Best Practice & Research Clinical Rheumatology 33 (2019) 48–65

Contents lists available at ScienceDirect

Best Practice & Research Clinical Rheumatology

journal homepage: www.elsevierhealth.com/berh

4

Rethinking patellofemoral pain: Prevention, management and long-term consequences

Kay M. Crossley [a, *], Marienke van Middelkoop [b], Christian J. Barton [a, c], Adam G. Culvenor [a, d]

[a] La Trobe Sport and Exercise Medicine Research Centre, School of Allied Health, La Trobe University, Melbourne, Victoria, Australia
[b] Department of General Practice, Erasmus MC University Medical Center Rotterdam, the Netherlands
[c] Department of Surgery, St Vincent's Hospital, University of Melbourne, Melbourne, Victoria, Australia
[d] Institute of Anatomy, Paracelsus Medical University Salzburg and Nuremberg, Salzburg, Austria

Keywords:
Patellofemoral pain
Risk factors
Impairments
Prevention
Treatment

A B S T R A C T

Patellofemoral pain is one of the most common knee complaints, particularly among physically active young individuals. Although once thought to be self-limiting, prospective studies have demonstrated the propensity towards the chronicity of patellofemoral pain (PFP). The pathogenesis of PFP is complex, with multiple interactive pathways suggested to contribute to its onset and persistence. Quadriceps weakness is one of the few risk factors of PFP, with at least moderate evidence from prospective studies, although limited clinical trials of lower limb strengthening have generally not been successful in preventing PFP. The challenge of managing PFP is reflected by a lack of evidence-based clinical guidelines. International consensus and current evidence recommends exercise therapy, focussed on hip and knee strengthening, as a cornerstone of management to reduce PFP. Rethinking management approaches beyond exercise therapy to incorporate movement retraining, education and psychosocial aspects provides potential avenues to enhance outcomes for patients with PFP.

* Corresponding author. La Trobe Sport and Exercise Medicine Research Centre, School of Allied Health, La Trobe University, Kingsbury Drive, Bundoora, 3086, Victoria, Australia.

E-mail addresses: k.crossley@latrobe.edu.au (K.M. Crossley), m.vanmiddelkoop@erasmusmc.nl (M. van Middelkoop), c.barton@latrobe.edu.au (C.J. Barton), a.culvenor@latrobe.edu.au (A.G. Culvenor).

https://doi.org/10.1016/j.berh.2019.02.004
1521-6942/

Introduction

International consensus for the preferred term to describe pain presenting around or behind the patella is 'patellofemoral pain' [1]. This is synonymous with other terms used to describe diffuse patellar pain, including patellofemoral pain syndrome, chondromalacia patella, anterior knee pain/syndrome and runner's knee. This chapter reviews the latest insights into the prevention, management and long-term consequences of patellofemoral pain (PFP). The first section of the chapter highlights the evidence for PFP aetiology, diagnosis and incidence/prevalence. Following this, risk factors, impairments, avenues for prevention and potential long-term consequences are explored. We conclude by outlining an evidence-based approach to PFP management, and given its particular recalcitrant nature, we propose a rethinking of traditional management approaches based on recent scientific evidence.

What is patellofemoral pain?

PFP is a common knee complaint and is particularly prevalent among physically active young individuals. PFP is characterised by retropatellar pain (behind the knee cap) or peripatellar pain (around the knee cap), specifically during knee loading activities such as running, cycling, squatting, stair climbing and/or during prolonged sitting with the knees flexed at 90° [1]. Other symptoms are crepitus and a feeling of 'giving way' [2].

