

## IDIOPATHIC PATELLOFEMORAL PAIN

<https://doi.org/10.71165/ma4y-9uzc>

### AUTHORS

**Maxence Bordes** - Clinique de la Sauvegarde, Lyon, France

**Guillaume Demey** - Clinique de la Sauvegarde, Lyon, France

**Benoit Pairoto de Fontenay** - Université Claude Bernard Lyon 1, Lyon, France

**Damien Dricot** - Clinique de la Sauvegarde, Lyon, France

**Mathieu Thauinat** - Centre Orthopédique Santy, Lyon, France

### SUMMARY

**Background:** Idiopathic patellofemoral pain (iPFP) is a prevalent cause of anterior knee pain, particularly among young, athletic females. While the diagnosis is primarily clinical, the underlying pathophysiology remains complex, involving various functional impairments rather than structural defects. Effective management requires a comprehensive understanding of these multifactorial mechanisms to avoid unnecessary surgical intervention.

**Objective:** This article aims to synthesize current literature regarding the biomechanical and neurophysiological mechanisms of iPFP and to provide a structured, evidence-based approach to clinical examination and multidisciplinary management.

**Key Points:** Pathogenesis involves functional patellar maltracking, often characterized by increased lateral translation and tilt during weight-bearing flexion. Contributing factors include quadriceps imbalance, arthrogenic muscle inhibition, and dynamic knee valgus secondary to hip abductor weakness or subtalar joint dysfunction. Hamstring tightness and psychological factors, such as kinesiophobia, also influence symptom severity. Clinical evaluation should utilize dynamic tests, including the single-leg squat and balance tasks, to identify motor control deficits. Management is strictly non-surgical, prioritizing patient education, activity modification, and targeted rehabilitation. Evidence supports combining quadriceps strengthening with proximal hip stabilization. Adjunctive therapies, such as medially directed patellar taping and foot orthoses, may provide short-term symptomatic relief, whereas invasive procedures and pharmacological interventions show limited efficacy in the absence of structural pathology.

**Conclusion:** Idiopathic patellofemoral pain is a functional disorder managed through a multimodal, non-operative approach. Successful outcomes depend on patient education, load management, and corrective exercise programs addressing both local knee deficits and proximal hip mechanics to facilitate a return to activity and prevent recurrence.

### KEYWORDS

Patellofemoral Pain Syndrome; Biomechanical Phenomena; Conservative Treatment; Quadriceps Muscle; Hip

## INTRODUCTION

---

Idiopathic patellofemoral pain (iPF) is a common cause of anterior knee pain. It particularly affects young, athletic females. This population has been widely studied in literature.

A diagnosis of iPF is easy to establish by questioning the patient. However, a physical examination and targeted diagnostic tests can be used to eliminate any structural defects such as chondromalacia patella or patellar instability. Likewise, it is important to differentiate secondary, post-traumatic or postoperative patellofemoral pain, even though they may be similar to iPF.

This article aims to describe the different mechanisms involved in iPF with reference to the literature. Addressing each of these mechanisms as part of a multidisciplinary treatment approach should clear the symptoms and allow most patients to return to normal. Treatment for iPF is never surgical.

## MECHANISMS OF IPFP

---

### 1. Patellar maltracking

Abnormal patellar tracking in iPF is a functional problem that occurs during weight-bearing flexion. It should not be confused with the patellar maltracking found with trochlear dysplasia. In fact, the abnormal patellar tracking occurs without there being any structural defect. Evidence of its existence has been provided by two comparative studies in symptomatic patients during weight-bearing flexion. Draper et al. used dynamic MRI to demonstrate an increase in lateral translation and tilt. [1] Likewise in a clinical study using a motion capture system, Wilson et al. demonstrated lateral translation and rotation (in the frontal plane) of the patella whereas asymptomatic subjects tended to medial translation and rotation of the patella.[2] They also reported an increased likelihood of increased patellar tilt in patients with iPF. In both these studies, the objective evidence of the maltracking was more pronounced the greater the angle of flexion. We are not aware of any prospective study of functional patellar maltracking as a risk factor of iPF. It appears instead to be a consequence of other functional problems originating outside the patellofemoral joint in patients with iPF. These various functional problems are described below.

### 2. Quadriceps imbalance

Contraction of quadriceps is one of the main factors influencing the position of the patella during weight-bearing flexion. Some studies report a vastus medialis activation delay in patients with iPF,[3],[4],[5] although a systematic review by Chester et al. found a huge variability in results.[6] Pal et al. combined electromyographic analysis with a search for functional patellar maltracking (lateral tilt and offset) using dynamic MRI and found a correlation between the latter and a vastus medialis activation delay.[7] However, the importance of this mechanism in the onset of iPF is hard to measure and the muscle imbalance would appear to be a consequence rather than a cause. Functional quadriceps problems are instead secondary to the pain, which can lead to arthrogenic muscle inhibition (AMI) in the knee.[8]

