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# Cyclist's Knee: A Regional Interdependent Biomechanical Injury

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## Abstract

Cyclist's Knee or Patellofemoral Pain Syndrome is the most frequently reported lower extremity repetitive stress injury incurred by cyclists. With a 40% recurrence rate after 2 years and 50% of the patients are still symptomatic or have functional impairments 5-8 years post treatment, makes this a frustrating and perplexing condition for both athletes and medical professionals. Numerous extrinsic and intrinsic risk factors have been theorized and researched. To date, no definitive etiology has been determined. Historically, cycling research and treatment has taken a cause-and-effect approach to this repetitive stress injury focusing on factors responsible for patellar maltracking. This pathomechanical action was felt to result from muscle imbalances. Research has also found malalignment and/or dysfunction at either end of the kinetic chain, the foot/ankle or pelvis/hip complex may negatively impact the functioning of the LE as a whole. The purpose of this clinical commentary is to elucidate evidence substantiating patellofemoral pain syndrome may be a simultaneous multifactorial repetitive stress injury due to the complex regional interdependent biomechanical nature of the LE. With this knowledge the development of more effective treatment protocols may bring about better outcomes.

**Keywords**

Patellofemoral Pain Syndrome; Regional Interdependence; Hip Dysfunction; Hyperpronation.

# 1 Introduction

Even with today's computerized technology for positioning a cyclist, repetitive stress injuries (RSI) are still incurred. Cyclist's Knee (Sanner, 2000) or Patellofemoral Pain Syndrome (PFPS) is the most commonly reported RSI among cyclists (Wanich et al. 2007; Silberman, 2007; Bini, 2011; Johnston et al., 2017). PFPS affects 40%-60% of recreational cyclists and 36%-62% of professional cyclists (Barrios, 1997; Wanich, 2007; Clarsen, 2010), which accounted for 57% of time-loss injuries (Clarsen, 2010). A range of 25%-40% of active people have reported PFPS symptoms (Wanich et al., 2007; Witvrouw et al., 2014; Bunt, 2018). Within the general population, 2 of 3 patients will still be symptomatic after 1 year of treatment (Collins et al., 2013) and approximately 40% will suffer a recurrence within 2 years (Crossley et al., 2016; Winters et al, 2021). Lankhorst et al. (2016) found 50% of the patients will still have symptoms and functional impairment 5-8 years after treatment. Bunt (2018) reported cases of PFPS increased by approximately 65% during the 20-year span from 1997-2017.

PFPS symptoms may include the following; pain, crepitus, restricted range of motion and swelling in the periarticular soft tissue structures surrounding the knee. The joint may also have a sensation of instability. With flexion and extension, crepitus with accompanying sharp pain may be experienced as the patellar facets repeatedly impact the femoral condyles with every pedal stroke. An average cyclist has a cadence of approximately 90 revolutions per minute resulting in approximately 5400 impacts per hour. A constant dull aching pain ensues from the chronic inflammatory response in the surrounding soft tissue structures as the result of long term pathomechanics at the patellofemoral and/or tibiofemoral joint (Goodfellow, 1976). Researchers agree the alteration in lower extremity (LE) alignment affects the load distribution at the knee (Tiberio, 1987, 1988; Powers, 2003a, 2003b, 2010; Shultz, 2009; Witvrouw, 2014).

Numerous extrinsic and intrinsic factors have been theorized and thoroughly researched including; cyclist positioning, equipment, training, muscular imbalance and anatomical malalignment. To date, there is no general consensus as to the origin, sequelae and the pathomechanics responsible for PFPS (Chrisman, 1986; Mirzabeigi et al, 1999; Doménech et al., 2014). With research being frequently inconclusive and often contradictory (Boling, 2013; Nakagawa, 2013; de Oliveira Silva et al., 2019) some researchers have been led to theorize PFPS to possibly be simultaneously multifactorial in nature (Wanich, 2007; Davis, 2010; Clarsen, 2010; Crossley, 2016; Willy et al., 2019).

# 2 Regional Interdependence

Erhard (1977) stated: "Dysfunction in any unit of the system will cause delivery of abnormal stresses to other segments of the system with the development of a subsequent dysfunction here as well". This sparked the theory of Regional Interdependence and subsequent research.

The theory of Regional Interdependence (RI) may be defined as: the possible causal relationship between seemingly unrelated dysfunctions remote from the patient's primary symptoms, which could be mutually contributory to the patient's condition (Wainner et al., 2001, 2007).

Investigations have examined RI within the spine (Cleland et al., 2005; Boyles, 2009), spinal regions and extremities (Strunce, 2009; Mintkin, 2010; Wong et al., 2018), LE and the pelvis/spine (Khamis et al., 2007; Ghasemi et al., 2016; Ingle, 2020; Zhu et al., 2021).