The pathogenesis of PFP is considered to be multifactorial but still largely unknown. In a recent consensus statement, Powers et al. (2017) emphasised the complexity of its aetiology by proposing a model showing the potential pathways that may contribute to PFP [3]. This model assumes that PFP is associated with abnormal loading of the patellofemoral joint (PFJ), i.e. elevated joint stress. Numerous factors have been associated with PFP in literature [4], and the presented model aims to summarise these factors and, in particular, describes the interaction between the individual factors. The main factors described in this model include the contact area of the PFJ, malalignment or maltracking, joint kinetics and kinematics and muscle tightness and forces [3]. Generalised quadriceps weakness and/or atrophy is the most evident factor in idiopathic PFP [4,5], although other factors, especially the interaction between factors, also seem to play an important role. The abnormal loading, as proposed in the model by Powers et al. (2017), may affect various patellofemoral structures (e.g. subchondral bone, infrapatellar fat pad, retinaculum, etc.) that can contribute to the experience of pain, i.e. nociception [3]. In 2005, Dye introduced a pathophysiological model for PFP by focussing on a loss of tissue homeostasis that may be caused by processes in the joint, such as inflammation, fat pad issues and increased intraosseous pressure [6]. A recent case–control study applied novel imaging techniques to investigate these potentially involved structures and processes [7–9]. According to this study, structural abnormalities visible on MRI – including cartilage loss, bone marrow lesions and signal intensity of the Hoffa fat pad – are not associated with PFP and should therefore not be acquired to diagnose patients with PFP [7]. However, more recently, Collins et al. showed that older adults with PFP seem to have a greater prevalence of OA features on MRI than healthy control subjects [10]. These findings suggest that structural changes in the PFJ may begin to appear towards middle age in some people with PFP. In osteoarthritis, compositional alterations are known to precede morphological alterations of cartilage, and this could also be true for PFP. Though, using quantitative MRI techniques for cartilage, no differences in cartilage composition between young subjects with PFP and healthy control subjects without knee pain have been demonstrated [8].

Another suggested pathophysiological mechanism of PFP is increased intraosseous pressure, possibly due to impaired venous outflow [9,11]. Although elevated patellar water content, indicative of an increased intraosseous pressure, was found in recreational runners with PFP compared to that in control subjects, no impaired venous blood flow was observed in the patellar bone [9,11]. The role of increased intraosseous pressure in the PFJ in patients with PFP therefore remains largely unclear and warrants further investigation.

Next to these structural approaches, it has been suggested that there may be presence of altered pain processing in subjects with PFP once there is a loss of tissue homeostasis, and pain may therefore become chronic [6]. Studies on pain sensitivity have demonstrated local and generalised hyperalgesia, the latter especially in female patients [12]. Though, contradictory results have been found, and it therefore remains unclear whether patients with PFP have altered peripheral or central processing of pain compared to healthy pain-free subjects [13].

As recently emphasised by Vicenzino et al. (2018), there is emerging evidence that suggests that the pathophysiological PFP models should encompass psychosocial and social aspects next to the biological, structural and somatic aspects [14]. There is limited evidence of mental health and cognitive differences in individuals with PFP compared to asymptomatic controls [15]. Features most likely correlated with pain and physical function in PFP include anxiety, depression, catastrophising and pain-related fear [15].

The ongoing uncertainty regarding the pathogenesis of PFP may relate to the presence of subgroups within the patient population with PFP. Selfe et al. (2016) were the first to describe subgroups of patients with PFP on the basis of six clinical tests. These included 'strong', 'weak and tighter' and 'weak and pronated foot' groups [16]. The identification of subgroups of patients with PFP by considering structural, biological, biomechanical and psychosocial factors may improve understanding of the pathogenesis of PFP and may guide the development of targeted treatments.

Incidence and prevalence of patellofemoral pain?

A wide range of incidence and prevalence of PFP has been reported in the literature. This was recently summarised by Smith et al. (2018) who described the results of 12 studies reporting incidence data of PFP and 13 reporting prevalence data [17]. Most studies were performed in selected populations such as military personnel and women. The annual prevalence of PFP was reported as 22.7%in the general population and 28.9% in adolescents [18,19]. In military, a point-prevalence of 13.5% was reported, while this was 35% in multi-day amateur cyclists [20,21]. Meta-analyses showed a point-prevalence of 7.2% in adolescents and 22.7% in female amateur athletes. The incidence of PFP has only been studied in selected populations, ranging from 9.1 to 571.4/1000 person-years in military personnel to 5.1%–14.9% in adolescent amateur athletes during one season.