### 3. Dynamic knee valgus

The direction of the force generated by quadriceps is another determining factor for patellar tracking. This direction can be measured during a clinical examination using the quadriceps angle, or Q angle. It is a static measurement. The Q angle is formed by extending one line between the anterior tibial tuberosity and the centre of the patella, and a second line between the centre of the patella and the anterior superior iliac spine. An increase in the Q angle increases the lateral stress on the patella. There is debate as to any link between an increased Q angle and iPPF. Some authors report an increase in Q angle as a risk factor for iPPF.[9] On the other hand, two recent systematic reviews report no link between Q angle and iPPF.[10],[11] The fact that some patients develop iPPF with lateral patellar translation but no increase in Q angle and no other structural malalignment would support the hypothesis of dynamic knee valgus. Dynamic knee valgus is an abnormal movement pattern of the lower limb, observed during weight bearing. The hypothesis is that excessive knee valgus during activities such as jumping or running is correlated to the development of iPPF by placing excessive lateral stress on the patellofemoral joint. This hypothesis has been confirmed in various studies of symptomatic patients,[12],[13] but ruled out as an iPPF risk factor by two systematic reviews.[10],[11] Dynamic knee valgus is probably therefore a consequence rather than a cause of iPPF. Furthermore, although debated, dynamic knee valgus could be a contributing factor in other knee injuries such as anterior cruciate ligament tears.[14],[15] From a biomechanical viewpoint, this problem is itself a consequence of internal rotation of the femur and tibia.[16] Internal rotation of femur originates in the hip, whereas internal rotation of tibia arises in the foot.

#### • Weak hip muscles

The excessive medial femoral rotation seen with dynamic knee valgus is the consequence of weak lateral rotators and abductor muscles in the hip (gluteus minimus and gluteus medius). Several recent systematic reviews have recognised the existence of a reduction in abduction, external rotation and extension of the hip in female athletes with iPPF compared to healthy volunteers.[17],[18] These studies assessed hip muscle strength during single-leg squats. However, the systematic review by Neal et al.[10] did not report this same risk factor, but on the contrary even reported greater hip strength as a predisposing factor of iPPF in an adolescent population. Once again, hip muscle weakness would appear to be a consequence rather than a cause of iPPF.

#### • Functional foot problems

Poor control of the subtalar joint during weight bearing could result in functional valgus of the hindfoot, which in turn can lead to internal rotation of the tibia. This internal tibial rotation can subsequently cause internal rotation of the femur and contribute to dynamic knee valgus. Barton is one of the authors who has most studied the link between iPPF and foot kinematics.[19] In a comparative study he evidenced a link between iPPF and an increase in hindfoot valgus. However, a recent meta-analysis concluded that current scientific proof is not strong enough to support this mechanism as a predisposing factor for iPPF.[20] Studies based on patient motor patterns are tricky to conduct and this could be a major shortcoming in current literature. Orthotics are commonly prescribed for iPPF and some studies have reported short-term clinical benefits.

### 4. Hamstring tone

As we saw with quadriceps imbalance, functional problems are not limited to the frontal plane. Several authors describe early hamstring contraction,[21] increased hamstring/quadriceps cocontraction,[20] and limited hamstring extensibility in patients with iPPF.[19] Martinez et al. identified hamstring stiffness as a risk factor for iPPF after a half marathon.[22] However, in the prospective study by Witvrouw, hamstring extensibility is not reported as an iPPF risk factor.[23] Hamstring stiffness could therefore also be a consequence of the pain and linked to the problem of AMI.

## 5. Knee-spine syndrome

There is no proven link between iPFJ and problems with the spine. However, many authors suspect the existence of such a link and there is a reported clinical benefit of exercises to strengthen the spine combined with work on the hip and knee muscles.[40] Tsuji et al. report a correlation between increased sacral tilt and patellofemoral joint pain in an elderly population.[24] These arguments support the notion of knee-spine syndrome.

## 6. Psychological factors

The psychological component should not be overlooked. Nevertheless, it is not a primary or systematic cause. It is important to understand the potential psychological mechanisms - subjectivity of pain, apprehension, low effort tolerance and secondary benefits. The intensity of the pain sometimes contrasts with the normality of the clinical examination and tests. Patients must be reassured and time taken to educate them in the treatment methods. Domenech et al. report kinesiophobia as a predictive factor of pain intensity in patients with iPFJ.[25]

## 7. Intense use and poor practices

External factors play an important role in the occurrence and consolidation of iPFJ. Frequent intense exercise with insufficient recovery time between sessions is thought to be a main cause of the onset of iPFJ.[26],[27] There is no published link between running technique or footwear and iPFJ,[28],[29] although these factors may influence (increase or reduce) stresses on the patellofemoral joint.[30]

## 8. Neurophysiological factors

The exact origin of the pain stimulus in patients with iPFJ is not known. The pain has for a long time thought to originate in the cartilage. The theory that iPFJ patients experience greater biomechanical stresses in the patellofemoral joint was not corroborated by a comparative study.[31] More recently, the notion of tissue homeostasis has emerged, suggesting that the pain stimulus is seated instead in the retinacula, Hoffa's fat pad and synovial membrane.[32],[33],[34] Central anomalies in terms of pain threshold have also been identified in patients with iPFJ.[35]

# PHYSICAL EXAMINATION

---

The history-taking and physical knee examination should be conducted as normal. iPFJ should be suspected with any mention of the characteristic features of patellofemoral joint pain combined with the correct circumstances: [36]

- Pain around or behind the patella, which is aggravated by at least one activity that loads the patellofemoral joint during weight-bearing (e.g. squatting, stair ambulation, jogging/running, hopping/jumping)

The patellofemoral joint may be painful during examination of the knee. Several tests help to identify crepitus during knee flexion movements, tenderness on patellar facet palpation, small effusion, pain on sitting, rising from sitting or straightening the knee following sitting. Pain during palpation of the retinacula is also typical. However, none of the patellar provocation or mobilization tests are particularly sensitive or specific to iPFJ.[37] Effort should also be made to check for signs of a structural anomaly, which would then require further diagnostic tests. The presence of effusion may suggest inflammation but does not rule out the diagnosis of iPFJ. Likewise, a flexion contracture with hamstring stiffness indicates a link with AMI.

