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Review Article

Etiology and Exercise Treatment of Patellofemoral Pain Syndrome

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Abstract: Objective: As a result of peripatellar pain or anatomical or biomechanical anomalies in the anterior knee, patellofemoral pain syndrome (PFPS) is a knee injury that can be made worse by weight-bearing activities like climbing and descending stairs. According to long-term follow-up studies, patellofemoral arthritis may eventually develop in 45% of PFPS patients who do not receive prompt and efficient treatment in the early stages, causing irreparable harm that may significantly impair the patient's quality of life. In order to prevent injuries, enhance daily life activities and athletes' sporting performance, it is important that we understand the mechanism and exercise treatment of PFPS. Methods: We reviewed the China Knowledge Network (CNKI) and PubMed life science database, searched for the terms "patellofemoral pain syndrome," "patellar tenderness," "running knee," and "anterior knee pain," and summarized the pertinent research. Results: Its cause is still unknown, and its etiology is complicated, with the main contributing factors being poor lower extremity function, decreased muscle strength, lack of flexibility, and impaired neuromuscular control. The majority of exercise therapy currently performed includes training the hip, knee, core, retraining the gait, and blood flow restriction training. The impact of the condition may depend on quick and efficient interventions. Conclusion: Exercise therapy had the strongest evidence base, particularly for the positive effects of either single hip or knee muscle strength training or a combination of the two, according to systematic evaluations that came to conclusions about the effectiveness of interventions. However, there was insufficient evidence to determine the ideal form of training and long-term effects. Contrarily, there is still scant evidence to support interventions such as gait retraining, blood flow restriction training, and core stability training. When it comes to selecting a course of treatment, a combination of treatments is typically advised and chosen in accordance with the precise evaluation of the patient's condition.

Keywords: Patellofemoral Pain Syndrome, Exercise Therapy, Quadriceps

1. Introduction

Patellofemoral pain syndrome (PFPS) is a knee injury in which anterior or peripatellar pain is predominant due to anatomical or biomechanical abnormalities [1, 2]. There is a lack of clear consensus in the literature regarding the definition and etiology of PFPS. The incidence of PFPS varies from person to person, accounting for 29.2% of women and 15.5% of men in the general population [3]. PFPS accounts for 25% of knee injuries in sports medicine outpatient clinics and severely hinders athletes and fitness enthusiasts from participating in sports [4]. Although PFPS itself is a benign, self-limiting disease, long-term follow-up studies have found that 45.5% of patients with PFPS may eventually develop irreversible patellofemoral arthritis if they do not receive timely and effective treatment in the early stages, resulting in irreversible damage that can seriously affect patients' daily lives [5]. There is no specific treatment for this disease, and the efficacy of exercise therapy for PFPS has been recommended by domestic and international guidelines (level A evidence) [6, 7], but there is a lack of sufficient evidence to confirm the best exercise modality for the treatment of PFPS. Therefore, there is an urgent need to explore exercise therapy ideas from the etiology of PFPS. In this paper, we will discuss the factors associated with PFPS, such as poor lower limb force lines, abnormal muscle function, impaired core neuromuscular control, and lack of flexibility, and explore the application of hip muscle training, knee muscle training, core stability training, gait retraining, and blood flow restrictive training in PFPS, in order to ensure the development of competitive sports and Theoretical basis and practical guidance were provided to ensure the development of competitive sports and the vigorous development of national fitness sports.

2. Etiology of Patellofemoral Pain Syndrome

Although there is a lack of consensus on the etiology of PFPS, studies have identified multiple factors as potential risk factors. Considered from a kinesiological perspective, they mainly include intrinsic and extrinsic factors, with extrinsic factors related to excessive exercise intensity, poor quality running shoes, and hard track; intrinsic factors mainly include impaired core neuromuscular control, abnormal muscle function, and poor lower extremity force lines, which can reduce patellofemoral joint contact area and increase patellofemoral joint reaction force, leading to patellofemoral joint overload and inducing knee pain or swelling, which in turn develops into PFPS (see Figure 1) [8, 9]. It is generally believed that the formation of PFPS may be related to the altered metabolic activity of cartilage and increased water content caused by repetitive knee overload exercise, and the increased water content can produce overstimulation of patellar mechanical pressure receptors, which in turn induces pain [10].

