle groups of hamstrings have the weakness of insufficient movements, such as initiative power insufficiency or passive stretch insufficiency [63]. More specifically, the BFLH becomes a weaker flexor of the knee when the hip is extended and becomes a weaker extender of the hip when the knee is flexed.

During sprinting, athletes usually gain forward momentum by contacting the ground with the ball of the foot while the ankles are kept rigid [64]. After a quick forward swing, to gain stronger forward momentum, athletes commonly tend to be more proactive in completing the movement of touching the ground by pressing down quickly and swinging the leg backward [65]. The hamstring muscles are always active throughout the gait cycle; because of the need to swing and contact the ground, they quickly switch between eccentric and concentric contraction [66,67]. The sudden change in hamstrings' function between the rapid, steady flexion activity and extension has been postulated to cause acute injury [67,68]. This is almost consistent with the view of Orchard's team: they reported that increased rates of hamstring injuries on batting and fielding in short form (50-over and T20) in Australian Cricket may relate to changes in intensity of running speed [69].

Flexion of the knee is largely passive and the crus is in the state of a dependent swing as the open link of the movement chain of the lower limb during the thigh is swung forward [69,70]. When the knee joint is partially flexed, the biceps femoris rotates the leg slightly outward in consequence of its oblique direction, whereas the semitendinosus and partly semimembranosus rotate the leg slightly inward. At the end phase of the swing forward phase, the hamstrings incur the greatest stretch. They are actively, eccentrically contracting to decelerate the lower limb and prepare for contacting the ground [19]. A kinetic study indicates that peak lengths were significantly larger in the biceps femoris than the semitendinosus and semimembranosus due to different moment arms in the hamstrings muscles because of their diversified shape and position [71]. It may be easy to cause hamstring strain if active knee extension occurs at this moment due to the situation mentioned above. This kind of case commonly happens when a soccer player is running at high speed with the ball or a tackle [72]. In a systematic review [24], three studies also reported such injuries [73,74].

The backward swing process of the thigh, with the stance status as the critical point, can be divided into two stages: before and after striking the ground [26]. At the end phase of the swing forward, the hamstring muscles are passively elongated due to eccentric contraction, then begin to play the role of the hip extensor and perform concentric contraction [75,76]. To actively contact the ground, the hamstrings actively contracted to pull down the leg quickly, making it swing backward. At this phase, the arch of the foot, ankle joint, and knee joint are highly tense and stable to prepare the body for coping with the impact of the ball of the foot striking the ground [70,77]. In this process, a hamstring injury is rarely seen due to the active shortening of the hamstring by concentric contraction, but joint ligament injury caused by weak stability of the knee and ankle joints is common [78]. During a swing backward after striking the ground, the knee joint is flexed quickly, and the leg is folded rapidly close to the thigh and hip when the hamstrings, especially the biceps femoris short head, continued to contract [79]. At the end phase of the swing backward, the hip is fully extended and the knee is flexed in preparation for the swing forward [70]. When hamstrings are quickly switched from concentric to eccentric contraction during sprinting, if the knee is to be stretched and the thigh is to be started to swing forward, it is very easy to cause the hamstrings to strain due to sudden eccentric contraction. This kind of injury usually occurs during the sudden acceleration in the thrust phase [80].

The two cases of action mentioned above, such as significantly greater anterior pelvic tilt or thoracic lateral flexion, both contain the sudden appearance or persistence of mis-

takes or abnormalities in action, and were deemed as an irrefutable factor contributing to the injury and re-injury [81–83]. However, this viewpoint is subject to be supported by experimental evidence. Differences in the functional demands of the hamstring muscles during acceleration and swing at maximum speed are also risk factors [84–86].

5. Differential Diagnosis

5.1. Typical Symptoms of Hamstring Strain Injuries

At present, there is no completely unified consensus on the definitions and classifications for muscle injuries [87,88]. The Munich Consensus Statement may be known as a highly comprehensive guideline for studying muscle injury [57,87]. The approach of the Munich Consensus Statement deals with muscle injuries in a comprehensive manner, which covers the incorporation of acute, overuse, direct, and indirect injury descriptors [57]. Usually, it is not difficult to classify one as an acute injury or overuse injury based on its onset process and pathological features. An acute muscle injury in sport is characterized as a closed trauma with a clearly defined cause or sudden occurrence. The stresses and strains generated by force applied to tissue are greater than the tissue can withstand [89]. Either internal forces cause the macro-trauma of the tissue as tensile ruptures (strains/laceration) or by external forces from direct contacts, such as by contusions by collision [9,89]. Non-contact acute muscle injury caused by excessive internal tension usually manifests as muscle fibers tear/rupture [90]. Injuries mostly occur in muscles that suffer from high active and passive tensions, which cause muscle fibers and their surrounding connective tissue to be damaged. Researchers considered that explosive and paroxysmal active tension is produced by the muscle contracting strongly instantly. And passive tension is caused by a stretch of the connective tissue elements between different muscle fibers [91].

