Biomechanical Load Characteristics, Injury Mechanism, Prevention and Intervention of Proximal Hamstring in Badminton Racket-Side Forward Lunge

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Abstract. The badminton racket-side forward lunge is a special step frequently used in the front court. During the landing buffer phase of this action, the proximal hamstring bears a relatively large centrifugal traction load, which is likely to cause tendon injury at the ischial tubercle, limiting daily activity and sports performance. This article systematically reviews the biomechanical load characteristics of the proximal hamstring during the badminton racket-side forward lunge, analyzes its specific injury mechanism, summarize and analyze the existing prevention and intervention strategies. The results showed that: in the landing buffer stage of the badminton racket-side forward lunge, the large flexion of the hip and knee joint form the bidirectional traction stress concentration effect on the proximal hamstring; Long term unilateral load accumulation and dislocation of the hip and knee motion sequence will further increase the risk of local injury; resistance and eccentric training and landing movement technology correction are the main damage prevention and control measures at present, and various external equipment can be used as auxiliary intervention measures. The existing research has some limitations, such as insufficient measured data, difficulty matching laboratory conditions to real-life badminton competition scenarios, and lack of long-term tracking. In the future, more field tests should be carried out based on the badminton match play to build a more suitable proximal hamstring training and injury prevention program for badminton.

Keywords: Biomechanical load, injury intervention, proximal hamstring, badminton, forward lunge.

1. Introduction

The hamstring is an important muscle group connecting the hip and knee joints. It starts from the ischial tuberosity at the proximal end and ends behind the knee joint at the distal end. In badminton, the racket-side forward lunge is frequently used in the front court game. Biomechanical studies show that the lower limbs on the racket side need to bear a horizontal ground reaction up to 2.40 times the body weight and a vertical ground reaction up to 2.06 times the body weight in the badminton racket-side forward lunge [1,2]. In this process, the landing buffer stage is a typical single leg deceleration action, and the lower limb muscles on the racket side absorb the landing impact through eccentric contraction; As a double joint muscle group across the hip and knee, the hamstring muscle has a large flexion of the hip joint during the landing buffer, the muscle-tendon unit is passively lengthened, and it bears significant horizontal and vertical centrifugal loads. Moreover, the blood supply and muscle strength of the proximal hamstring tendon are weak, and the repair response is poor [3]. Therefore, this stage is an action stage with a high risk of proximal hamstring injury in the badminton racket-side forward lunge. The injury of the proximal hamstring tendon will cause pain in the ischium tuberosity area, which will affect for a long time and limit daily activities and sports performance [4].

At present, the prevention and intervention methods mainly include resistance and eccentric overload training, movement technology correction and external equipment intervention. However, the existing research on the forward lunge in badminton mostly focuses on the overall biomechanical characteristics of the lower limb, and the laboratory research is difficult to accurately fit the real training and competition scenes. There is a relative lack of specific and systematic research on the proximal hamstring on the racket side, and the relevant data on muscle and tendon mechanics are insufficient. At the level of prevention and intervention, there is a lack of targeted neuromuscular training combined with actual combat, which is difficult to effectively reduce the injury rate and

injury recurrence rate of the proximal hamstring on the racket side, and it is difficult to correctly judge whether the patient can return to high-intensity training.

Therefore, this article aims to systematically elaborate the biomechanical load characteristics of the proximal hamstring in the badminton racket-side forward lunge, analyze its injury mechanism and comprehensively summarize and analyze the intervention strategies, so as to provide a theoretical reference for performance improvement and injury prevention and intervention for Badminton Athletes.

2. Overall kinematic characteristics of badminton forward lunge

The forward lunge of badminton is a core specific technique to deal with the front court ball, and it is also an important inducement for injury of lower limb muscles and tendons in badminton. Most of the existing biomechanical researches name the lunge movement based on the spatial orientation of the laboratory. This paradigm is different from the lunge mode in the badminton practical combat scene. Therefore, this article takes the lower limb on the racket side as the classification basis from the perspective of the actual combat. This article defines the badminton racket-side forward lunge as: Taking the right-handed badminton player as an example, the lower limb (right leg) on the same side of the racket completes the forward lunge, including the forehand and backhand directions in the front court; The same goes for badminton players who hold the racket with their left hand. According to the anatomical characteristics, the blood supply at the ischial tubercle of the proximal hamstring tendon is weak, and it is a weak area with a high incidence of tendon lesions and sports injuries when bearing the shear-pull compound load. For the badminton crowd, proximal hamstring injury is highly correlated with the forward lunge movement, and the racket-side limb is in a unique mechanical environment, and the injury risk has obvious limb asymmetry.