As often noted in the literature, women seem to be at higher risk to develop PFP than men. Smith et al. found that female military personnel are twice as likely to develop PFP compared to male colleagues [17]. The phenomenon is most clearly seen in adolescents. Molgaard et al. (2011) found a PFP prevalence of 69% in female adolescents compared to 31% in male adolescents [22]. PFP has also been particularly associated with participation in sports activities. The most common overuse injury in running is PFP, with an annual incidence ranging from 4% to 21% in recreational runners [23–25].

Is patellofemoral pain self-limiting?

There is emerging evidence that PFP is not self-limiting. Long-term follow-up studies indicate that more than 50% of patients with PFP have an unfavourable outcome after 5–20 years [26–28]. The prognosis of adolescents with PFP seems to be similar or even worse than adults with PFP: rates of persistent symptoms up to 78% have been reported in this particular subgroup of patients [27,29,30]. Collins et al.(2013) and Lankhorst et al.(2016) described prognostic factors of adults and adolescents using data from two randomised controlled trials [26,31]. Both studies showed that patients with longer symptom duration and worse scores on the Anterior Knee Pain Scale were most likely to have an unfavourable outcome, both after one year and after five to eight years of follow-up. These outcomes were consistent with those given in a literature overview that concluded that a long duration of symptoms was the most frequently reported variable associated with a poor outcome [32].

Several authors have suggested that PFP may be a precursor to patellofemoral osteoarthritis (PFOA) [33–35]. While adequate evidence to support this is lacking [36], there are multiple converging risk factors associated with both knee conditions including crepitus, female sex and pain around the patella [5,34,37]. Additionally, increased contact pressure and shear stress have been reported in individuals with PFP, suggesting that altered joint stress may occur before structural damage in patients with PFOA [38]. Only a few studies aimed to investigate the longitudinal relationship between PFP and PFOA, with conflicting results [26,39]. This may be related to the radiography techniques applied and the follow-up time of the studies, as X-ray cannot detect early OA changes. Though, as van der Heijden et al. (2016) showed, quantitative imaging techniques suggested no changes in cartilage composition in young patients (mean age: 23 years) with PFP [8]. It therefore remains unknown whether PFP is a precursor of PFOA, and future longitudinal studies are needed to confirm this possible relationship.

Patellofemoral pain risk factors

The first step towards prevention and management of PFP is the identification of possible risk factors. The multifactorial nature of PFP is reflected by systematic reviews identifying over 100 variables that have been investigated in relation to PFP risk [5,40]. Yet, few factors have moderate to strong evidence supporting their role as a PFP risk factor upon synthesising the literature (Fig. 1). This is in contrast to the many physical, structural, biomechanical and psychological factors identified as impairments in people with prevalent PFP (Fig. 2). In a systematic review conducted in 2012, which included seven prospective studies, Lankhorst et al. identified quadriceps muscle weakness as the only significant risk factor for PFP when pooling data [5]. This first systematic review of PFP risk factors has recently been updated by Neal et al. (2018), who synthesised the evidence concerning predictive variables for PFP in the total population, as well as in three distinct high-risk subgroups – military recruits, adolescents and recreational runners [40]. A total of 18 prospective studies (4818 participants) were included, of which 483 developed PFP over 1.5–30 months of follow-up. Moderate evidence was found that quadriceps weakness increases PFP risk, particularly in military populations, and especially when strength was normalised to body mass index (BMI) (standardised mean difference (SMD) −0.69, 95% confidence interval (CI) −1.02 to −0.35). Interestingly, quadriceps weakness was not identified as a risk factor for PFP in adolescence, highlighting the heterogeneity of PFP risk factors across the lifespan [41]. Although moderate evidence suggests that hip muscle weakness is not a risk factor for PFP (SMD range −0.09 to −0.20) in the total population, in adolescents, moderate evidence was found that stronger hip abduction musculature increases the risk of PFP (SMD 0.71, 95% CI 0.39 to 1.04) [40]. The greater hip abduction strength observed may be a surrogate of high physical activity levels, which is common in adolescents who develop PFP [42]. Strong to moderate evidence also suggests that age, height, weight, BMI, body fat and Q-angle are not risk factors for PFP [40]. Although pooled data did not specifically identify a greater risk of PFP in women, six of the seven studies including data on sex reported a greater proportion of women developing PFP than men.