The most severe acute injury of hamstrings is avulsion, which usually involves the entheses in adults. This injury pattern occurs more commonly at the ischial tuberosity than at the distal ligamentous insertion [18]. In such a case, avulsion almost always involves the conjoint tendon, such as the biceps femoris and semitendinosus muscles. It often results in either complete or incomplete tearing of the semimembranosus due to retraction of the avulsion parts. This is the most common form of proximal avulsion [18]. Oblique coronal magnetic resonance imaging demonstrates a large hematoma, usually accompanied by retraction of the semitendinosus muscle and the long head of the biceps femoris tendon [24]. It is reported that avulsion usually occurs in the setting of prior or chronic injury, with abnormal entheses morphologic features or degeneration being the most likely predisposing factors [18].

Overuse injuries are caused by repetitive microtrauma to tissue, usually accompanied by progressively increasing pain [92]. An overuse injury is often associated with underlying pathology which is accumulated by a long-term inappropriate load. Our study will not elaborate on it in detail due to its complex pathology. As knowledge of hamstring injuries continues to grow, researchers suggested that not all hamstring injuries are the same [93]. For instance, the stretch type of muscle fibers injury and the injuries involving the tendon are totally different in hamstrings.

5.2. Grade of Hamstring Strain Injury

Appropriately classifying hamstring injuries is necessary to develop treatment strategies, predicting prognosis, and determining the readiness for return to play, which is maybe the most important, [7]. For classification of injury severity, the modification of Peetrons classification [12,94] was used, and the grading system is as follows: Grade 0—negative MRI without any visible pathology; Grade 1—edema, but no architectural structure distortion, and this kind of symptom commonly occurs in overuse hamstring injury; Grade 2—architectural structure disruption indicating partial tear; Grade 3—total muscle or tendon rupture, the two kinds of symptom commonly appearing in acute hamstring strain injury, including hamstring tendon avulsions, ischial epiphyseal avulsions, proximal tendinopathies of hamstring, and associated severe pain in the back of the thigh [9,12].

For the severity of the injury, in the 180 cases with some muscle pathology visible on MRI (Grades 1–3), 151 (84%) affected the biceps femoris, while 20 (11%) occurred in the semimembranosus and 9 (5%) in the semitendinosus [12]. In another five-year follow-up study with 207 injuries, 27 (13%) were of Grade 0, 118 (57%) were of Grade 1, 56 (27%) were of Grade 2, and 6 (3%) were of Grade 3 [12]. These studies demonstrated that Grade 1 and 2 injuries are the most common, while Grade 3 injuries are relatively rare.

Therefore, studying the structure of hamstrings, especially BFLH, and its mechanics during sprinting can help us to further understand the potential injury risk factors. It is needed for the effective prevention of hamstring injury and the improvement of rehabilitation.

6. Risk Factors and Prevention for Hamstring Injury

Combined with the above description of the morphology and structure of the hamstring autogenous tissue materials and the analysis of the performance of motor control in sprinting, the sudden or persistent of mistakes or abnormal movements during sprints are a major external risk factor for hamstring injuries; they lead to non-compliant changes in the direction of the force and the destruction of the material structure. Differences in the functional demands of the hamstring muscles during acceleration and swing at maximum speed are also risk factors. The differences may come from asynchrony in the coordination or intensity of stimulation. Structural differences caused by morphological diversity and different tissue elements are also potential risk factors. This difference is due to different loads during musculoskeletal phylogenetic assembly.

Prevention of a first-time hamstring injury is important due to the frequent recurrence and considerable impairment. Therefore, further research is needed to specifically define the most effective prevention programs based on the material structure and motor control of hamstrings in sprinting. For example, the results from the meta-analysis suggested that the Nordic Hamstring Exercises were effective in reducing the incidence of hamstring injury; the teams using the Nordic Hamstring Exercise in isolation or as part of a larger injury prevention program reduced hamstring injury rates by up to 51% [86]. Results from another case series supported the incidence of hamstring injury decreased by using of isokinetic strengthening exercises or adding agility and flexibility into strength training [95].