The second stage involves dynamic leg tests. The aim is to detect any iPPF and allow the clinician to search for objective signs of functional leg problems secondary to iPPF. A simple walking test may be helpful, however there are more specific dynamic tests that will reveal hip muscle weakness, dynamic knee valgus and poor subtalar control respectively:

- Single-leg balance: ask the patient to stand on one leg with the hands on the hips and bend the knee to about 60° for 1 minute. Inability to maintain the pose for 1 minute or pelvic movement will indicate weakness of the hip abductor muscles.[38]
- Single-leg squat: Ask the patient to stand on one leg and squat. This test will reveal dynamic knee valgus (compare with the static leg axis).[39] This test will also trigger pain with a sensitivity of over 90%.[40]

## TREATMENT

---

First, we will list the various therapeutic tools at our disposal. For each tool we will try to provide scientific proof of efficacy. We will see that, in current literature, the various procedures are studied as part of combined programmes, making it hard to interpret the results. Finally, we will propose a treatment programme based on our own clinical experience.

### 1. Education

The benefit of patient education for the treatment of iPPF has been the subject of a recent review.[41] Patient education is essential and should routinely cover several aspects:

- Reassurance: the intensity of the pain contrasts with the normalcy of clinical examinations and tests. In addition, the symptoms sometimes become chronic and patients may have already tried several treatments. It is important to reassure the patient as to the functional nature of their condition and restore their faith in their own abilities.
- Recognition: Proving the existence of a functional problem by means of a clinical examination will give the patient evidence of their condition. It is important to involve the patient in the diagnostic process. Patients should be told about the causative triggers, mechanisms and consequences of their functional problem.
- Self-recovery: Teaching self-recovery techniques is an integral part of patient education to make the recovery process more successful and long-lasting.
- Activity modification and load management: Teaching patients strategies for modifying their activity levels in order to reduce the symptoms and gradually return to the desired level of activity.[42]

### 2. Rehabilitation

Physical therapy forms the cornerstone of treatment. The treatment arsenal is huge and there has been a recent spate of publications about comparative studies. It is important to note that patient assessment usually takes place between 6 and 12 weeks.

- Muscle strengthening: Muscle strengthening exercises are the most widely studied form of treatment and the most widely practised for iPPF. Strengthening the quadriceps muscle is a proven method, despite there being no evidence of a causal link between quadriceps weakness and iPPF. This clinical outcome is probably explained by the common association between AMI and iPPF, as well as the gradual increase of weight-bearing on the joint. On the contrary, despite the fact that iPPF patients have been found to have

weak hip muscles, rehabilitation programmes do not always include the corresponding strengthening exercises. Several meta-analyses have shown that quadriceps strengthening combined with hip muscle exercises give better outcomes than quadriceps strengthening alone.[43],[44],[45] On the other hand, a programme for strengthening the hip muscles and improving motor control in the legs and spine also appears better than quadriceps strengthening alone.[40] The literature does not always contain an accurate description of the method and frequency of these muscle strengthening exercises. One randomized study reported superior clinical outcomes with high-dose high-repetition therapy (9 sets of 30 reps) than with low-dose low-repetition therapy (5 sets of 10 reps) for muscle strengthening exercises done three times a week.[46] Randomized studies have compared open chain vs. closed chain quadriceps strengthening but found no significant difference between the two techniques.[47],[48] We are not aware of any studies on the benefits of isokinetic exercises for iPPF.

- Stretches: In literature, stretching exercises tend to be combined with other physical therapy so we are unable to isolate this particular treatment. Moyano et al. report superiority of stretching exercises with proprioceptive neuromuscular facilitation compared to traditional stretches.[49]
- Proprioception: Proprioception exercises may be beneficial in the treatment of iPPF. The concept has not been widely studied but some articles do include a few exercises of a proprioceptive nature. Baldon et al. compared a quadriceps muscle strengthening programme to a hip/knee strengthening programme combined with proprioception exercises and reported a better clinical outcome in the latter group.[50]
- Gait retraining: Gait retraining for the treatment of iPPF has been the subject of a recent review.[51] It was proposed following the realization that iPPF could persist or recur even after well-observed conventional exercises. The general principle is based on feedback mechanisms. The feedback can be provided in various forms (e.g. visual, auditory, or haptic) and using different techniques (e.g. video monitor, electromyogram). In one study of 10 runners with iPPF, Noehren et al. demonstrated a reduction in hip adduction and pain thanks to real-time video feedback.[52] In another study, Bramah et al. report a clinical benefit from a 10% increase in step rate for runners with iPPF.[53] For this study, subjects were given feedback during running exercises using a metronome.