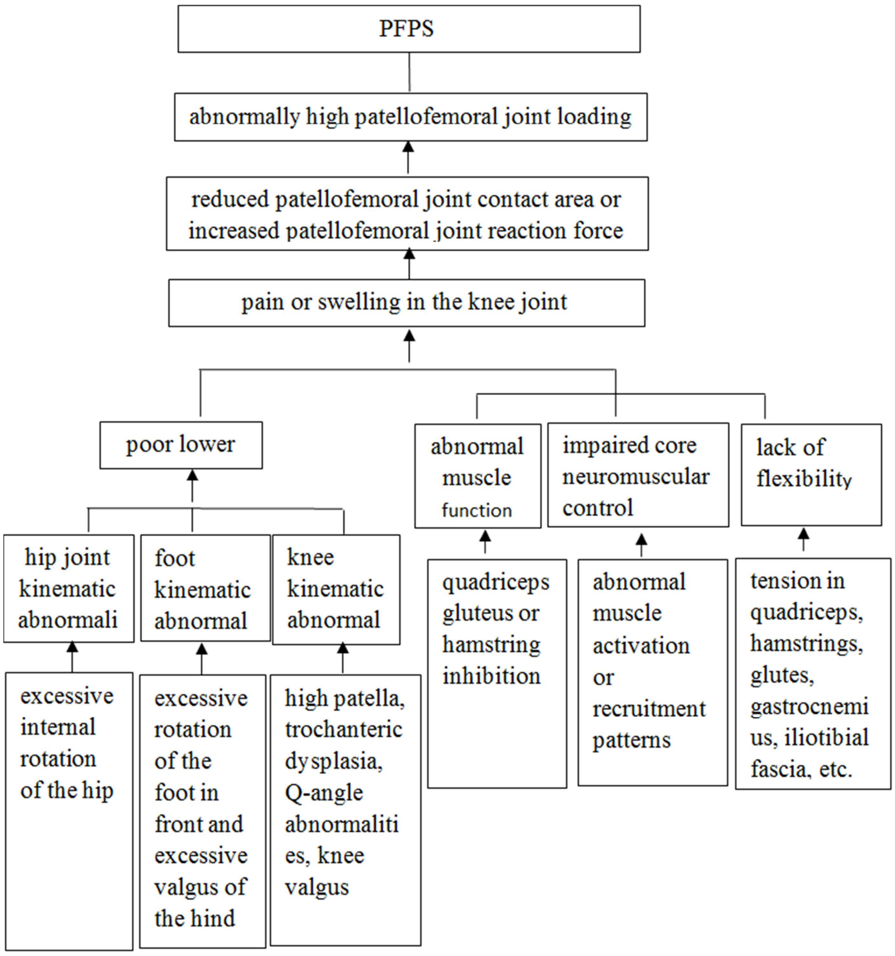

Figure 1. *Influencing factors of PFPS.*

2.1. Poor Lower Limb Force Lines

Patients with PFPS usually have changes in lower extremity force lines when performing functional activities such as running, squatting, and going up and down stairs, which include foot abnormalities (excessive foot rotation forward, excessive hindfoot valgus, etc.), knee anatomical and kinematic abnormalities (high patella, femoral talus dysplasia, Q-angle abnormalities, knee valgus, etc.) and hip kinematic abnormalities (excessive hip internal rotation). Coronal projection angles were used clinically to assess changes in lower extremity force lines in patients with PFPS during single-leg squatting or going up and down stairs, and it was found that patients with greater coronal projection angles had excessive hip internal rotation and knee abduction and external rotation and were more likely to develop PFPS [9]. Erkocak et al. further showed that excessive foot rotation anteriorly, excessive hindfoot valgus, and knee valgus underlie the pathogenesis of patients with PFPS [11]. This poor lower limb force line can also cause inward rotation of the tibia, leading to changes in lower limb joint loading and ultimately the development of PFPS. the above studies suggest that abnormal hip-knee-ankle kinematics are closely related to the development of PFPS, but the causal relationship between lower limb force line abnormalities and PFPS needs to be further investigated.