Abundant literature exists linking dysfunction between individual LE joints: the hip and knee (Tsuji et al., 2002; Powers 2003a, 2010; Currier et al., 2007; Souza, 2009; Finnoff et al., 2011), hip and the foot (Barwick, 2012), foot and hip (Gross et al., 2007; Pinto et al., 2008; Malik et al., 2017; Hornestam et al., 2021) and the foot and knee (Tiberio, 1988; Powers, 2003b; Molgaard, 2011; Shamus, 2015). There is research that has been conducted examining the impact of dysfunction at the foot/ankle on the LE pertaining to skeletal alignment and gait (Nguyen, 2009; Resende, 2014; Svoboda et al. 2016; Nikkhouamiri, 2019; Dodelin, 2020; Golchini, 2020; Park, 2022).

## 3 Knee Joint

The femur, tibia and patella articulate to form the knee joint. There are 3 compartments in the knee joint, medial tibiofemoral, lateral tibiofemoral and patellofemoral. Structures in any of those 3 compartments may be responsible for producing the pain perceived as PFPS. While the knee is classified as a hinge joint, primarily flexing and extending through the sagittal plane, it is also capable of movement in the transverse and coronal planes (Jawad, 2017).

The tibia's and fibula's distal articulation is with the talus, it is classified as a mortise joint and hinge joint. Due to the constraints of the ankle's retinaculum in conjunction with the ankle's medial and lateral ligaments, the ankle joint movement is primarily dorsiflexion and plantarflexion. A small amount of lower leg long axial rotation occurs when the tibia/fibula internally rotates due to the medial longitudinal arch (MLA) pronation during the midstance phase of gait. Then, as the foot transitions from midstance into propulsion or toe off phase, the MLA elevates and supinates causing the tibia to then externally rotate back to neutral.

Published evidence strongly supports knee kinetics being directly influenced proximally by hip (Lee, 2003; Robinson, 2007; Neumann, 2010; Powers, 2010; Nakagawa et al., 2012; 2015; Itoh, 2016) and distally by foot/ankle complex (James, 1978; Muller, 1983; Tiberio, 1987, 1988; Powers, 2003b). This dual dependency may account for the knee being the most common LE structure to be injured by repetitive stress in cyclists (Callaghan, 2005; Wanich, 2007; Bini, 2011).

The Quadriceps Angle (QA) is commonly utilized to determine knee alignment. This angle formed at the intersection of 2 lines, 1 connecting the anterior superior iliac spine to the midpoint of the patella and the other line is created by connecting the center of the patella to the tibial tubercle. An increased QA has been linked to PFPS (Powell, 1986; Ruby et al., 1992; Sanner, 2000; Shultz et al., 2006; Kaya, 2012; Lankhorst, 2016). Research suggests that the QA is influenced by numerous factors including: pelvic positioning, hip rotation, tibia rotation and foot alignment (McClay, 1998; Hruska, 1998; Powers, 2003a).

Patella alta (PA) or high-riding patella is a common condition incurred by athletes, Research has linked it to iliotibial band tightness (Asayama, 2025) and quadriceps femoris weakness (Stefanik et al, 2010, 2012). It is characterized by an elevated positioning of the patella in relation to the femoral condyles. Clinically, PA is associated with patellofemoral pathomechanics, instability and patellofemoral joint degeneration (Ward, 2004, 2007; Syed, 2009; Stefanik et al., 2010, 2011).

The Insall-Salvati ratio is utilized in the evaluation for PA. With the knee in a semi-flexed weight-bearing posture, the length of the patellar tendon is divided by length of the superior-inferior aspect of the patella. PA is diagnosed by an Insall-Salvati ratio of ≥1.2. (Insall, 1971).

## 4 Pelvic/Hip Interdependence

The femoroacetabular joint, the proximal link in the LE kinetic chain, is the interface between the pelvis and the LE. It is classified as a ball and socket joint allowing it to be capable of multiplanar movement (Ramage, 2023; Chang et al., 2023, Gold et al. 2024).

Researchers have linked 4 pelvis/hip risk factors to PFPS, which are: pelvis misalignment (Oshima et al., 2019; Suits, 2021; Park, 2022), femur malalignment (Lee et al., 2003, 2014; Emamvirdi, 2019), femur dysfunction (Powers; 2003a; Jacobs, 2007; Reiman, 2009; Sousa, 2010; Meira, 2011; Xie, 2023), hip musculature dysfunction (Dolak, et al., 2011; Barton et al., 2013; Xie, 2022; Reitz, 2024) and quadriceps dysfunction (Neptune, 2000; Powers, 2003b; Lankhorst, 2012).