### 3. Additional treatments

#### - Adhesive strapping or taping

Taping involves placing adhesive strips on the skin in a certain direction and under a certain amount of tension to adjust patellar tracking. Taping applied medially to the patella can combat lateral translation during flexion (McConnell technique). According to Pfeiffer et al., taping has an immediate effect on patellar tracking (dynamic MRI). However, this effect is not seen after exercise.<sup>54</sup> Another study found no effect on patellar medialization.[55] In addition, taping has been reported to cause earlier activation of vastus medialis obliquus.[4] In their meta-analysis, Barton et al. confirmed the clinical benefit of taping for short-term symptom alleviation (12 weeks) when combined with physical therapy.[56] Another taping method known as Kinesio-Taping has met with some commercial success. It differs from the traditional McConnell technique insofar as the tapes are placed in a circular arrangement around the patella and the mechanism of action is focused on proprioception. The short-term ability of this technique to reduce symptoms has been validated clinically in combination with a physical rehabilitation protocol.[57]

#### - Leg brace

Draper et al. used dynamic MRI to confirm that patellar kinematics can be modified by wearing a brace.<sup>1</sup> However, according to a consensus of iPPF experts, the short- and mid-term benefits of a brace are uncertain.[58]

The Cochrane review by Smith et al. reports that wearing a brace does not reduce knee pain or improve knee function in patients with iPPF.[59] It also describes negative effects due to the discomfort and skin abrasion.

- Orthopaedic insoles

The hypothesis of functional problems with the hindfoot has prompted the use of orthopaedic insoles. One randomized study found evidence of the benefits of these insoles compared with a wait-and-see policy.[60] Another study reported similar results in combination with physiotherapy.[61] The soles used were commercially-available designs with added arch support and a varus-producing wedge. Given the limited ability of soles to alter foot biomechanics, they are ultimately more effective at reducing symptoms than modifying any functional hindfoot problems. According to the consensus statement on iPPF, the use of foot orthoses can reduce pain in the short term and allow a faster resumption of activities.[58]

## 4. Medication

There is no evidence that non-steroidal anti-inflammatory drugs are an effective treatment for iPPF. However, their short-term use during the acute phase if there is any associated effusion could provide rapid relief from the intensity of the pain and improve patient compliance with the treatment programme.

## 5. Other treatments

In the absence of any structural injury, invasive treatments have little place in the management of iPPF. However, once all other treatment options have been exhausted then this option could be considered, and so it is important to understand the outcomes. If there is no structural damage then surgery is contraindicated as a treatment for iPPF. Kettunen et al. conducted a randomized study in 2007 to compare arthroscopy vs. exercise alone.[62] The study had many limitations, such as small population size, high incidence of cartilage damage and wide variety of arthroscopic procedures. The authors found no significant difference in functional outcomes at nine months between the two groups. Kesary et al. recently reported the clinical benefit of botulinum toxin injections when combined with physiotherapy for iPPF.[63] This therapeutic option has yet to be evaluated. Intra-articular hyaluronic acid has been assessed in a randomized study that found no clinical benefit.[64] Finally, comparative studies have evaluated a number of other treatments but found no clinical benefit: manipulation of the lumbar spine or legs, electrostimulation, ultrasound, blood flow restriction and acupuncture.

## 6. Summary

Patient education is an essential part of the management of iPPF. The priorities are activity modification and improved load management in order to reduce symptoms. A short course of non-steroidal anti-inflammatory drugs may be prescribed at this stage, especially if there is significant effusion or AMI. Physiotherapy should then begin, focusing on exercises to strengthen the quadriceps and gluteal muscles. The exercise programme should then be customized based on the patient's level of symptoms (during, immediately after and the next day), exercise and sporting activities. In the most severe cases or special situations (elite athletes), admission to a rehabilitation unit may be an option. In all cases, patients must be shown exercises that they can do themselves. Taping or orthopaedic insoles may be combined in the short-term with physiotherapy. For treatment-resistant forms or in case of hospitalisation, we have used retraining therapy.

# CONCLUSION

Idiopathic patellofemoral pain is a common condition, and it is important to understand the various mechanisms involved and their consequences in order to educate patients and provide suitable care. We present an algorithm for summarising the pathogenesis and treatment of this disorder. Treatment is multimodal and multidisciplinary. It is essential for the patient to be involved in their own treatment regime to effect deep functional change and prevent a recurrence of the iPF upon resumption of activities (Fig. 1).