Despite more than 100 individual variables investigated in relation to PFP risk, a clear lack of risk factors has been identified. Further longitudinal studies are required to identify risk factors for PFP with larger samples, providing opportunities to explore interactions of various factors, which may be important in predicting PFP. Emerging evidence also points to the association of psychological factors with PFP, with levels of anxiety, depression, fear of movement and catastrophising being reported as features of PFP in a recent systematic review [15]. Future prospective studies may uncover important psychological risk factors for PFP, providing new targets for preventative trials.

Why is patellofemoral pain more common in women than in men?

Women are twice more likely to develop PFP than men [17]. The exact mechanisms underpinning this sex discrepancy is not known but may be related to key PFP risk factors being more prevalent in

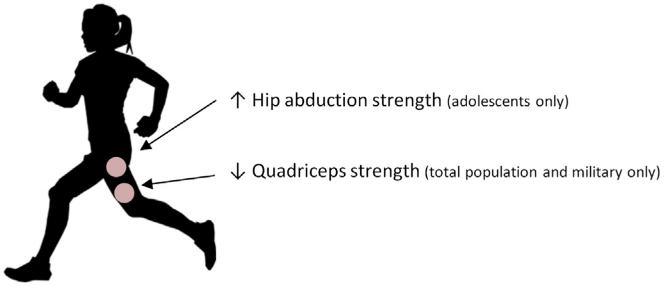


Fig. 1. Prospective risk factors for patellofemoral pain with at least moderate evidence from a systematic review [40].

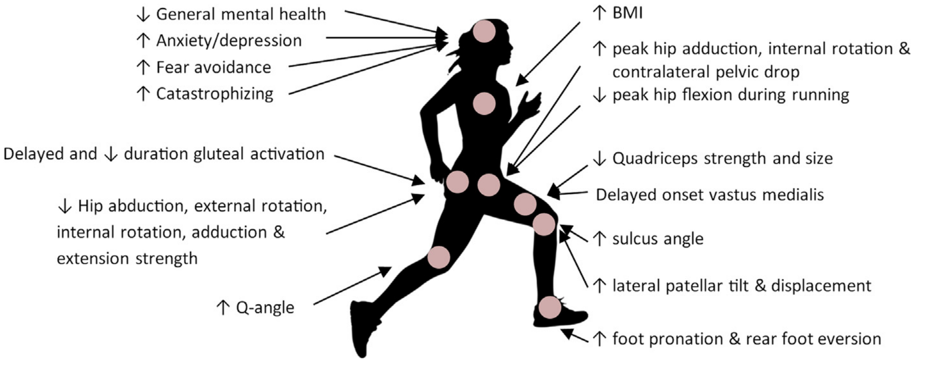


Fig. 2. Physical, structural, biomechanical and psychological factors associated with patellofemoral pain (based on systematic review evidence) [4,15,83–88].

women than in men. For example, women of all ages (>14 years) typically have half to three-quarters the quadriceps strength of men, with discrepancies, although of lower magnitude, persisting after adjustment for body weight [43]. Although there is compelling evidence from more than 30 biomechanical studies showing that healthy uninjured women display greater dynamic knee abduction angles during weight-bearing tasks than their male counterparts [44], which is a common impairment in people with PFP, greater knee abduction has limited evidence as a risk factor for PFP [5]. Further research should help to elucidate other potential mechanisms underlying the greater incidence of PFP in women than in men.

The increasing awareness of patellofemoral pain in adolescents

Knee pain is common during adolescence, and there is emerging evidence that one of the most frequent knee conditions among adolescents is PFP. While a high frequency of sports participation, including sport specialisation in young athletes, can lead to overuse injuries in a developing musculoskeletal system, one-third of adolescents with PFP do not participate in sport [42]. The exact mechanisms driving the high prevalence of PFP in adolescence and the reasons for the disparity in adolescent cases (i.e. highly active vs relatively sedentary) are not known. While the highly active adolescents participating in sport an average of five times per week may represent a typical excessive loading phenotype of PFP [42], perhaps a lack of neuromuscular control or motor skill development in the growing musculoskeletal system (secondary to inactivity) mediates the development of PFP in less active adolescents who subsequently have a decreased preparedness for any activity [45]. Future research is required to confirm the mechanisms underpinning the development of PFP in different subgroups of adolescents. Nevertheless, simple muscle strength deficits are unlikely to be a significant factor in the development of PFP in adolescents, as, unlike their adult counterparts, quadriceps weakness is not a feature of adolescent PFP [46].