In addition, the influence and interaction of hamstring strength, flexibility, fatigue, and age are also etiological factors. They should be addressed to prevent hamstrings injury [85].

7. Review Limitations

The major limitations of the present study include the following two aspects: First, it only describes the diversity of the material morphology of the hamstrings, without analyzing the source of the morphological difference of the same structure among different individuals and the possible influence on injury; Second, the performance of motor control in sprinting was only investigated during the swing phase, but not in the contact stage. Although the detail obtained during the swing phase helps the understanding of the performance of movement, investigation of limb's work and power during the contact phase provides a deeper understanding of accelerated locomotion. Therefore, they are directions for future investigation.

8. Conclusions

Hamstring injury is the most common and destructive damage due to the high incidence of the initial injury and frequent recurrence. Mostly hamstring injuries are acute injuries and appear in the biceps femoris. This is closely related to the diverse shapes of the components in the hamstrings and their tendons. The difference in shape brings them different stress statuses during rapid muscle contraction. The intricate connection of gradient compliance between tissue materials with different mechanical properties leads to the susceptibility of materials to detach near the junction sites under sudden stress conditions, which is perhaps the primary reason most damage occurs near these sites. This opinion holds truth for all materials after the elastic state. Due to the anatomical characteristics that

span multiple joints, the insufficiency of the motor function of the hamstring muscle also brings the risk of injury when performing multi-functional movements during exercise. It hints that the leg should strictly avoid unnecessary overextension during the swing and make sure to maintain the proper hip angle and knee angle during the swing. In future research, therefore, the more detailed understanding of the motor function performance, the exact location, and the specific morphology of hamstrings when the injury occurs via detailed experiments, the more conducive to understanding the mechanism of the injury; this will be helpful to propose targeted prevention strategies for hamstring injuries.

Author Contributions: Conceptualization, Y.S. (Yinbin Shi) and L.L.; methodology, software, literatures collected, Y.S. (Yinbin Shi) and M.S.; validation, G.X. and Y.S. (Yuliang Sun); writing original draft preparation, Y.S. (Yinbin Shi); writing review and editing, M.S. and Y.S. (Yuliang Sun); visualization, G.X.; supervision, L.L.; funding acquisition, Y.S. (Yinbin Shi). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [a state scholarship fund of the China Scholarship Council], grant number [201810038]. It was also partly supported by [the sport regular subject fund of Shaanxi Provincial Bureau], grant number [20180523]. And The APC was partly funded by [201810038].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: We should choose to exclude this statement because the study did not report any data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ekstrand, J.; Hägglund, M.; Waldén, M. Epidemiology of muscle injuries in professional football (soccer). *Am. J. Sport. Med.* **2011**, *39*, 1226–1232. [CrossRef] [PubMed]
2. Dalton, S.L.; Kerr, Z.Y.; Dompier, T.P. Epidemiology of hamstring strains in 25 NCAA sports in the 2009–2010 to 2013–2014 academic years. *Am. J. Sport. Med.* **2015**, *43*, 2671–2679. [CrossRef] [PubMed]
3. Erickson, L.N.; Sherry, M.A. Rehabilitation and return to sport after hamstring strain injury. *J. Sport Health Sci.* **2017**, *6*, 262–270. [CrossRef]
4. Sherry, M. Examination and treatment of hamstring related injuries. *Sport. Health* **2012**, *4*, 107–114. [CrossRef] [PubMed]
5. Opar, D.A.; Drezner, J.; Shield, A.; Williams, M.; Webner, D.; Sennett, B.; Kapur, R.; Cohen, M.; Ulager, J.; Cafengiu, A. Acute hamstring strain injury in track-and-field athletes: A 3-year observational study at the P enn R elay C arnival. *Scand. J. Med. Sci. Sport.* **2014**, *24*, e254–e259. [CrossRef]
6. Wan, X.L.; Qu, F.; Garrett, W.E.; Liu, H.; Yu, B. Relationships among hamstring muscle optimal length and hamstring flexibility and strength. *J. Sport Health Sci.* **2017**, *6*, 275–282. [CrossRef]
7. Yu, B.; Li, L. Research in prevention and rehabilitation of hamstring muscle strain injury. *J. Sport Health Sci.* **2017**, *6*, 253. [CrossRef]
8. Wan, X.; Qu, F.; Garrett, W.E.; Liu, H.; Yu, B. The effect of hamstring flexibility on peak hamstring muscle strain in sprinting. *J. Sport Health Sci.* **2017**, *6*, 283–289. [CrossRef]
9. Wangensteen, A. Acute Hamstring Injuries: Diagnosis and Prognosis. Ph.D. Thesis. 2018. Available online: https://ostrc.no/globalas-sets/publications/phd-thesis/wangensteen_2018_phd-thesis.pdf (accessed on 2 September 2022).
10. Schroeter, S.; Heiss, R.; Hammer, C.M.; Grim, C.; Engelhardt, M.; Hotfiel, T. Diagnosis of Proximal Hamstring Injuries. *Sport. Orthop. Traumatol.* **2022**, *38*, 47–57. [CrossRef]
11. Jokela, A.; Stenroos, A.; Kosola, J.; Valle, X.; Lempainen, L. A systematic review of surgical intervention in the treatment of hamstring tendon ruptures: Current evidence on the impact on patient outcomes. *Ann. Med.* **2022**, *54*, 978–988. [CrossRef]
12. Ekstrand, J.; Healy, J.C.; Waldén, M.; Lee, J.C.; English, B.; Hägglund, M. Hamstring muscle injuries in professional football: The correlation of MRI findings with return to play. *Br. J. Sport. Med.* **2012**, *46*, 112–117. [CrossRef] [PubMed]
13. Askling, C.M.; Tengvar, M.; Thorstensson, A. Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br. J. Sport. Med.* **2013**, *47*, 953–959. [CrossRef]
14. Kenneally-Dabrowski, C.J.; Brown, N.A.; Lai, A.K.; Perriman, D.; Spratford, W.; Serpell, B.G. Late swing or early stance? A narrative review of hamstring injury mechanisms during high-speed running. *Scand. J. Med. Sci. Sport.* **2019**, *29*, 1083–1091. [CrossRef] [PubMed]
15. Grange, S.; Reurink, G.; Nguyen, A.Q.; Riviera-Navarro, C.; Foschia, C.; Croisille, P.; Edouard, P. Location of Hamstring Injuries Based on Magnetic Resonance Imaging: A Systematic Review. *Sport. Health* **2022**, *14*, 1–13. [CrossRef] [PubMed]
16. Miyamoto, N.; Hirata, K. Site-specific features of active muscle stiffness and proximal aponeurosis strain in biceps femoris long head. *Scand J. Med. Sci. Sport.* **2021**, *31*, 1666–1673. [CrossRef]