Khamis et al. (2007, 2015) researched the relationship between anterior pelvic rotation and the femur. They reported anterior pelvic tilt causes the femur to internally rotate. Later investigations studied the interaction between pelvic malalignment and knee. Researchers found that anterior pelvic rotation triggered compensatory mechanisms that may affect the kinetics at the knee (Crossley, 2018; Oshima et al., 2019; Suits, 2021; Park, 2022).

Lee (2003, 2014) theorized rotation of either the femur or tibia would have a major influence on the patellofemoral joint contact areas and pressures. Powers et al. (2003a) utilizing dynamic magnetic resonance imaging (MRI) was able to analyse weight bearing knee joint motion of patients with PFPS. It was observed that excessive internal rotation of the femur was responsible for the patella appearing to abnormally track. Sousa et al. (2010) later confirmed those findings.

Abnormal patella tracking may be the most popular theory investigated. The medial/lateral excursion of the patella was thought to be the result of muscular dysfunction between the vastus lateralis (VL) and vastus medialis (VM) as the knee extends. Researchers theorized a strength imbalance existed between the muscles (Moller et al. 1986; Cesarelli, 1999; Neptune, 2000; Powers, 2003b; Lobo et al., 2018; Yang, 2020; Abelleyrra Lastoris, 2023). Many of these studies reported inconclusive findings, while others published contradictory data. An alternative theory had the unsynchronized contraction of the VL and VM, with a delay in the VM. (Neptune, 2000; Cowan, 2001, 2002; Boling, 2006; Van Tiggelen, 2009).

The musculature of the hip and thigh are the primary suppliers of power in pedaling motion (Burke, 1986; Pruitt, 2006; Bini, 2011, 2014; Callaghan, 2005). The gluteal region, posterior thigh along with the adductor muscles extend the femur, while simultaneously the quadriceps femoris extend the lower leg.

Alternative hypotheses have implicated a strength imbalance within the hip or thigh musculature as a potential risk factor responsible for the femoral malalignment responsible for pathomechanics at the knee joint. Evidence has been published indicating weakness in the abductors or external rotators of the femur (Long-Rossi, 2009; Prins, 2009; Salsich, 2010; Willison, 2011; Jellad, et al., 2021; Alammari, 2023). Another muscle imbalance was suggested involving the antagonistic actions of the thigh adductors and abductors (Baldon et al., 2009; Reitz, 2024). According to Neumann (2010) the bidirectional sagittal plane torque of the adductor musculature affords them to be continually involved in the pedalling motion. The adductor magnus (AM), the primary adductor of the femur also contributes to femoral extension and internal rotation (Dostal, 1986; Delp et al., 1999; Neumann, 2010; Kendall).

Researchers have found the repetitive motion of cycling may cause an overdevelopment of the AM (Hug, 2006; Endo et al. 2007; Neumann, 2010; Ema, 2016) and an adduction and internal rotation malalignment of the femur may result (Arnold, 2001; Benn et al., 2018). Further substantiation to the adductor/abductor imbalance theory may be found in the studies which found subjects with PFPS showed weaker abductors (Witvrouw et al., 2014; Jellad, et al., 2021; Alammari, 2023) or greater hip adductor strength (Willson, 2008; Boling et al., 2009) than asymptomatic subjects.

## 5 Foot/Ankle Interdependence

The foot/ankle complex, the distal link for the LE, is considered the foundation for the skeletal system. There has been ample literature reporting that hyperpronation may be responsible for malalignment of the LE, thereby altering gait and pressures at the knee (Perry, 1992; Lafortune et al., 1994; Hetsroni et al., 2006; Nguyen, 2009; Boling, 2009; Peterson , 2017; Dodelin, 2020; Reitz, 2023), Hyperpronation has also been listed as a risk factor for other LE RSI (Reitz, 2023).

Using high speed cinematography Francis (1986, 1988) was able to record the medial displacement of the knee during the power phase, 12 to 6 o'clock, hypothesizing the deviation resulted from subtalar hyperpronation. He warned of the pathomechanical effects hyperpronation could impact on the cyclist's lower extremity. Bailey (2003) was also able to capture excessive medial knee excursion in the coronal plane using video.

Hyperpronation has been shown to alter tibial rotation in both the coronal and transverse plane (Eng, 1993; Barton et al., 2009, 2010; Molgaard, 2011; Pietrzak, 2014) thereby affecting both the femur's static and dynamic alignment. These alterations may affect the kinetics of the patellofemoral, patellotibial and tibiofemoral joints (Eng, 1993; Hintermann, 1998; Barton et al., 2009, 2010). Snook (2001) reported that hyperpronation results in a loss of propulsive power and a delay in the timing of the tibia's external rotation as the foot supinates.

