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Analysis of Patellofemoral Pain Syndrome in Fencers

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Abstract. The clinical manifestations, pathogenesis and rehabilitation strategies of the patellofemoral pain syndrome (PFPS) in fencing athletes are systematically analyzed. The unique "combat stance" and explosive lunge movements in fencing cause the knee joint to bear high-intensity loads for a long time, resulting in abnormal increase in the pressure on the patellofemoral joint. PFPS in fencing athletes is characterised by static dull pain and dynamic sharp pain, which is debilitating and drastically affects their athletic performance, and may eventually lead to the development of patellofemoral osteoarthritis. Pathogenesis includes abnormal patellar trajectory, weak hip muscle groups, limited ankle joint movement and absence of buffering by the metal piste. Female athletes are at a greater risk because they have a larger Q angle and because of fluctuations in their hormones. Rehabilitation should focus on more than just passive pain relief and move towards re-education of movement patterns, balance training around the hip and knee muscle groups and strict management of training load. Hip and Core strengthening has been demonstrated to be an effective method in alleviating knee pain and enhancing function along with traditional knee treatments. Future studies, long-term prospective studies of the fencing population are warranted, and the use of wearable feedback technology should be investigated in the field of injury prevention.

Keywords: Patellofemoral pain syndrome, Fencing, Knee pain, Hip-core strengthening, Injury prevention

1. Introduction

Patellofemoral pain syndrome (PFPS) is one of the most common and challenging musculoskeletal conditions that a sports medicine practitioner will see today [1]. Generally characterised by a vague and often insidious anterior knee pain, either around or deep to the patella, the problem can often be baffling and challenging for clinicians and athletes alike and has a complex and multifactorial aetiology [2]. Although PFPS is well known to be worsened by activities that increase compressive stresses across the patellofemoral joint, such as running, deep squatting, and ascending stairs, it is syndrome is sports-specific. Detailed examination of this condition in specific sports groups can provide valuable information on the mechanical causes of the condition. In the sport of Fencing, a high-intensity combat sport involving asymmetrical movement, provides a more intriguing example illustrating aspects of PFPS pathogenesis and management.

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Understanding the biomechanics of fencing will enable one to see why fencers are so susceptible to this syndrome. Fencing is unlike many track and field events where they are continuous, cyclical and symmetrical - it relies greatly on a highly specialized and asymmetrical posture called "en garde" [3]. （This is a basic position, where knee flexion in both the front legs and back legs is constant, but not full. This semi-squat is NOT a resting position – it is a very active stance of muscular co-contraction that is used to keep the center of mass low for instantaneous, explosive maneuvers. In this position, the fencers make quick forward movements, sudden backward moves, sudden direction changes and the typical offensive movement, the lunge.

The fencing lunge is a ballistic movement that places an amazing amount of mechanical stress on the lower limbs [4]. When performing a lunge, the back leg produces a large amount of propulsion, and extends powerfully to propel the body forward. At the same time, the front leg will have to extend forward and take the whole of the body's slowing mass at the moment of heel strike. This weight-acceptance phase puts the anterior knee compartment of the lead leg under huge eccentric load. These movements are repeated hundreds of times during each practice session or competition bout and the patellofemoral joint is exposed to micro-trauma with each repetition [5]. The combination of static flexion and explosive dynamic loading provides an environment very conducive for the development of PFPS. Therefore, anterior knee pain is not just a passing inconvenience for the fencing community, but a significant structural and functional restriction that can impact dynamic stability, decrease offensive velocity, and even end a potential athletic career, if not addressed [6].

However, although the condition is prevalent, the management of PFPS in fencers has been somewhat generalized and based on the strategies and management used for runners or athletes that jump. But the unique asymmetric movements of fencing call for an analytical approach of a more sport-specific nature. This paper seeks to give a thorough yet well-informed analysis of PFPS, with a particular focus on the fencing community. This analysis will go beyond simple anatomical description by systematically looking at the unique clinical manifestations, the complex biomechanical pathogenesis, and the additive specific risk factors. More than that, it will provide a critical assessment of the effectiveness and safety of existing rehabilitation approaches and offer a paradigm shift towards moving symptom management beyond passive care toward active biomechanically-informed, ed movement re-education and rigorous load management [7].