17. Silder, A.; Thelen, D.G.; Heiderscheit, B.C. Effects of prior hamstring strain injury on strength, flexibility, and running mechanics. *Clin. Biomech.* **2010**, *25*, 681–686. [CrossRef]
18. Koulouris, G.; Connell, D. Hamstring muscle complex: An imaging review. *Radiographics* **2005**, *25*, 571–586. [CrossRef]
19. Chumanov, E.S.; Heiderscheit, B.C.; Thelen, D.G. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Med. Sci. Sport. Exerc.* **2011**, *43*, 525–532. [CrossRef]
20. Sun, Y.; Wei, S.; Zhong, Y.; Fu, W.; Li, L.; Liu, Y. How joint torques affect hamstring injury risk in sprinting swing–stance transition. *Med. Sci. Sport. Exerc.* **2015**, *47*, 373. [CrossRef]
21. Schache, A.G.; Brown, N.A.; Pandy, M.G. Modulation of work and power by the human lower-limb joints with increasing steady-state locomotion speed. *J. Exp. Biol.* **2015**, *218*, 2472–2481. [CrossRef]
22. Nagahara, R.; Matsubayashi, T.; Matsuo, A.; Zushi, K. Alteration of swing leg work and power during human accelerated sprinting. *Biol. Open* **2017**, *6*, 633–641. [CrossRef]
23. Liu, Y.; Sun, Y.; Zhu, W.; Yu, J. The late swing and early stance of sprinting are most hazardous for hamstring injuries. *J. Sport Health Sci.* **2017**, *6*, 133. [CrossRef]
24. Danielsson, A.; Horvath, A.; Senorski, C.; Alentorn-Geli, E.; Garrett, W.E.; Cugat, R.; Samuelsson, K.; Hamrin Senorski, E. The mechanism of hamstring injuries—A systematic review. *BMC Musculoskelet. Disord.* **2020**, *21*, 641. [CrossRef]
25. Li, L.; Wang, D. Parallel and cross-sectional hamstring injuries in sprint running. *J. Sport Health Sci.* **2017**, *6*, 141. [CrossRef]
26. Standring, S. *Gray's Anatomy E-Book: The Anatomical Basis of Clinical Practice*, 41st ed.; Elsevier Health Sciences: Amsterdam, The Netherlands, 2016.
27. Huard, J.; Li, Y.; Fu, F.H. Muscle injuries and repair: Current trends in research. *JBJS* **2002**, *84*, 822–832. [CrossRef]
28. Schweitzer, R.; Zelzer, E.; Volk, T. Connecting muscles to tendons: Tendons and musculoskeletal development in flies and vertebrates. *Development* **2010**, *137*, 2807–2817. [CrossRef]
29. Zelzer, E.; Blitz, E.; Killian, M.L.; Thomopoulos, S. Tendon-to-bone attachment: From development to maturity. *Birth Defects Res. C Embryo Today* **2014**, *102*, 101–112. [CrossRef]
30. Benjamin, M.; Toumi, H.; Ralphs, J.; Bydder, G.; Best, T.; Milz, S. Where tendons and ligaments meet bone: Attachment sites ('entheses') in relation to exercise and/or mechanical load. *J. Anat.* **2006**, *208*, 471–490. [CrossRef]
31. Nordin, M.; Frankel, V.H. *Basic Biomechanics of the Musculoskeletal System*; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2001.
32. Rehorn, M.R.; Blemker, S.S. The effects of aponeurosis geometry on strain injury susceptibility explored with a 3D muscle model. *J. Biomech.* **2010**, *43*, 2574–2581. [CrossRef]
33. van der Made, A.D.; Wieldraaijer, T.; Kerkhoffs, G.; Kleipool, R.; Engebretsen, L.; Van Dijk, C.; Golanó, P. The hamstring muscle complex. *Knee Surg. Sport. Traumatol. Arthrosc.* **2015**, *23*, 2115–2122. [CrossRef]