Anterior cruciate ligament (ACL) injury and patellofemoral pain

Patellofemoral pain is one of the most common and troublesome complications following ACL injury and surgical reconstruction (ACLR) [47]. Approximately one third of adults suffer from PFP at any point in time following ACLR [48]. This is typically attributed to graft site morbidity following a bone-patellar tendon-bone (BPTB) autograft rather than pathology to the patellofemoral articulation per se. Although some systematic reviews have observed a higher prevalence of PFP following a BPTB autograft than a hamstring-tendon autografts [49,50], other systematic reviews have observed no difference in PFP prevalence between graft types [48,51], suggesting that factors other than graft site morbidity are implicated. While further longitudinal studies are required to elucidate the mechanisms driving PFP following ACLR, it may be related to altered biomechanics, concomitant cartilage damage or

Table 1
Randomised controlled trials evaluating prevention of patellofemoral pain.

Study	Year	Setting	Female sex, number (%)	Mean age, years	Intervention	Control	Intervention duration	Developed PFP (intervention vs control)	Effect size, risk ratio (95% CI)
Foot orthoses/footwear									
Bonanno [89]	2018	Military recruits	65 (21%)	22	Prefabricated foot orthoses	Flat insole	11 weeks	7/153 vs 14/153	0.50 (0.21, 1.20) P = 0.114
Schwellnus [90]	1990	Military recruits	NR	19 (range 17–25)	Neoprene flat insoles	Normal footwear	9 weeks	6/237 vs 43/1151	0.68 (0.29, 1.57) P = 0.360
Milgrom [91]	1991	Military recruits	0 (0%)	NR	Basketball shoes	Normal infantry boots	14 weeks	25/187 vs 35/203	0.78 (0.48, 1.24) P = 0.290
Patellofemoral braces									
Van Tiggelen [92]	2004	Military recruits	32 (19%)	19 (range 17–26)	Dynamic PFJ brace (Donjoy On-Track)	No brace	6 weeks	10/54 vs 42/113	0.50 (0.27, 0.92) P = 0.020
BenGal [93]	1997	Intensive physical training volunteers	17 (28%)	Range 18-25	Knee brace (with patellar support)	No brace	8 weeks	4/27 vs 19/33	0.26 (0.10, 0.67) P = 0.007
Strengthening/stretching exercises									
Brushoj [94]	2008	Military recruits	NR	21 (range 19–26)	Lower limb strength and movement quality	Upper limb strength	12 weeks	17/487 vs 16/490	1.07 (0.55, 2.09) P = 0.845
Coppack [57]	2011	Military recruits	410 (27%)	Median 20 (IQR 17–25)	Lower limb strength/ stretch	Normal warm up	14 week	10/759 vs 36/743	0.25 (0.13, 0.52)[b] P < 0.001
Pope [95]	2000	Military recruits	0 (0%)	Range 17-35	Lower limb stretching added to warm up	Normal warm up	12 weeks	27/735 vs 40/803	0.74 (0.46, 1.19) P = 0.209
Cumps [96]	2008	Volleyball athletes	65 (50%)	25	Lower limb strength and movement quality	Normal training	16 weeks	7/76[a] vs 4/53[a]	1.58 (0.60, 4.20)[c]

PFP, patellofemoral pain; IQR, interquartile range; NR, not reported.
[a] also included patellar tendinopathy and other anterior knee pain complaints in the definition of patellofemoral pain.
[b] Hazard ratio (95% CI).
[c] Odds ratio (95% CI).

the development of early-onset PFOA [52–55]. Indeed, there is emerging evidence that ACL injury may share some similar risk factors with PFP. For example, one study identified a high external knee abduction moment upon landing from a jump to be a risk factor for both PFP and ACL injury in adolescent female athletes [56]. As young women with PFP may have risk factors that put them at future risk of ACL rupture, perhaps PFP should be considered as a potential risk factor for ACL injuries. The link between PFP and ACL injury may provide opportunities for prevention programs to target both conditions simultaneously.