2.2. Abnormal Muscle Function

2.2.1. Quadriceps Imbalance

Currently, related studies suggest that quadriceps imbalance may be closely related to the development of PFPS. According to the muscle fiber course, among them, the vastus medialis oblique (VMO) and the medial support band are the medial fixation tissues that limit the lateral displacement of the patella during patellar motion, while thevastus lateralis (VL), the iliotibial bundle and the lateral support band are the main structures that maintain lateral stability [12]. It is generally believed that when the VMO is inhibited or the muscle is atrophied, during knee flexion or extension, the patella is displaced and tilted towards the lateral side of the knee by the traction of the VL, resulting in increased pressure on the lateral patellofemoral joint and increased friction between the patella and the cartilage of the lateral femoral epicondyle, leading to pain, which in turn develops into PFPS. Pattyn et al. found that compared to healthy subjects, patients with PFPS had lower VMO and VL cross-sectional The cross-sectional area of both VMO and VL was lower in PFPS patients compared to healthy subjects, especially the VMO atrophy was the most pronounced [13]. However, it has been suggested that the imbalance between VMO and VL activation in PFPS patients is the main cause of PFPS, with the VL/VMO EMG ratio being greater than that of the bipedal half-squat and >1 during the unilateral full knee extension maneuver in the seated position, whereas Gallina et al. found that VL activation preceded VMO during the knee extension maneuver in PFPS patients compared to healthy subjects, whereas There was no difference in the activation of VMO between PFPS patients and healthy subjects [14]. This suggests that it remains to be further explored whether PFPS patients have PFPS due to VMO inhibition or unbalanced VMO and VL activation.

2.2.2. Abnormal Gluteal Muscle Function

Studies have shown that PFPS is closely associated with abnormal hip muscle function. The gluteus maximus (GMAX) muscle alone increases hip external rotation when contracted, and increases hip abduction and external rotation when contracted together with the gluteus medius (GMD) muscle. The main role of the gluteus muscle is to limit hip internal rotation and maintain normal lower extremity biologic force lines, thus correcting abnormal patellar motion trajectories. However, the causes of PFPS due to problems with the gluteal muscles are not yet uniform.

Impaired internal contraction and horizontal internal rotation of the coronal plane of the hip may be associated with abnormal activation of GMD [15]. Park et al. found that patients with PFPS had 10% less GMD muscle contraction activity during a jumping task and 10% more during the landing period of the same task compared to healthy subjects, suggesting that knee pain is associated with GMD activation, specifically with the motor units that complete the task [16]. These motor units need to be activated under greater demand in order to exert increased hip abduction and external rotation during the centrifugal phase of the task. Furthermore, a systematic study showed no difference in GMD and GMAX activation levels in PFPS patients compared to healthy female subjects, but reduced hip abduction and external rotation forces, suggesting that hip activation may not be a major factor affecting PFPS [17].

Compared to GMD, there are fewer studies on GMAX. Souza et al. showed that PFPS patients had greater GMAX activation in movements such as step-down and running compared to healthy subjects, but there were no differences in GMD activation, hip and knee kinematics, suggesting abnormal GMAX activation in PFPS patients [18]. Barbosa et al. found a positive correlation between GMAX activation and coronal plane projection angle, with coronal plane projection angle greater than 15° suggesting increased GMAX activation [19]. Holden et al. further confirmed that coronal projection angle was associated with knee valgus, and that a knee valgus shift greater than 10.6° in adolescent females predicted the occurrence of PFPS [20]. These studies suggest that GMAX function may be altered in those experiencing PFPS and that additional assessment of neuromuscular function of the GMAX is needed.

There is a lack of studies correlating the gluteus minimus with PFPS, which may be related to its deeper location and smaller size.