34. Battermann, N.; Appell, H.-J.; Dargel, J.; Koebke, J. An anatomical study of the proximal hamstring muscle complex to elucidate muscle strains in this region. *Int. J. Sport. Med.* **2011**, *32*, 211–215. [CrossRef] [PubMed]
35. Chleboun, G.S.; France, A.R.; Crill, M.T.; Braddock, H.K.; Howell, J.N. In vivo measurement of fascicle length and pennation angle of the human biceps femoris muscle. *Cells Tissues Organs* **2001**, *169*, 401–409. [CrossRef] [PubMed]
36. Garrett Jr, W.E.; Rich, F.R.; Nikolaou, P.K.; Vogler, J. Computed tomography of hamstring muscle strains. *Med. Sci. Sport. Exerc.* **1989**, *21*, 506–514. [CrossRef]
37. Thomopoulos, S.; Marquez, J.P.; Weinberger, B.; Birman, V.; Genin, G.M. Collagen fiber orientation at the tendon to bone insertion and its influence on stress concentrations. *J. Biomech.* **2006**, *39*, 1842–1851. [CrossRef]
38. Thomopoulos, S.; Genin, G.M.; Galatz, L.M. The development and morphogenesis of the tendon-to-bone insertion—What development can teach us about healing. *J. Musculoskelet. Neuronal Interact.* **2010**, *10*, 35–45.
39. Deymier, A.C.; An, Y.; Boyle, J.J.; Schwartz, A.G.; Birman, V.; Genin, G.M.; Thomopoulos, S.; Barber, A.H. Micro-mechanical properties of the tendon-to-bone attachment. *Acta Biomater.* **2017**, *56*, 25–35. [CrossRef]
40. Lin, S.; Liu, J.; Liu, X.; Zhao, X. Muscle-like fatigue-resistant hydrogels by mechanical training. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 10244–10249. [CrossRef]
41. Sharma, P.; Maffulli, N. Biology of tendon injury: Healing, modeling and remodeling. *J. Musculoskelet. Neuronal Interact.* **2006**, *6*, 181.
42. Knudsen, A.B.; Larsen, M.; Mackey, A.L.; Hjort, M.; Hansen, K.K.; Qvortrup, K.; Kjaer, M.; Krogsgaard, M.R. The human myotendinous junction: An ultrastructural and 3D analysis study. *Scand. J. Med. Sci. Sport.* **2015**, *25*, e116–e123. [CrossRef]
43. Jakobsen, J.R.; Krogsgaard, M.R. The Myotendinous Junction-A Vulnerable Companion in Sports. A Narrative Review. *Front. Physiol.* **2021**, *12*, 635561. [CrossRef]
44. Woo, S.L.Y.; Buckwalter, J.A. Injury and repair of the musculoskeletal soft tissues. Savannah, Georgia, 18–20 June 1987. *J. Orthop. Res.* **1988**, *6*, 907–931. [CrossRef]
45. Gnanasekaran, D.; Veeramani, R.; Karuppusamy, A. Morphometric study of pulleys of the thumb. *Anat. Cell Biol.* **2018**, *51*, 71–78. [CrossRef]
46. Jarvinen, T.A.; Jarvinen, T.L.; Kaariainen, M.; Kalimo, H.; Jarvinen, M. Muscle injuries: Biology and treatment. *Am. J. Sport. Med.* **2005**, *33*, 745–764. [CrossRef]
47. Takala, T.E.; Virtanen, P. Biochemical composition of muscle extracellular matrix: The effect of loading. *Scand. J. Med. Sci. Sport.* **2000**, *10*, 321–325. [CrossRef]
48. Gillies, A.R.; Lieber, R.L. Structure and function of the skeletal muscle extracellular matrix. *Muscle Nerve* **2011**, *44*, 318–331. [CrossRef]