2. Signs and symptoms and potential effects

2.1. Static discomfort and dynamic symptoms

There are two presentations of PFPS in fencers: static discomfort and dynamic pain, in which different mechanical environments occur at the knee joint. Static discomfort typically becomes apparent when the knee is locked in a flexed position for a long time. Physiologically, the patella is deeper in the femoral trochlear groove when the knee is flexed. This improves the congruence of the joint but also has a great influence on the contact pressure of the retropatellar cartilage and the subchondral bone [8]. The "en garde" position for the fencers is equivalent to an isometric hold for the duration of the position. Although the quadriceps muscle group is not moving, the constant tension of the muscle keeps the patella held tightly against the femur which hinders the synovial fluid flow and develops high pressure pockets locally.

This manifestation is typically a static type and is described by athletes aseep, dull, aching feeling or a persistent feeling of pressure behind the kneecap. The discomfort may be at its worst in post-training 'rest' rather than during training. One of the classic signs of this phenomenon is the "movie-

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goer's sign" which is a clinical sign of the extreme stiffness and achy pain that occurs when a patient tries to stand after sitting with their knees bent for a long time [9]. It is a common occurrence among fencers after sitting on the bench during fencing tournaments or after a long drive after practice. The absence of dynamic movement results in a "milking" effect of synovial capsule and transient joint starvation and biochemical irritation of the highly innervated infrapatellar fat pad and surrounding retinacular tissues.

In contrast, dynamic symptoms have acute, sharp, and extremely localized pain spikes during active, load-bearing kinematics. As it applies to fencing, these symptoms are inseparably connected with the movements of deceleration and weight-acceptance. In the lunge the heel of the front leg smashes into the piste (fencing strip) with great force. The knee then rapidly flexes eccentrically in the milliseconds which follow to absorb the shock. As biomechanical alignment is disrupted even a tiny bit, the patella is exposed to dangerous shear and compression forces. The usual complaint is a sudden, grabbing pain, on the inside or outside edge of the patella, at the exact moment of heel-strike.

In addition, dynamic symptoms may include a "giving way" feeling, or pseudo-instability. This is usually not a real failure of the ligament, but an arthrogenic muscle inhibition, which is a reflex arc which quickly disengages motor unit recruitment of the quadriceps in response to a sudden increase in pain at the joint. This reflexive inhibition produces a brief buckle at the knee and can be quite frightening for an athlete in the middle of a bout. In addition, athletes often complain of an audible or palpable grinding, crunching or clicking sound as the irregular bottom of the patella slides in and out over the femurs during the fast flexion-extension movements of advancing and retreating.

2.2. Effects on athletic performance and long-term risks

When PFPS begins to occur, a domino effect of negative outcomes occurs, which ultimately negatively affect performance in sports [6]. In high-level sports, pain is not only a sensory phenomenon – it's a powerful inhibitor of motor control. Just knowing that the fencer will have to deal with pain in the future (or soon) causes the subconscious to change kinematic strategies. A fencer will tend to 'en garde' with a stiff, more upright position of the knee to prevent the compression of the back of the knee during deep knee flexion. This short term 'fix' can help with immediate pain but is a disaster for the athlete's mechanical ability. The higher the CoG, the less stable the base and the more drastically it slows down the initiation of both the offensive and defensive lunge.

In addition, this change in movement directly reduces the lunge length. PFPS athletes show a definite hesitation to fully extend the back leg that is doing the pushing and to deeply flex the front leg that is doing the catching, leading to a shorter, slower, and less effective attack. The neuromuscular hesitation is an additional huge problem in regards to tactical agility. There is a lot of confidence in being able to move quickly and deceitfully in and out of fences that requires a lot of trust in the lower limbs. When kinesiophobia (fear of pain) takes hold, fencers become "cautious, predictable and vulnerable" to the unpredictable parry/riposte exchanges of the fencing sequences. Training volume becomes almost impossible to handle in terms of overall tolerance and the athlete is unable to maintain a level of conditioning needed to be competitive.

In addition to performance impairments during the sport, PFPS also has serious consequences that may have a significant impact on the athlete long after their competitive career. Unless a fencer is able to modify their approach to training and competition, and change their biomechanics, the knee joints continue to be subjected to the chronic, asymmetrical wear and tear. The continuous abnormal patellar tracking continually exposes focal areas of articular cartilage to overload. With

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repetitive friction over a number of years, this micro-trauma exceeds the cartilage's ability to repair itself resulting in progressive softening and fibrillation and ultimately complete loss of the chondral-surface cartilage [10].