The complete movement cycle of the badminton forward lunge can be divided into three stages: kicking out, landing buffer, and kicking out recovery. In the kicking out stage, the forward momentum is generated by the pushing and stretching of the supporting leg, and the stride leg moves forward at the same time. The landing buffer stage is a high-risk stage for proximal hamstring tendon injury, from the front heel touches the ground to the hip and knee flexion absorbs the ground reaction force by centrifugal contraction of lower limb muscles, and the proximal hamstring tendon and soft tissue at the ischial tubercle are subjected to two-way traction load. The step leg shrinks centripetally to recover the center of gravity in the kicking-out recovery stage. In the badminton racket-side forward lunge, the ankle mainly regulates the plantar pressure distribution and calf muscle group, but has no direct correlation with the proximal hamstring. Therefore, the ankle motion parameters are not included in this article.

3. Biomechanical load characteristics of the proximal hamstring in the badminton racket-side forward lunge

3.1. Flexion characteristics of hip and knee joints in racket-side forward lunge

The test results of the right forward lunge of high-level badminton athletes show that in the support phase, the peak flexion angle of the hip joint can reach 77.3 °± 4.1 °, the peak adduction angle of the knee joint can reach 28.9 °± 6.8 °, and the peak internal rotation angle of the knee joint can reach 20.3 °± 1.3 ° [5]. Compared with high-level athletes, amateur badminton players have a larger peak flexion angle of the hip joint, and show a smaller peak adduction and internal rotation angle of the knee joint, so that amateurs' proximal hamstring has a higher passive traction effect under the condition of relatively stable knee posture in the forward lunge, which may increase the risk of injury in this part.

3.2. Vertical and horizontal load characteristics of the racket-side forward lunge

The peak value of the vertical ground reaction force can reach 2.06 times of body weight, and the peak value of the horizontal ground reaction force can reach 2.40 times of body weight [1,2]. The horizontal shear force combined with the vertical impact load forces the hip and knee joints to flex significantly to brake, and the tibia moves forward and backward relative to the pelvis, which increases the stretching range and pulling effect of the hamstring, and produces high-strength pulling stress on the proximal hamstring at the ischial tubercle; the local stress at the tendon bone junction is concentrated, which is prone to injury.

3.3. Mechanical characteristics of bi-directional tendon traction in the landing buffer stage of the racket-side forward lunge

At this stage, the proximal hamstring showed a unique bi-directional tensile stress mode; that is, part of the tensile stress generated at the starting point of the sciatic tubercle and the posterior insertion of the knee joint was superimposed on the starting point of the tendon of the sciatic tubercle due to the large flexion of the hip joint, resulting in local stress concentration. Muscle-bone simulation test showed that the peak strain of biceps longus tendon complex extension in hamstring muscle group could reach about 12.0% under the mode of large-scale hip flexion centrifugal deceleration [6]. The landing buffer of badminton racket-side forward lunge has a similar action mode. This stage is accompanied by a wide range of hip flexion, and the bi-directional traction continuously acts on the weak area of tendon-bone starting point where the blood supply is scarce. Under repeated movements, the proximal hamstring micro-injury recovers slowly and continuously, and even leads to muscle tear.

4. Specific injury mechanism of proximal hamstring in racket-side forward lunge

4.1. Long-term unilateral load accumulation of landing buffer

The front court game of badminton is highly dependent on the racket-side forward lunge, and long-term unilateral high-intensity load causes changes in the cross-sectional area, stiffness and load tolerance of the hamstring of the lower limb at the racket side; Existing patellar tendon experiments have confirmed that long-term unilateral specific load can increase the cross-sectional area and stiffness of the dominant patellar tendon by 17% and 18% [7]. Although this conclusion can not directly represent the measured data of the proximal hamstring tendon, it can reflect the general adaptation of the tendon to the unilateral load mechanical environment and provide indirect biomechanical evidence for this article to elaborate the load accumulation mechanism of the proximal hamstring tendon on the racket side of badminton. Under the continuous load accumulation of a forward lunge, the proximal hamstring tendon has the potential for overload injury. When the mechanical stress of the tendon exceeds the physiological tolerance threshold, it is possible to initiate pathological changes in the tendon and evolve into chronic tendon disease under the adverse cycle of multiple factors such as inflammation, mechanical stress, and vascularity [8].