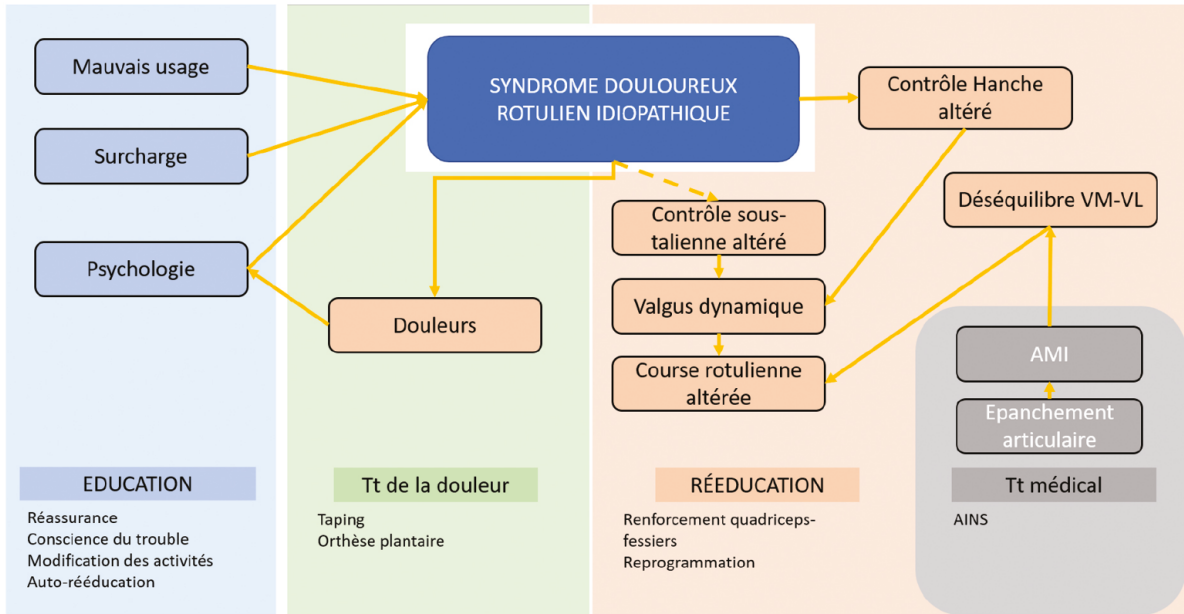


Figure 1: Algorithm for the pathogenesis and treatment of idiopathic patellofemoral syndrome.

## REFERENCES

1. Draper CE, Besier TF, Santos JM, Jennings F, Fredericson M, Gold GE, et al. Using Real-Time MRI to Quantify Altered Joint Kinematics in Subjects with Patellofemoral Pain and to Evaluate the Effects of a Patellar Brace or Sleeve on Joint Motion. *J Orthop Res* 2009;27:571–7. <https://doi.org/10.1002/jor.20790>.
2. Wilson NA, Press JM, Koh JL, Hendrix RW, Zhang L-Q. In Vivo Noninvasive Evaluation of Abnormal Patellar Tracking During Squatting in Patients with Patellofemoral Pain. *J Bone Joint Surg Am* 2009;91:558–66. <https://doi.org/10.2106/JBJS.G.00572>.
3. Chen H-Y, Chien C-C, Wu S-K, Liao J-J, Jan M-H. Electromechanical delay of the vastus medialis obliquus and vastus lateralis in individuals with patellofemoral pain syndrome. *J Orthop Sports Phys Ther* 2012;42:791–6. <https://doi.org/10.2519/jospt.2012.3973>.
4. Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. *Arch Phys Med Rehabil* 2001;82:183–9. <https://doi.org/10.1053/apmr.2001.19022>.
5. Cavazzuti L, Merlo A, Orlandi F, Campanini I. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. *Gait Posture* 2010;32:290–5. <https://doi.org/10.1016/j.gaitpost.2010.06.025>.
6. Chester R, Smith TO, Sweeting D, Dixon J, Wood S, Song F. The relative timing of VMO and VL in the aetiology of anterior knee pain: a systematic review and meta-analysis. *BMC Musculoskelet Disord* 2008;9:64. <https://doi.org/10.1186/1471-2474-9-64>.
7. Pal S, Draper CE, Fredericson M, Gold GE, Delp SL, Beaupre GS, et al. Patellar maltracking correlates with vastus medialis activation delay in patellofemoral pain patients. *Am J Sports Med* 2011;39:590–8. <https://doi.org/10.1177/0363546510384233>.
8. Greuel H, Herrington L, Liu A, Jones RK. How does acute pain influence biomechanics and quadriceps function in individuals with patellofemoral pain? *Knee* 2019;26:330–8. <https://doi.org/10.1016/j.knee.2018.12.008>.
9. Lankhorst NE, Bierma-Zeinstra SMA, van Middelkoop M. Factors associated with patellofemoral pain syndrome: a systematic review. *Br J Sports Med* 2013;47:193–206. <https://doi.org/10.1136/bjsports-2011-090369>.
10. Neal BS, Lack SD, Lankhorst NE, Raye A, Morrissey D, van Middelkoop M. Risk factors for patellofemoral pain: a systematic review and meta-analysis. *Br J Sports Med* 2019;53:270–81. <https://doi.org/10.1136/bjsports-2017-098890>.
11. Pappas E, Wong-Tom W. Prospective Predictors of Patellofemoral Pain Syndrome: A Systematic Review With Meta-analysis., Prospective Predictors of Patellofemoral Pain Syndrome: A Systematic Review With Meta-analysis. *Sports Health* 2012;4, 4:115, 115–20. <https://doi.org/10.1177/1941738111432097>, 10.1177/1941738111432097.
12. Nakagawa TH, Moriya ETU, Maciel CD, Serrão FV. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther* 2012;42:491–501. <https://doi.org/10.2519/jospt.2012.3987>.
13. Myer GD, Ford KR, Foss KDB, Goodman A, Ceasar A, Rauh MJ, et al. The Incidence and Potential Pathomechanics of Patellofemoral Pain in Female Athletes. *Clinical Biomechanics (Bristol, Avon)* 2010;25:700. <https://doi.org/10.1016/j.clinbiomech.2010.04.001>.
14. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med* 2005;33:492–501. <https://doi.org/10.1177/0363546504269591>.
15. Cronström A, Creaby MW, Ageberg E. Do knee abduction kinematics and kinetics predict future anterior cruciate ligament injury risk? A systematic review and meta-analysis of prospective studies. *BMC Musculoskelet Disord* 2020;21:563. <https://doi.org/10.1186/s12891-020-03552-3>.