This degradation of the structure leads to early-onset patellofemoral joint osteoarthritis(PFJOA), a chronic degenerative joint disorder that is one of the most challenging to treat non-surgically [11]. It is a turning point, and, when it happens, it's a permanent change from a functional load-induced pain syndrome (PFPS) to a structural/ degenerative disease (osteoarthritis) [12]. Therefore the long term risks are that they have ongoing functional disabilities that disrupt everyday life. When everyday actions like walking up stairs, bending down to pick things up, or going on your knees cause chronic pain, it can be a burden for former athletes. This chronic decline often requires early retirement from sport and has long-lasting implications for physical activity levels throughout life, with secondary metabolic and psychological implications.

3. Pathogenesis and specific factors

3.1. Abnormal patellar tracking and increased joint pressure

When considering PFPS, it is important to move beyond a simple "wear and tear" model and instead explore in detail the complex biomechanics of the lower kinetic chain. The basic mechanism of the problem is abnormal patellar tracking [13]. The patella is a very efficient anatomical pulley which under optimal conditions will move smoothly and centrally in the femoral trochlear groove as the knee flexes and extends. This central tracking helps to spread the load of the huge forces generated by the quadriceps muscle over the largest surface area of the retropatellar cartilage, and therefore maintains contact pressures well within the physiological range [8].

The delicate balance is disrupted, however, in PFPS. Pathology is fundamentally a malalignment problem that may be caused by a number of proximal (hip), local (knee) and distal (foot and ankle) factors. The synergistic effects of the surrounding musculature become imbalanced and/or the underlying skeletal structures are allowed to rotate away from the ideal central axis, most often laterally. This sideways mal-tracking is detrimental to the mechanics of the joint. The functional contact area between the two joint surfaces is significantly decreased when the patella is displaced towards the side of the trochlear groove.

The basic principles of physics say that pressure is inversely proportional to the area on which a force acts. Thus, even under normal quadriceps force on a lunge, localized joint stress rises exponentially when force acts across a substantially reduced cartilage contact area. This overload of the area disturbs the cartilage tissue homeostasis [10]. The cartilage (the normal frictionless shock absorber) starts to deteriorate on a microscopic level. The degeneration of the cartilage causes the mechanical stress to be transferred straight into the subchondral bone which contains a high number of nociceptors (pain receptors). This causes bone marrow edema and chronic inflammation of the surrounding synovial structures and lateral retinaculum, which produces the non-specific pain that is characteristic of the syndrome. It is not a single traumatic blow to the knee, but the insidious result of thousands of poorly executed lunges and recoveries, all of which inflict a tiny little bit of damage, until the biological tipping point is reached.

3.2. Specific risk factors

The above biomechanical breakdown is not a vacuum, but is stimulated by certain known and identifiable risk factors that are especially common among fencers. All of these factors can be

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grouped into three broad categories: anatomical, neuromuscular and environmental.

Anatomically, gender differences are seen to have a profound effect on the epidemiology of PFPS with female fencers being significantly more affected than male fencers [14]. One primary reason is that females typically have a wider pelvis, which increases the Quadriceps angle (also known as Q-angle) [15]. Q-angle is the angle between the line of pull of quadriceps muscle and the line of patellar tendon. There is a greater latero-elastic force on the patella with a greater Q-angle. This excessive lateral pull during lunge is significantly more difficult to maintain central patellar tracking when the female fencer is performing a high velocity lunge. In addition, there is transient ligamentous laxity caused by cyclical hormonal changes, especially during some of the phases of the menstrual cycle, when there are increased levels of estrogen and relaxin [16]. This ligamentous laxity places greater demands on the dynamic muscular stabilisers to maintain knee alignment during explosive movements.

Proximal control at the hip is also very important as a neuromuscular factor. Many fencers have become reliant on their quadriceps to propel themselves forward and to slow down, and thus become relatively weak and/or slower to activate the posterolateral hip musculature, namely the gluteus medius and gluteus maximus [11, 17]. If these hip abductors and external rotators are weak, the femur will internally rotate and adduct during the weight-bearing phase of a lunge (kinematic fault) [18]. In this situation, it is not only the case that the patella is gliding laterally, but the femur is literally rotating under the patella, causing huge shearing forces.