49. Wisdom, K.M.; Delp, S.L.; Kuhl, E. Use it or lose it: Multiscale skeletal muscle adaptation to mechanical stimuli. *Biomech. Model. Mechanobiol.* **2015**, *14*, 195–215. [CrossRef]
50. Thomopoulos, S.; Williams, G.R.; Gimbel, J.A.; Favata, M.; Soslowsky, L.J. Variation of biomechanical, structural, and compositional properties along the tendon to bone insertion site. *J. Orthop. Res.* **2003**, *21*, 413–419. [CrossRef]
51. Lieber, R.L.; Ward, S.R. Cellular mechanisms of tissue fibrosis. 4. Structural and functional consequences of skeletal muscle fibrosis. *Am. J. Physiol. -Cell Physiol.* **2013**, *305*, C241–C252. [CrossRef]
52. Kernell, D. Muscle regionalization. *Can. J. Appl. Physiol.* **1998**, *23*, 1–22. [CrossRef]
53. Schneider-Kolsky, M.E.; Hoving, J.L.; Warren, P.; Connell, D.A. A comparison between clinical assessment and magnetic resonance imaging of acute hamstring injuries. *Am. J. Sport. Med.* **2006**, *34*, 1008–1015. [CrossRef]
54. Verrall, G.M.; Slavotinek, J.P.; Barnes, P.G.; Fon, G.T. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: Comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. *Am. J. Sport. Med.* **2003**, *31*, 969–973. [CrossRef] [PubMed]
55. Koulouris, G.; Connell, D. Evaluation of the hamstring muscle complex following acute injury. *Skelet. Radiol.* **2003**, *32*, 582–589. [CrossRef] [PubMed]
56. Tidball, J.G. Mechanisms of muscle injury, repair, and regeneration. *Compr. Physiol.* **2011**, *1*, 2029–2062. [PubMed]
57. Hamilton, B.; Alonso, J.M.; Best, T.M. Time for a paradigm shift in the classification of muscle injuries. *J. Sport Health Sci.* **2017**, *6*, 255–261. [CrossRef] [PubMed]
58. Smith, L.; Xia, Y.; Galatz, L.M.; Genin, G.M.; Thomopoulos, S. Tissue-engineering strategies for the tendon/ligament-to-bone insertion. *Connect. Tissue Res.* **2012**, *53*, 95–105. [CrossRef] [PubMed]
59. Ruan, M.F.; Li, L.; Chen, C.; Wu, X. Stretch Could Reduce Hamstring Injury Risk during Sprinting by Right Shifting the Length-Torque Curve. *J. Strength Cond. Res.* **2018**, *32*, 2190–2198. [CrossRef]
60. Egger, A.C.; Berkowitz, M.J. Achilles tendon injuries. *Curr. Rev. Musculoskelet. Med.* **2017**, *10*, 72–80. [CrossRef]
61. Kuske, B.; Hamilton, D.F.; Pattle, S.B.; Simpson, A.H. Patterns of Hamstring Muscle Tears in the General Population: A Systematic Review. *PLoS ONE* **2016**, *11*, e0152855. [CrossRef]
62. Woodley, S.J.; Mercer, S.R. Hamstring muscles: Architecture and innervation. *Cells Tissues Organs* **2005**, *179*, 125–141. [CrossRef]
63. Beltran, L.; Ghazikhanian, V.; Padron, M.; Beltran, J. The proximal hamstring muscle-tendon-bone unit: A review of the normal anatomy, biomechanics, and pathophysiology. *Eur. J. Radiol.* **2012**, *81*, 3772–3779. [CrossRef]
64. Lieberman, D.E.; Venkadesan, M.; Werbel, W.A.; Daoud, A.I.; D'Andrea, S.; Davis, I.S.; Mang'eni, R.O.; Pitsiladis, Y. Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature* **2010**, *463*, 531–535. [CrossRef]