2.2.3. Abnormal Hamstring Function

The hamstrings act as antagonist muscles of the quadriceps and work together to maintain knee stability. Abnormal hamstring function is closely related to the occurrence of PFPS. Citaker et al. found in a comparative study of hamstring strength in the lower limbs of patients with PFPS that hamstring strength was lower in the affected limb compared to the healthy limb, which may be related to the compensatory mechanism by which patients with PFPS respond to reduced quadriceps strength in order to maintain knee stability [21]. Apibantaweesakul et al. compared healthy subjects and PFPS patients at different angular peak moments found that the hamstring/quadriceps ratio was significantly greater in PFPS patients than in healthy subjects at 15°, 30°, 45°, 60°, and 75° of knee flexion, suggesting that altered knee co-activation mechanisms and thus reduced joint stability lead to muscle imbalance in PFPS patients [22]. Due to the variable disease duration of PFPS patients in these studies, there is not sufficient evidence to confirm that abnormal hamstring function is a factor in the pathogenesis of PFPS, and functional training targeting the hamstrings has not achieved significant clinical benefit.

2.3. Impaired Core Neuromuscular Control

Neuromuscular control refers to the conscious dynamic control of muscles by the body's nervous system before and after joint movement or loading in order to maintain or restore joint stability. Impaired core neuromuscular control may be associated with impaired core stability and core strength, leading to instability of local structures in response to internal and external disturbances, and this instability is related to the pathogenesis of PFPS [23]. Core strength supports the stability of the core as well as limb movement, and core muscles transmit signals to the central nervous system via sensory nerves to produce adaptations, while effectively enhancing proprioceptive feedback via motor nerves to maintain limb balance and postural stability. During exercise, the knee joint not only has to maintain its own stability and function, but also needs to generate additional forces to maintain the stability of the core, increasing the load on the joint and thus increasing the risk of injury. Motealleh et al. found different activation of the core and femoral muscles in patients with PFPS and healthy subjects during stair climbing [24]. Rojhani et al. also demonstrated that the core and femoral muscles were activated differently in patients with PFPS compared to PFPS patients showed earlier activation of the transversus abdominis, internal abdominal oblique and erector spinae muscles in response to sudden accidents compared to healthy subjects, both studies suggesting that PFPS patients have abnormal muscle recruitment patterns that alter proprioceptive afferents, leading to impaired postural control during movement and putting the knee at increased risk of injur [25]. Because the research on impaired neuromuscular control on knee stability is unclear, further research on the specific mechanisms of neuromuscular control and knee injury is still needed to develop targeted rehabilitation training programs to improve neuromuscular control and reduce injury occurrence.

2.4. Lack of Flexibility

In addition, increased tension in soft tissues such as the iliotibial bundle, gastrocnemius, quadriceps, and hamstrings may also be associated with the occurrence of PFPS [12]. During flexion, quadriceps tension leads to increased patellofemoral joint stress, during extension, soft tissue tension in the iliotibial bundle, gastrocnemius and hamstrings leads to increased joint stress, especially excessive tension in the iliotibial bundle, which will lead to lateral displacement of the patella and produce abnormal patellar motion trajectory, which in turn develops into PFPS.

3. Exercise Therapy for Patellofemoral

Because patients do not pay attention to post-injury rehabilitation and prevention of re-injury without professional rehabilitation, it is highly likely to cause a vicious cycle of muscle atrophy-pain-muscle atrophy, leading to serious diseases such as knee osteoarthritis. Relevant guidelines point to exercise therapy as the safest and most effective, long-lasting rehabilitation tool for treating patients with PFPS [7, 9], but there is a lack of sufficient evidence to confirm the best exercise modality for treating PFPS. Currently, there is no evidence that a single intervention modality is effective for all patients with PFPS, and limited evidence that combined interventions are more effective for patients with PFPS. It has been established that hip and knee muscle training can be effective in improving muscle recruitment of lower limb muscles and increasing hip and knee muscle strength, thereby blocking the vicious cycle of muscle atrophy-pain-muscle atrophy, reducing pain, and improving knee function to prevent recurrence of knee pain [26].