## 6 Discussion

Pedalling requires the synchronized functioning of properly aligned lower extremity structures, both skeletal and soft tissue. Asplund (2004) found as little as 3 millimetres of structural malalignment may result in decreased performance and an increased risk of injury.

Cyclists who develop PFPS have a pessimistic long-term prognosis with a 40% recurrence rate after 2 years and 50% of the patients are still symptomatic or have functional impairments 5-8 years post treatment.

Two researchers published observations significant to the theory of RI. Liebler (2001) stated, "A joint must have normal mobility in order for its corresponding muscles to work efficiently, evidence has shown that muscle strength and function become altered due to motion restrictions." This dysfunction is termed arthrogenic muscle inhibition. It is defined as the chronic reflex inhibition of the surrounding musculature of a joint whose structures have been damaged or distended. This damage diminishes the afferent signals and motor neuron pool excitability resulting in the joint's pathomechanics (Sedory, 2007). Neumann (2010) commented in his conclusion, "Muscle actions are currently best understood when activated from the anatomic position. What is needed, however, is a greater understanding of how a muscle's action (and strength) changes when activated outside the anatomic position."

Multiple international conferences drew the same conclusion, indicating PFPS is a multifactorial overuse injury (Davis et al., 2010; Powers et al., 2012, 2017; Crossley, 2016; Collins, 2018). However, since the concept of RI is relatively new with limited supporting research, RI is still considered speculative. As such the medical and research communities continue to approach PFPS as a cause-and-effect condition.

Researchers have advocated the RI theory and have encouraged its implementation into physical therapy protocols (Bialosky et al., 2008, 2009; Sueki, 2013; Cheatam, 2014; Collebrusco, 2016; Svoboda et al., 2016).

Studies have demonstrated treatment to a region may affect functioning and outcomes in remote and seemingly unrelated regions (DeLoe et al., 2004; Cleland et al. 2005; Currier et al., 2007; Boyles et al., 2009; Strunce et al., 2009; Souza, 2009; Synder et al., 2009; Mintkin, 2010; Sueki, 2013). Recent research advocates a multifactorial approach to PFPS treatment (Santos et al., 2015; Shamus, 2015; Svoboda et al. 2016; Halabchi et al., 2017; Nikkhouamiri, 2019; Willy et al., 2019; Dodelin, 2020; Golchini, 2020). Effective protocols have included the combination of the following procedures: hip abductor strengthening, hip external rotator strengthening, core strengthening, gait modification, foot orthotics and patellar taping. Some studies have reported expedited favourable outcomes through the incorporation of multiple modalities simultaneously (Hosey et al., 2011; Dolak et al., 2011; Yalfani, 2020l Raju et al., 2024). The data collected in studies investigating the impact of the usage of foot orthotics on the LE reflected foot orthotics were able to realign the LE and correct pathomechanics (Hatton et al., 2008; Trotter, 2008a, 2008b; Eslami et al., 2009; Fatini-Pagani et al., 2014).

The concept of LE RI may be strongly supported by the paper in which Reitz (2023) indicated that in addition to PFPS, hyperpronation may be a major component to other RSI incurred by other structures in the LE including: Medial Tibial Stress Syndrome (Hintermann, 1998; Pietrzak, 2014), Iliotibial Band Syndrome (Dodelin, 2018; Damien et al., 2018), Deep Gluteal Pain Syndrome (Rothbart, 1988) and Femoroacetabular Impingement (Khamis, 2007).

In an effort to further improve long term outcomes Selhorst et al. (2015) developed an algorithm assessing multiple factors and developing a treatment protocol. They reported their primary goals were met and that with minor changes the algorithm could be more effective.

Researchers have also theorized that RI may have a broader scope of impact on the body than just to the musculoskeletal system. Neurological (Nikkhouamiri, 2019; Golchini, 2021), neurophysiological (Bialosky, 2008; Hendrick et al., 2015), biopsychosocial (Hill, 2011) and somatovisceral (Cervero, 1999) interactions may also exist within RI.

## 7 Conclusions

PFPS will continue to be incurred and be a recurrent RSI among cyclists until further research focusing on the impact regional dysfunction of the LE extremity has on structural alignment and the functioning of the primary muscles associated with pedalling. Such knowledge would be beneficial in developing a screening procedure not only as a preventative measure ensuring all possible risk factors are analysed and appropriate interventions taken. Should a cyclist develop PFPS the same procedure may be utilized ensuring the correction of all dysfunctions attaining successful long-term outcomes.

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