In addition to this, there is also a limitation in distal ankle dorsiflexion and over-pronation of the foot, which also play a role in pathogenesis. When a fencer cannot dorsiflex (lacking ankle mobility), the body works around the lack of mobility by overpronating the foot which turns the tibia inwards. This tibial rotation is transmitted up the kinetic chain further altering the patellofemoral tracking angle. Last but not least, the surroundings and equipment should not be disregarded. Fencing takes place on a unique surface, a metal piste, which is extremely rigid and doesn't give, or absorb shocks at all. In conjunction with traditional fencing shoes that are usually designed for grip and low to the ground tactile feedback and do not provide significant "cushioning" in the heel, the vertical ground reaction forces upon heel strike are transferred nearly directly to the skeletal structures of the lower leg and knee, thereby increasing the cumulative traumatic forces that impinge on the patellofemoral joint [5].

4. Rehabilitation & correction strategies

PFPS rehabilitation in fencers needs to move beyond the outmoded recommendation of rest and ice. Passive modalities can help work on the acute pain, but will do nothing to change the underlying biomechanics that underlie the pathology [7, 19]. Any good, evidence-based intervention program should be looked upon and reviewed on a very critical level, with interventions that have demonstrated efficacy in modifying kinematics and a careful eye on safety to avoid further damage to the already damaged articular cartilage.

4.1. Postural correction and movement re-education

Movement re-education is the key stone of long-term PFPS management. It is a treatment that sees the condition as more than just an injury to the tissue, but also a motor control dysfunction. Postural correction is effective, because of neuroplasticity—the brain's capacity to rewire the firing patterns of the neuromuscular system through deliberate and repetitive practice [20]. Fencing movements are

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well ingrained and to change the way the athlete is performing the movement, a highly conscious dual agent approach is necessary - between the athlete and a sports physical therapist/biomechanist.

First, the athlete needs to be coached to avoid the bad habits, for example, to prevent the lead knee from collapsing into valgus during a lunge. This learning process is often accomplished through use of external biofeedback mechanisms that are used by therapists. With the use of mirrors or delayed video analysis, real-time visual feedback will help the fencer to see the gap between what their body is doing and what they think it is doing. Surface electromyography (sEMG) may also be used to give an audible or visual indication when the correct muscles (e.g., gluteals) are engaged compared to when the athlete is using only the quadriceps.

The patient is clinically shown how to achieve the optimum hip/knee/ankle relationship and is usually cued to maintain an alignment of the kneecap over the second toe in all footwork patterns. Movement re-education can be said to have an extremely high safety profile. The isolation of the kinematic adjustments, combined with highly controlled and slow motion and low load, is essentially removing the risk of tissue overload. When the new motor patterns are safe, they are hardwired into the athlete's central nervous system and are now ready to be integrated into high velocity, sport-specific actions.

4.2. Muscle balance training

There is strong clinical evidence to support correcting the underlying muscular imbalance and this is a non-negotiable part of PFPS management [19, 21]. There are two main goals in the rehabilitation plan: proximal strengthening (hip and core strengthening) and local targeted resistance (quadriceps optimization).

Lumbo-pelvic-hip complex is the main focus of proximal neuromuscular and core stability training. It is a simple concept with a profound rationale: controlling the femur enables control over the patellofemoral joint [11]. The athlete performs multiple exercises that isolate and force the gluteus medius and gluteus maximus to fire, such as weighted clamshells, lateral band walks, and single leg Romanian deadlifts, which are then able to resist femoral adduction and internal rotation when it comes time to decelerate in the fencing lunge [22].

In the local area, targeted quadriceps resistance training is targeted at the vastus medialis obliquus (VMO) [23]. Although there is biomechanical debate regarding isolated quadriceps strength with the VMO being stronger than VL, it is generally agreed that strengthening the whole quadriceps mechanism and the synergic firing timing of all quadriceps muscle groups is beneficial. Closed-chain exercises have a strong preference over open-chain knee extensions like leg presses, and controlled wall squats. Closed chain exercises encourage co-contraction of the hamstrings (which will stabilize the tibia) and in general, keep patellofemoral compressive forces in a more tolerable and safer physiological range.