3.1. Hip Muscle Strength Training

It was shown that 12 weeks of hip abduction exercises significantly altered VMO and VL activation patterns and reduced pain in patients with PFPS [27]. Şahin et al. also found that 12 weeks of hip-knee rehabilitation not only significantly reduced pain but also significantly improved knee function in patients with PFPS compared to single knee rehabilitation, suggesting that hip-knee rehabilitation is associated with better functional better recovery [28]. However, Hott et al. conducted 6 weeks of health education combined with hip training, traditional knee training, and free physical activity interventions in patients with PFPS and found no difference in the short-term effects of the three training methods on patients' pain, knee self-efficacy scale, and external hip rotation strength [29]. The reasons for the conflicting results of the above studies may be related to the differences in hip intervention protocols and the patients' conditions, and a single hip strength training may have no effect on the function of PFPS patients.

3.2. Knee Muscle Strength Training

It was found that patients with PFPS had decreased muscle strength, especially quadriceps muscle strength was the most common, and enhancing quadriceps muscle strength can be achieved with open-chain or closed-chain knee training, but the results were mixed. Miao et al. found that closed-chain knee flexion bipedal half-squats were more effective in improving VMO/VL balance than seated single-leg extensions, suggesting that closed-chain knee flexion is more conducive to selective activation of VMO [30]. Because compared with open-chain, closed-chain knee flexion activates receptors in tendon cells, improves proprioception, increases joint stability, and improves muscle balance. Irish et al. used closed-chain weight-bearing Interventions using closed-chain weight-bearing movements (double-legged squat, leg push-up, lunge) in patients with PFPS found that such movements selectively activated VMO and also had a recruitment effect on VL, which may be related to the need for synergistic force of multiple muscles in multiple joints during closed-chain centrifugal training, increasing muscle fiber recruitment capacity, increasing patellofemoral joint area, and decreasing patellofemoral joint pressure [31]. However, Chiu et al. found that 8 weeks of both open-chain and closed-chain quadriceps strength training significantly increased patellofemoral contact area, decreased joint stress, and improved pain and function in patients with PFPS [32]. Alrshood et al. further confirmed that open-chain and closed-chain training have the same effect on patellofemoral joint stability, and it seems that closed-chain training has a better short-term effect on PFPS, while the open-chain effect was found to be more effective at long-term follow-up [33]. The conflicting results of these studies may be due to the complexity of the effects of different test maneuvers and interventions on PFPS. There is no effective means to identify the exact risk factors for each patient, and therefore, there is not yet sufficient evidence to confirm the best intervention for the treatment of PFPS.

3.3. Core Stability Training

Studies have confirmed that core stability training to improve neuromuscular control is effective in preventing the occurrence of PFPS. Zazulak et al. conducted a three-year follow-up study of female athletes with knee injuries and found that trunk resetting errors and displacements were significantly higher in response to sudden disturbances from external forces than in uninjured female athletes, suggesting that patients with knee injuries have abnormal proprioceptive input that leads to neuromuscular control [34]. Motealleh et al. conducted core neuromuscular control training combined with conventional rehabilitation training for 4 weeks in 28 patients with PFPS and found that core neuromuscular control training combined with conventional rehabilitation training was more effective than conventional rehabilitation training in improving pain, balance, and motor performance in patients with PFPS [35]. Luo Pei et al. used neuromuscular control training combined with hip and knee strength training three times a week for 60 min for 6 weeks in 30 patients with PFPS and found that compared with single hip and knee strength training, neuromuscular control training combined with hip and knee strength training not only significantly improved patients' pain and knee function, but also increased hip and knee extensor muscle strength, decreased hip internal rotation knee internal rotation, and ankle rotation angle [36]. These studies suggest that combined interventions can significantly reduce the potential risk factors for the development of PFPS and effectively prevent the development of PFPS. However, few studies have used core stability training to improve neuromuscular control as a rehabilitation method, and there is insufficient evidence that this method has an impact on neuromuscular function and biomechanical aspects of patients.