65. Macadam, P.; Cronin, J.B.; Uthoff, A.M.; Johnston, M.; Knicker, A.J. Role of Arm Mechanics During Sprint Running: A Review of the Literature and Practical Applications. *Strength Cond. J.* **2018**, *40*, 14–23. [CrossRef]
66. Degen, R.M. Proximal Hamstring Injuries: Management of Tendinopathy and Avulsion Injuries. *Curr. Rev. Musculoskelet. Med.* **2019**, *12*, 138–146. [CrossRef]
67. van Beijsterveldt, A.M.; van de Port, I.G.; Vereijken, A.J.; Backx, F.J. Risk factors for hamstring injuries in male soccer players: A systematic review of prospective studies. *Scand. J. Med. Sci. Sport.* **2013**, *23*, 253–262. [CrossRef]
68. Martin, R.L.; Cibulka, M.T.; Bolgla, L.A.; Koc, T.A., Jr.; Loudon, J.K.; Manske, R.C.; Weiss, L.; Christoforetti, J.J.; Heiderscheit, B.C. Hamstring Strain Injury in Athletes. *J. Orthop. Sport. Phys. Ther.* **2022**, *52*, CPG1–CPG44. [CrossRef]
69. Orchard, J.W. Hamstrings are most susceptible to injury during the early stance phase of sprinting. *Br. J. Sport. Med.* **2012**, *46*, 88–89. [CrossRef]
70. Arnold, A.S.; Thelen, D.G.; Schwartz, M.H.; Anderson, F.C.; Delp, S.L. Muscular coordination of knee motion during the terminal-swing phase of normal gait. *J. Biomech.* **2007**, *40*, 3314–3324. [CrossRef]
71. Thelen, D.G.; Chumanov, E.S.; Hoerth, D.M.; Best, T.M.; Swanson, S.C.; Li, L.; Young, M.; Heiderscheit, B.C. Hamstring muscle kinematics during treadmill sprinting. *Med. Sci. Sport. Exerc.* **2005**, *37*, 108–114. [CrossRef]
72. Chu, S.K.; Rho, M.E. Hamstring injuries in the athlete: Diagnosis, treatment, and return to play. *Curr. Sport. Med. Rep.* **2016**, *15*, 184. [CrossRef]
73. Askling, C.M.; Tengvar, M.; Saartok, T.; Thorstensson, A. Proximal hamstring strains of stretching type in different sports: Injury situations, clinical and magnetic resonance imaging characteristics, and return to sport. *Am. J. Sport. Med.* **2008**, *36*, 1799–1804. [CrossRef]
74. Askling, C.M.; Tengvar, M.; Saartok, T.; Thorstensson, A. Acute first-time hamstring strains during slow-speed stretching: Clinical, magnetic resonance imaging, and recovery characteristics. *Am. J. Sport. Med.* **2007**, *35*, 1716–1724. [CrossRef] [PubMed]
75. Guex, K.; Gojanovic, B.; Millet, G.P. Influence of hip-flexion angle on hamstrings isokinetic activity in sprinters. *J. Athl. Train.* **2012**, *47*, 390–395. [CrossRef] [PubMed]
76. Schmitt, B.; Tim, T.; McHugh, M. Hamstring injury rehabilitation and prevention of reinjury using lengthened state eccentric training: A new concept. *Int. J. Sport. Phys. Ther.* **2012**, *7*, 333.
77. Chinn, L.; Hertel, J. Rehabilitation of ankle and foot injuries in athletes. *Clin. Sport. Med.* **2010**, *29*, 157. [CrossRef] [PubMed]
78. Kaminski, T.W.; Hartsell, H.D. Factors contributing to chronic ankle instability: A strength perspective. *J. Athl. Train.* **2002**, *37*, 394. [PubMed]
79. Schache, A.G.; Dorn, T.W.; Blanch, P.D.; Brown, N.A.; Pandy, M.G. Mechanics of the human hamstring muscles during sprinting. *Med. Sci. Sport. Exerc.* **2012**, *44*, 647–658. [CrossRef]