4.2. Adverse traction pattern induced by dislocation of hip and knee motion sequence

In the actual combat fatigue state, with the interference of trunk torsion and swing, the hip and knee flexion sequence is easy to be inconsistent in racket-side forward lunge. The hip flexion is advanced and the angle becomes larger, and the knee flexion lags behind, which makes the muscle-tendon unit withstand impact and traction in a non-optimal mechanical posture, which may lead to uneven stress distribution, thereby amplifying the stress concentration effect in the proximal hamstring tendon bone junction area. All fibrocartilage related to normal tendon insertion and tendon insertion organs are avascular tissues, which leads to poor repair response in tendon attachment area and surrounding tissues [3]. Therefore, in the frequent badminton racket-side forward lunge landing buffer, if the proximal hamstring tendon continues to bear high-strength centrifugal traction load in

the abnormal passive stretching state, due to the poor repair response of this part, its micro damage is easy to accumulate, which may aggravate the injury and even result in a muscle tear.

5. Existing prevention and intervention strategies of proximal hamstring injury in badminton racket-side forward lunge

5.1. Resistance and eccentric overload training of proximal hamstring

The implementation of high-weight slow resistance training may be easier to induce adaptive changes in the tendon, and make the evidence of collagen turner more sufficient, which is helpful to strengthen the proximal hamstring tendon and reduce the risk of injury [9]. In the 10-week intervention test for football players, pre-match hamstring strength training with centrifugal overload as the core can effectively reduce the strain events (the incidence of strain injury in the training group is 20.0%, and that in the control group is about 66.7%), and can improve the running performance of athletes [10]. The existing Meta-analysis of achilles tendon and patellar tendon in healthy people confirmed that long-term mechanical load stimulation can significantly regulate tendon stiffness, material properties and cross-sectional area; subgroup analysis further suggested that the adaptive remodeling of tendon stiffness mainly depends on load intensity and is not determined by muscle contraction form [11]. This conclusion can provide a theoretical basis for the design of proximal hamstring training program. Therefore, for the badminton racket-side forward lunge, which is a special action of landing centrifugal deceleration with large hip flexion, people should learn from the above training logic and combine more front court footwork to design a proximal hamstring strength intervention program that is more conducive to improving the movement performance in actual combat, to improve the stiffness of the proximal hamstring tendon, improve its load tolerance, adaptation and repair ability, and reduce the risk of injury in a more realistic training situation.

5.2. Technical movements correction of landing movement of badminton racket-side forward lunge

Modify the landing posture of the racket-side forward lunge, control the stride amplitude, optimize the flexion sequence of the hip and knee joints, and limit the excessive torsion of the trunk at the moment of landing, so as to avoid the muscle-tendon unit entering the adverse traction posture. The optimization of technical movements can make the flexion angle of hip and knee joints more reasonable when landing, improve the power transmission mode of forward lunge landing, reduce the unreasonable shear force on the lower limb, and reduce the injury risk of the proximal hamstring muscle-tendon union.

5.3. External equipment intervention

The external equipment intervention for the injury of the proximal hamstring can indirectly reduce the pull and impact load of the proximal hamstring during the landing phase of the badminton racket-side forward lunge by assisting the hamstring to exert force, improving muscle stretch, adjusting the lower limb power chain, etc. At present, it mainly includes dynamic hamstring protectors, thigh compression clothing, intramuscular patches, and arch support insoles. Wearing a new type of dynamic hamstring protector can significantly improve the grade of athletes' Single-Leg Glute Bridge test (30 ± 4 times vs 23.5 ± 5 times, $p<0.05$), but it will reduce the speed of short-distance sprint (10-meter sprint 2.01 ± 0.1s vs 1.88 ± 0.1s, $p<0.05$) [12]. It can be seen that it helps to temporarily improve the output ability of the hamstring but affects the overall performance of athletes; The dynamic spring protector can quickly output considerable force in the early flexion stage of the knee joint and assist the hamstring in exerting force, which is conducive to reducing the load of hamstring and reducing its risk of injury [12]. Although thigh compression clothing is widely used in badminton, there is a lack of evidence to prove that relevant limb compression clothing has beneficial or harmful effects on lower limb sports injury, subjective fatigue level and biomechanical indexes [13]. The use of