3.4. Gait Retraining

Incorrect movement patterns are closely associated with PFPS. Common incorrect movement patterns include increased internal rotation of the hip and decreased contralateral pelvis. Gait retraining aims to improve brain control of correct movement patterns in the central nervous system and alter the timing of movement, thereby restoring normal motor function of the lower extremity. The 2021 International Classification of Functioning, Disability and Health-Patellofemoral Pain clinical practice guideline (I) recommends gait retraining as level C evidence, suggesting that a forefoot landing pattern significantly increases PFPS compared to a rearfoot landing patients' running frequency, reducing peak hip inversion and decreasing pain [7]. A systematic review study evaluated the use of gait retraining changing from a rearfoot landing to a forefoot landing pattern as an intervention for PFPS as significantly reducing hip inversion angle, increasing trunk pronation, improving gait, and decreasing pain, while incorporating real-time feedback from movement analysis had a greater impact on movement patterns in patients with PFPS [37]. The essence of retraining is to provide multiple types of feedback, such as visual, auditory and tactile, to combine correct movement with movement sensation to reinforce movement patterns and improve neurological modulation. A single hip or knee muscle training only strengthens the muscle function and does not substantially change the incorrect movement pattern. Because gait retraining is difficult to implement, most studies currently limit participants' gait retraining to running in a laboratory setting, and the efficacy of interventions outside the laboratory is unknown, while the effectiveness of the training and the severity of the injury sustained are unclear, and there is an urgent need to design high-quality randomized controlled trials to investigate the efficacy of different experimental conditions and training modalities on PFPS patients with different degrees of injury.

3.5. Blood Flow Restriction Training

Blood flow restriction training (BFR) is the use of special devices (e.g., tourniquets, elastic bands, compression cuffs, etc.) to apply external pressure to the limb to block or restrict blood flow to the limb thereby causing local ischemia, combined with physical training to improve physical function [38]. For patients with severe symptoms and low tolerance to standard strength training programs, following the American College of Sports Medicine (ACSM) 2009 guidelines, the use of BFR is recommended in rehabilitation programs. for many patients with PFPS, high-load exercise can cause increased symptoms in the patellofemoral joint, whereas BFR not only does not cause pain in patients, but also achieves muscle hypertrophy with low-intensity loading and increases muscle strength. Giles et al. studied 69 patients with PFPS randomly divided into BFR and no BFR groups (classical strength training program with 70% of 1RM) and compared the efficacy of quadriceps strength training with and without BFR and found that the BFR group had reduced pain and significantly increased muscle strength compared to the no BFR group, but follow-up after 6 months found that both groups had the most severe pain, Kujala score and muscle hypertrophy and muscle strength were not significantly different between the two groups [39]. It indicates that BFR can be used as a short-term classical strength training for alternative treatment in patients with PFPS with low tolerance, but the long-term efficacy needs to be further studied. The 2017 International World Conference on Patellofemoral Pain concluded that more high-quality studies are needed to determine the application or rejection of the BFR approach in the rehabilitation program of patients with PFPS [39].

4. Conclusion

PFPS has a high morbidity and disability rate with a complex and variable etiology. Abnormally high patellofemoral joint loading is the direct cause of knee pain and swelling in patients with PFPS, and greater pain severity and longer duration of symptoms are indicators of poor prognosis. Therefore, early and effective interventions may be critical to the impact of the condition. Systematic evaluations, in drawing conclusions about the effectiveness of interventions, agreed that exercise therapy had the strongest evidence base, particularly for positive effects of either single hip or knee muscle training or a combination of both, but there was insufficient evidence to determine the optimal form of training and long-term effects. In contrast, supporting evidence regarding core stability training, gait retraining, and interventions for BFR remains limited. In order to select the optimal exercise treatment modality for PFPS, higher quality evidence and studies are needed.

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Biography

Qiu Nie (1994-), female, technician, mainly researches on musculoskeletal pain rehabilitation and sports injury rehabilitation.