16. Souza RB, Draper CE, Fredericson M, Powers CM. Femur Rotation and Patellofemoral Joint Kinematics: A Weight-Bearing Magnetic Resonance Imaging Analysis. *Journal of Orthopaedic & Sports Physical Therapy* 2010;40:277–85. <https://doi.org/10.2519/jospt.2010.3215>.
17. Crowell KR, Nokes RD, Cosby NL. Weak Hip Strength Increases Dynamic Knee Valgus in Single-Leg Tasks of Collegiate Female Athletes. *Journal of Sport Rehabilitation* 2021;30:1220–3. <https://doi.org/10.1123/jsr.2021-0043>.
18. Dix J, Marsh S, Dingenen B, Malliaras P. The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review. *Phys Ther Sport* 2019;37:197–209. <https://doi.org/10.1016/j.ptsp.2018.05.015>.
19. Barton CJ, Levinger P, Crossley KM, Webster KE, Menz HB. The relationship between rearfoot, tibial and hip kinematics in individuals with patellofemoral pain syndrome. *Clin Biomech (Bristol, Avon)* 2012;27:702–5. <https://doi.org/10.1016/j.clinbiomech.2012.02.007>.
20. Martinelli N, Bergamini A, Burssens A, Toschi F, Kerkhoffs G, Victor J, et al. Does the Foot and Ankle Alignment Impact the Patellofemoral Pain Syndrome? A Systematic Review and Meta-Analysis. *Journal of Clinical Medicine* 2022;11:2245. <https://doi.org/10.3390/jcm11082245>.
21. Patil S, Dixon J, White LC, Jones AP, Hui ACW. An electromyographic exploratory study comparing the difference in the onset of hamstring and quadriceps contraction in patients with anterior knee pain. *Knee* 2011;18:329–32. <https://doi.org/10.1016/j.knee.2010.07.007>.
22. Martinez-Cano JP, Ramos-Rivera JC, Gómez-García J, Casas-Barragán GA, Rosales MC, Escobar-Gonzalez SS. Anterior knee pain in runners after a half-marathon race. *J Clin Orthop Trauma* 2021;23:101640. <https://doi.org/10.1016/j.jcot.2021.101640>.
23. Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. *Am J Sports Med* 2000;28:480–9. <https://doi.org/10.1177/03635465000280040701>.
24. Tsuji T, Matsuyama Y, Goto M, Yimin Y, Sato K, Hasegawa Y, et al. Knee-spine syndrome: correlation between sacral inclination and patellofemoral joint pain. *J Orthop Sci* 2002;7:519–23. <https://doi.org/10.1007/s007760200092>.
25. Domenech J, Sanchis-Alfonso V, López L, Espejo B. Influence of kinesiophobia and catastrophizing on pain and disability in anterior knee pain patients. *Knee Surg Sports Traumatol Arthrosc* 2013;21:1562–8. <https://doi.org/10.1007/s00167-012-2238-5>.
26. Hall R, Barber Foss K, Hewett TE, Myer GD. Sport specialization's association with an increased risk of developing anterior knee pain in adolescent female athletes. *J Sport Rehabil* 2015;24:31–5. <https://doi.org/10.1123/jsr.2013-0101>.
27. Rathleff MS, Vicenzino B, Middelkoop M, Graven-Nielsen T, van Linschoten R, Hölmich P, et al. Patellofemoral Pain in Adolescence and Adulthood: Same Same, but Different? *Sports Med* 2015;45:1489–95. <https://doi.org/10.1007/s40279-015-0364-1>.
28. Malisoux L, Theisen D. Can the “Appropriate” Footwear Prevent Injury in Leisure-Time Running? Evidence Versus Beliefs. *J Athl Train* 2020;55:1215–23. <https://doi.org/10.4085/1062-6050-523-19>.
29. Ceyskens L, Vanelderden R, Barton C, Malliaras P, Dingenen B. Biomechanical Risk Factors Associated with Running-Related Injuries: A Systematic Review. *Sports Med* 2019. <https://doi.org/10.1007/s40279-019-01110-z>.
30. Dos Santos AF, Nakagawa TH, Serrão FV, Ferber R. Patellofemoral joint stress measured across three different running techniques. *Gait Posture* 2019;68:37–43. <https://doi.org/10.1016/j.gaitpost.2018.11.002>.
31. Wirtz AD, Willson JD, Kernozek TW, Hong D-A. Patellofemoral joint stress during running in females with and without patellofemoral pain. *Knee* 2012;19:703–8. <https://doi.org/10.1016/j.knee.2011.09.006>.
32. Post WR, Dye SF. Patellofemoral Pain: An Enigma Explained by Homeostasis and Common Sense. *Am J Orthop (Belle Mead NJ)* 2017;46:92–100.
33. Sanchis-Alfonso V, Roselló-Sastre E. Immunohistochemical analysis for neural markers of the lateral retinaculum in patients with isolated symptomatic patellofemoral malalignment. A neuroanatomic basis for anterior knee pain in the active young patient. *Am J Sports Med* 2000;28:725–31. <https://doi.org/10.1177/03635465000280051801>.