intramuscular plaster is also a common external intervention method for lower limbs. Experiments have confirmed that the inhibitory type of intramuscular plaster can immediately improve the stretch of the hamstring muscle; the test was conducted on female college students at an interval of 15 minutes after the intervention, and it was found that the popliteal angle can be increased by 14.56 °, but it has little effect on the muscle strength of hamstring and quadriceps, and its long-term injury prevention value remains to be verified [14]. The arch support insole can effectively inhibit the increase of foot varus angle and avoid the decline of hip flexion angle during the racket-side forward lunge, which may help to stabilize the motion frame [15].

Although the use of external hamstring protectors has effect, there is a risk of kinematic chain compensation. Local joint constraints may change the state and function of adjacent joints, affecting the mechanical performance and injury risk of the proximal hamstring. Therefore, equipment intervention can be used as auxiliary method of training intervention, but can not replace the resistance and eccentric overload training of the proximal hamstring.

6. Deficiencies of existing research

There are still some obvious shortcomings in the current research on badminton proximal hamstring injury. First of all, most studies focus on the analysis of the mechanical characteristics of the overall hamstring muscle group in sprint, football, and other events, less targeted research on the badminton racket-side lower limb, especially the lack of specific quantitative research on the local stress characteristics of the proximal hamstring at the ischial tubercle, resulting in the inability to intervene more effectively and prevent the injury at this part. Secondly, the existing mainstream eccentric and isometric intensive training is mostly based on the standardized laboratory paradigm, and its training environment is relatively fixed; there is a gap between it and the actual competition situation of the badminton racket-side forward lunge landing process such as the footwork, hip knee dynamic coupling and instantaneous impact, and the special adaptability of the training intervention needs to be improved. Thirdly, at present, the research on the intervention of external protective devices, intramuscular patches, functional insoles and other equipment lacks the measured evidence from high-level badminton players, and the compensation of kinematic chain generated by relevant equipment in the badminton racket-side forward lunge has still not been systematically demonstrated and solved. Finally, most of the existing research focus on the instantaneous mechanical indicators and short-term intervention effect, and lack the analysis of stiffness attenuation, load offset, and damage evolution of the proximal hamstring tendon under the condition of fatigue accumulation, the research on the mechanism and intervention of badminton proximal hamstring injury is still lacking.

7. Conclusion

This article systematically reviews the biomechanical load characteristics, injury mechanism, existing prevention and intervention strategies of the proximal hamstring in the badminton racket-side forward lunge. Based on the existing research, it can be seen that the landing process of the badminton racket-side forward lunge has unique mechanical characteristics of unilateral high tensile load and high shear load, and the proximal hamstring tendon is prone to micro damage under the effect of frequent high centrifugal load and fatigue accumulation, affecting daily life and sports performance. Resistance and centrifugal overload training are the main intervention methods for the prevention of proximal hamstring injury, which can help to improve its stiffness, load adaptation and tolerance, and reduce the incidence of injury. The technical correction of forward lunge landing movement can make the load-bearing and conduction mode more reasonable when landing, and help to reduce the injury risk of the proximal hamstring on the racket side. Dynamic hamstring protectors, intramuscular patches, arch support insoles and other equipment can through assisting in exerting force, improving muscle extensibility, and adjusting the lower limb power chain to possibly help to reduce the incidence of injury in the proximal hamstring on the racket side, but there may be

compensation in the kinematic chain, which means these sorts of equipment can be used as auxiliary intervention but can not replace muscle training. Current research lacks sufficient biomechanical data and systematic understanding of fatigue-induced injury mechanisms. Future studies should integrate more specific dynamic analysis and long-term intervention validation to develop more effective proximal hamstring injury prevention strategies for badminton athletes.

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