80. Morin, J.B.; Gimenez, P.; Edouard, P.; Arnal, P.; Jimenez-Reyes, P.; Samozino, P.; Brughelli, M.; Mendiguchia, J. Sprint Acceleration Mechanics: The Major Role of Hamstrings in Horizontal Force Production. *Front. Physiol.* **2015**, *6*, 404. [CrossRef] [PubMed]
81. Croisier, J.-L. Factors associated with recurrent hamstring injuries. *Sport. Med.* **2004**, *34*, 681–695. [CrossRef]
82. Kalema, R.N.; Duhig, S.J.; Williams, M.D.; Donaldson, A.; Shield, A.J. Sprinting technique and hamstring strain injuries: A concept mapping study. *J. Sci. Med. Sport* **2022**, *25*, 209–215. [CrossRef]
83. Kalema, R.N.; Schache, A.G.; Williams, M.D.; Heiderscheit, B.; Siqueira Trajano, G.; Shield, A.J. Sprinting Biomechanics and Hamstring Injuries: Is There a Link? A Literature Review. *Sports* **2021**, *9*, 141. [CrossRef]
84. Milanese, S.; Eston, R. Hamstring injuries and Australian Rules football: Over-reliance on Nordic hamstring exercises as a preventive measure? *Open Access J. Sport. Med.* **2019**, *10*, 99. [CrossRef] [PubMed]
85. Green, B.; Bourne, M.N.; van Dyk, N.; Pizzari, T. Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *Br. J. Sport. Med.* **2020**, *54*, 1081–1088. [CrossRef] [PubMed]
86. van Dyk, N.; Behan, F.P.; Whiteley, R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: A systematic review and meta-analysis of 8459 athletes. *Br. J. Sport. Med.* **2019**, *53*, 1362–1370. [CrossRef]
87. Mueller-Wohlfahrt, H.W.; Haensel, L.; Mithoefer, K.; Ekstrand, J.; English, B.; McNally, S.; Orchard, J.; van Dijk, C.N.; Kerkhoffs, G.M.; Schamasch, P.; et al. Terminology and classification of muscle injuries in sport: The Munich consensus statement. *Br. J. Sport. Med.* **2013**, *47*, 342–350. [CrossRef] [PubMed]
88. Tol, J.L.; Hamilton, B.; Best, T.M. Palpating muscles, massaging the evidence? An editorial relating to 'Terminology and classification of muscle injuries in sport: The Munich consensus statement'. *Br. J. Sport. Med.* **2012**, *47*, 340–341. [CrossRef] [PubMed]
89. Hagglund, M.; Walden, M.; Bahr, R.; Ekstrand, J. Methods for epidemiological study of injuries to professional football players: Developing the UEFA model. *Br. J. Sport. Med.* **2005**, *39*, 340–346. [CrossRef]
90. Jarvinen, T.A.; Jarvinen, M.; Kalimo, H. Regeneration of injured skeletal muscle after the injury. *Muscles Ligaments Tendons J.* **2013**, *3*, 337–345. [CrossRef]
91. Heiderscheit, B.C.; Sherry, M.A.; Silder, A.; Chumanov, E.S.; Thelen, D.G. Hamstring strain injuries: Recommendations for diagnosis, rehabilitation, and injury prevention. *J. Orthop. Sport. Phys. Ther.* **2010**, *40*, 67–81. [CrossRef]
92. Van Wilgen, C.P.; Verhagen, E. A qualitative study on overuse injuries: The beliefs of athletes and coaches. *J. Sci. Med. Sport* **2012**, *15*, 116–121. [CrossRef]
93. Brukner, P. Hamstring injuries: Prevention and treatment—An update. *Br. J. Sport. Med.* **2015**, *49*, 1241–1244. [CrossRef]
94. Peetrons, P. Ultrasound of muscles. *Eur. Radiol.* **2002**, *12*, 35–43. [CrossRef]
95. Sugiura, Y.; Sakuma, K.; Sakuraba, K.; Sato, Y. Prevention of Hamstring Injuries in Collegiate Sprinters. *Orthop. J. Sport. Med.* **2017**, *5*, 2325967116681524. [CrossRef]