34. Dye SF. The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. *Clin Orthop Relat Res* 2005;100–10. <https://doi.org/10.1097/01.blo.0000172303.74414.7d>.
35. De Oliveira Silva D, Rathleff MS, Petersen K, Azevedo FM de, Barton CJ. Manifestations of Pain Sensitization Across Different Painful Knee Disorders: A Systematic Review Including Meta-analysis and Metaregression. *Pain Med* 2019;20:335–58. <https://doi.org/10.1093/pm/pny177>.
36. Crossley KM, Stefanik JJ, Selfe J, Collins NJ, Davis IS, Powers CM, et al. 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 1: Terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome measures. *Br J Sports Med* 2016;50:839–43. <https://doi.org/10.1136/bjsports-2016-096384>.
37. Haim A, Yaniv M, Dekel S, Amir H. Patellofemoral Pain Syndrome: Validity of Clinical and Radiological Features. *Clinical Orthopaedics and Related Research* 2006;451:223–8. <https://doi.org/10.1097/01.blo.0000229284.45485.6c>.
38. Lopes Ferreira C, Barton G, Delgado Borges L, Dos Anjos Rabelo ND, Politti F, Garcia Lucareli PR. Step down tests are the tasks that most differentiate the kinematics of women with patellofemoral pain compared to asymptomatic controls. *Gait Posture* 2019;72:129–34. <https://doi.org/10.1016/j.gaitpost.2019.05.023>.
39. Crossley KM, Zhang W-J, Schache AG, Bryant A, Cowan SM. Performance on the single-leg squat task indicates hip abductor muscle function. *Am J Sports Med* 2011;39:866–73. <https://doi.org/10.1177/0363546510395456>.
40. Cook C, Mabry L, Reiman MP, Hegedus EJ. Best tests/clinical findings for screening and diagnosis of patellofemoral pain syndrome: a systematic review. *Physiotherapy* 2012;98:93–100. <https://doi.org/10.1016/j.physio.2011.09.001>.
41. de Oliveira Silva D, Pazzinato MF, Rathleff MS, Holden S, Bell E, Azevedo F, et al. Patient Education for Patellofemoral Pain: A Systematic Review. *Journal of Orthopaedic & Sports Physical Therapy* 2020;50:388–96. <https://doi.org/10.2519/jospt.2020.9400>.
42. Rathleff MS, Graven-Nielsen T, Hölmich P, Winiarski L, Krommes K, Holden S, et al. Activity Modification and Load Management of Adolescents With Patellofemoral Pain: A Prospective Intervention Study Including 151 Adolescents. *Am J Sports Med* 2019;0363546519843915. <https://doi.org/10.1177/0363546519843915>.
43. Lack S, Barton C, Sohan O, Crossley K, Morrissey D. Proximal muscle rehabilitation is effective for patellofemoral pain: a systematic review with meta-analysis. *Br J Sports Med* 2015;49:1365–76. <https://doi.org/10.1136/bjsports-2015-094723>.
44. Nascimento LR, Teixeira-Salmela LF, Souza RB, Resende RA. Hip and Knee Strengthening Is More Effective Than Knee Strengthening Alone for Reducing Pain and Improving Activity in Individuals With Patellofemoral Pain: A Systematic Review With Meta-analysis. *Journal of Orthopaedic & Sports Physical Therapy* 2018;48:19–31. <https://doi.org/10.2519/jospt.2018.7365>.
45. Wallis JA, Roddy L, Bottrell J, Parslow S, Taylor NF. A Systematic Review of Clinical Practice Guidelines for Physical Therapist Management of Patellofemoral Pain. *Phys Ther* 2021;101:pzab021. <https://doi.org/10.1093/ptj/pzab021>.
46. Østerås B, Østerås H, Torstensen TA, Vasseljen O. Dose-response effects of medical exercise therapy in patients with patellofemoral pain syndrome: a randomised controlled clinical trial. *Physiotherapy* 2013;99:126–31. <https://doi.org/10.1016/j.physio.2012.05.009>.
47. Herrington L, Al-Sherhi A. A controlled trial of weight-bearing versus non-weight-bearing exercises for patellofemoral pain. *J Orthop Sports Phys Ther* 2007;37:155–60. <https://doi.org/10.2519/jospt.2007.2433>.
48. Witvrouw E, Danneels L, Van Tiggelen D, Willems TM, Cambier D. Open versus closed kinetic chain exercises in patellofemoral pain: a 5-year prospective randomized study. *Am J Sports Med* 2004;32:1122–30. <https://doi.org/10.1177/0363546503262187>.
49. Moyano FR, Valenza MC, Martin LM, Caballero YC, Gonzalez-Jimenez E, Demet GV. Effectiveness of different exercises and stretching physiotherapy on pain and movement in patellofemoral pain syndrome: a randomized controlled trial. *Clin Rehabil* 2013;27:409–17. <https://doi.org/10.1177/0269215512459277>.