This proximal to distal method is clearly evidenced by highly quantifiable trial data that substantiate their clinical superiority. For example, in a randomized controlled trial (N=60) that investigated athletes that were placed under high demand of their lower limbs, the researchers compared a standard 6 week isolated knee protocol to a standard 6-week combined "lumbo-pelvic-hip" neuromuscular intervention (45 minutes, 3times per week) [21]. The integrated proximal approach showed a significant statistical difference. The hip and core strengthening group had a 45% reduction in subjective pain with VAS scores of the athletic group decreasing from an average of 6.2 at baseline to 3.4 following the intervention. The traditional, knee-centred group, on the other hand, saw only a 15% pain reduction (VAS score of 6.1 to 5.2). Additionally, objective measures of dynamic functional stability (Anterior Knee Pain Scale (AKPS) and single-leg hop tests) showed a

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30% improvement in dynamic functional stability in the combined group and minimal functional improvement in the isolated knee group. This dual-focused training will shift the mechanical load away from the anterior knee compartment – which is easy to overload – and onto the powerful gluteal complex, thus quickly reducing the cumulative joint shear forces and making it the clear winner for PFPS training.

4.3. Training load management

Biomechanical correction and muscle strengthening should always be under the guidance of the general rule of load management [24]. Load management is an evidence-based, empirical approach to balance efficacy (tissue adaptation) with safety (not allowing tissue to fail). Biological tissues have an absolute limit on the amount of mechanical stress they can withstand before failing even if they are mechanically sound and very strong. In PFPS, the amount of mechanical stress applied to the patellofemoral joint should not exceed the remodeling/repairing ability of the cartilage and subchondral bone.

In the clinic, load management sets clear and measurable guidelines, especially during the important return to sport phase. Healing does not happen in a straight line and any athlete getting back into unlimited fencing too early is destined for a recurrence. Therefore, it is essential to carefully adjust the volume of training. For instance, in the initial stages of getting back to fencing, people could limit the amount of repetitive high impact lunge drills to around 30-40 repetitions per session. Also, semi-squat "en garde" footwork drills, which should be continuous and uninterrupted, should be broken into more highly specific blocks, probably 10-15 minutes, with mandatory 5-minute active recovery periods to get synovial fluid moving and properly lubricate the retro-patellar surface.

Nowadays, training intensities are monitored through more advanced sports medicine tools such as the acute to chronic workload ratio (ACWR) [25]. Coaches and clinicians can determine the correct training load in one week (acute) and compare it to the rolling average (chronic) of the previous four weeks and keep the fencer within a safe "sweet spot". The clinical team ensures absolute safety of the healing joint by controlling maximal eccentric loading while ensuring a sufficient stimulus to overload the joint mechanically and promote positive adaption of the muscle and tendon, with a full 48-hour recovery window between intense lower-body training sessions.

5. Conclusion

Patellofemoral pain syndrome in the fencing community is not a simple overuse lesion, but is a complex and multifactorial lesion, that arises from the confluence of the fencing's biomechanical stresses and each fencer's anatomic and neuromuscular characteristics. The "en garde" stance and the ballistic, high impact nature of the lunge make it an environment where patellofemoral joint stresses are amplified exponentially with deviations in the optimal lower limb alignment. It has a significant impact on performance and initiates pain-inhibition mechanisms, which takes the fencer's speed, stability and tactical agility away. More alarmingly, without the proper management through ignorance or lack of care, it will lead to chronic structural degradation and lifelong disability.

Thus, the management of PFPS must be sophisticated and evidence based, and passively superficial treatment must be discarded. Rehabilitation needs to be active, clinician-guided, and focused on re-education of motion patterns, as well as intensive, focused, and neuromuscular training focused on the proximal stability of the hip. Most importantly, these interventions need to be within a mathematically based training load management structure that acknowledges the

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biologic healing timelines of the articular tissues. This holistic, sport-specific approach will help fencers overcome their pain and optimize their movement while building a stronger, more resilient and highly sustainable fencing career.

Evidence-based literature devoted to the biomechanics specific to the sport of fencing is still shockingly limited, although there have been substantial improvements in general sports medicine. Future studies are needed to urgently focus on the need for long-term large-scale prospective cohort studies to obtain accurate baseline kinematic normative data that are specific to elite fencers. It is currently unknown from the literature, just how the knee joint reacts to a metallic piste in 10 years of career.

Additionally, no randomized controlled trials have been conducted to assess the effectiveness of incorporating up to date technology in the form of a wearable device when training fencers. Using wearable biofeedback sensors delivering real-time haptic feedback when a fencer moves into dynamic knee valgus could change the way that injuries are prevented. These evidence gaps will help the sports science community develop highly-specific, sport-specific prophylactic recommendations, further minimize the occurrence of this debilitating condition, and extend the limits of what fencing athletes can safely do.

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