50. Baldon R de M, Serrão FV, Scattone Silva R, Piva SR. Effects of Functional Stabilization Training on Pain, Function, and Lower Extremity Biomechanics in Women With Patellofemoral Pain: A Randomized Clinical Trial. *Journal of Orthopaedic & Sports Physical Therapy* 2014;44:240–51. <https://doi.org/10.2519/jospt.2014.4940>.
51. Davis IS, Tenforde AS, Neal BS, Roper JL, Willy RW. Gait Retraining as an Intervention for Patellofemoral Pain. *Curr Rev Musculoskelet Med* 2020;13:103–14. <https://doi.org/10.1007/s12178-020-09605-3>.
52. Noehren B, Scholz J, Davis I. The effect of real-time gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome. *Br J Sports Med* 2011;45:691–6. <https://doi.org/10.1136/bjsm.2009.069112>.
53. Bramah C, Preece SJ, Gill N, Herrington L. A 10% Increase in Step Rate Improves Running Kinematics and Clinical Outcomes in Runners With Patellofemoral Pain at 4 Weeks and 3 Months. *Am J Sports Med* 2019;47:3406–13. <https://doi.org/10.1177/0363546519879693>.
54. Pfeiffer RP, DeBeliso M, Shea KG, Kelley L, Irmischer B, Harris C. Kinematic MRI Assessment of McConnell Taping before and after Exercise. *Am J Sports Med* 2004;32:621–8. <https://doi.org/10.1177/0363546503261693>.
55. Derasari A, Brindle TJ, Alter KE, Sheehan FT. McConnell Taping Shifts the Patella Inferiorly in Patients With Patellofemoral Pain: A Dynamic Magnetic Resonance Imaging Study. *Phys Ther* 2010;90:411–9. <https://doi.org/10.2522/ptj.20080365>.
56. Barton C, Balachandar V, Lack S, Morrissey D. Patellar taping for patellofemoral pain: a systematic review and meta-analysis to evaluate clinical outcomes and biomechanical mechanisms. *Br J Sports Med* 2014;48:417–24. <https://doi.org/10.1136/bjsports-2013-092437>.
57. Logan CA, Bhashyam AR, Tisosky AJ, Haber DB, Jorgensen A, Roy A, et al. Systematic Review of the Effect of Taping Techniques on Patellofemoral Pain Syndrome. *Sports Health* 2017;9:456–61. <https://doi.org/10.1177/1941738117710938>.
58. Collins NJ, Barton CJ, Middelkoop M van, Callaghan MJ, Rathleff MS, Vicenzino BT, et al. 2018 Consensus statement on exercise therapy and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: recommendations from the 5th International Patellofemoral Pain Research Retreat, Gold Coast, Australia, 2017. *Br J Sports Med* 2018;52:1170–8. <https://doi.org/10.1136/bjsports-2018-099397>.
59. Smith TO, Drew BT, Meek TH, Clark AB. Knee orthoses for treating patellofemoral pain syndrome. *Cochrane Database Syst Rev* 2015;2015:CD010513. <https://doi.org/10.1002/14651858.CD010513.pub2>.
60. Mills K, Blanch P, Dev P, Martin M, Vicenzino B. A randomised control trial of short term efficacy of in-shoe foot orthoses compared with a wait and see policy for anterior knee pain and the role of foot mobility. *Br J Sports Med* 2012;46:247–52. <https://doi.org/10.1136/bjsports-2011-090204>.
61. Collins N, Crossley K, Beller E, Darnell R, McPoil T, Vicenzino B. Foot orthoses and physiotherapy in the treatment of patellofemoral pain syndrome: randomised clinical trial. *BMJ* 2008;337:a1735. <https://doi.org/10.1136/bmj.a1735>.
62. Kettunen JA, Harilainen A, Sandelin J, Schlenzka D, Hietaniemi K, Seitsalo S, et al. Knee arthroscopy and exercise versus exercise only for chronic patellofemoral pain syndrome: a randomized controlled trial. *BMC Medicine* 2007;5:38. <https://doi.org/10.1186/1741-7015-5-38>.
63. Kesary Y, Singh V, Frenkel-Rutenberg T, Greenberg A, Dekel S, Schwarzkopf R, et al. Botulinum toxin injections as salvage therapy is beneficial for management of patellofemoral pain syndrome. *Knee Surgery & Related Research* 2021;33:39. <https://doi.org/10.1186/s43019-021-00121-3>.
64. Hart JM, Kuenze C, Norte G, Bodkin S, Patrie J, Denny C, et al. Prospective, Randomized, Double-Blind Evaluation of the Efficacy of a Single-Dose Hyaluronic Acid for the Treatment of Patellofemoral Chondromalacia. *Orthop J Sports Med* 2019;7:2325967119854192. <https://doi.org/10.1177/2325967119854192>.