Is patellofemoral pain preventable?

The identification of modifiable risk factors for PFP, including quadriceps weakness, paves the way for prevention strategies to be developed and evaluated. Several randomised controlled trials have been performed and report the effectiveness of different interventions to reduce the risk of new-onset PFP. Most of these injury prevention trials have been performed in young male military recruits (Table 1), a population at high risk of PFP due to a rapid spike in intense physical activity as part of military training. Interventions aimed at reducing the risk of PFP have focussed on the use of foot orthoses or specific footwear, lower limb strengthening and stretching programs or patellofemoral braces for 6 and 16 weeks. In summary, use of foot orthoses (pre-fabricated vs flat insoles; or flat insoles vs no orthosis) or athletic footwear (basketball shoes vs normal infantry boots) did not significantly reduce the risk of PFP (Table 1). In contrast, patellofemoral braces (compared to no brace) significantly decreased the risk of PFP by as much as 50%–74%. The effect of lower limb strengthening and stretching programs (compared to normal warm up or upper limb strengthening) was mixed. One study reported a statistically significant 75% reduction in PFP risk [57], whereas three other studies reported no significant reduction in risk (Table 1). These results suggest that patellofemoral braces could reduce PFP risk in young adults with an increase in physical training and in military recruits.

Although the lower limb strengthening and stretching programs were generally not effective in reducing the risk of PFP in military and sporting populations, the actual interventions were often poorly described, with limited information about whether necessary progressions were provided and quality of movement optimised and not always specific to PFP prevention. Future trials of PFP prevention should evaluate the effectiveness of neuromuscular training programs specifically aimed at known risk factors for PFP, i.e. optimising quadriceps strength. Such programs have proven effective in the prevention of ACL injuries [58]. The emerging appreciation of health education including training load optimisation to avoid overload of the PFJ [59] is another attractive target for future prevention trials. Targeting large population groups known to be at elevated risk of PFP, such as active adolescents, female athletes and runners, should be a priority. Adopting new methods of PFP registration, such as the Oslo Sports Trauma Research Centre Overuse Injury Questionnaire [60], may also help to capture a more accurate incidence rate.

Evidence-based management of patellofemoral pain

There are few published guidelines to help clinicians choose the appropriate evidence-based treatment for PFP. This is despite its high prevalence among active individuals and frequent presentations to general medicine, sports medicine and physiotherapy practices.

The 2017 Patellofemoral Pain Research Retreat and treatment Consensus meeting provided recommendations, which build on the recommendations from the 2015 meeting [1], and included evidence published up to July 2017, synthesised with expert panel voting [61]. When interpreting these recommendations, treatment decisions should be integrated with information gathered from individual patients regarding their preferences, experiences, presentation and values, along with the values, expertise and skills of individual practitioners to create a patient-centred treatment approach [62].

Recommendations

Six recommendations were made on the basis of consistency between consensus voting and current evidence:

Exercise therapy

1. Exercise is recommended to reduce pain in the short, medium and long term and improve function in the medium and long term.
2. Combining hip and knee exercises is recommended to reduce pain and improve function in the short, medium and long term, and this combination should be used in preference to knee exercises alone.

Combined interventions

3. Combined interventions are recommended to reduce pain in adults with PFP in the short and medium term. Combined interventions as a management program incorporate exercise therapy, as well as one of the following: foot orthoses, patellar taping or manual therapy.

Foot orthoses

4. Foot orthoses are recommended to reduce pain in the short term. Other adjunctive interventions
5. Patellofemoral joint, knee and lumbar mobilisations are not recommended in isolation.
6. Electro-physical agents are not recommended.

Should exercise-therapy for patellofemoral pain focus on the quadriceps or the hip?

Exercise therapy is critical to the management of PFP. Usual components include (i) quadriceps-focussed exercise therapy and (ii) hip-focussed exercise therapy. It is likely that exercise therapy to improve muscle function of the whole lower limb and trunk, balance and co-ordination may help to improve pain and function. However, as recommended [61], the greatest evidence supports hip- and quadriceps-focussed exercise therapy. The specific exercises should be chosen depending on an individual patient's presentation, preferences and needs.

Do we need to retrain the vastus medialis obliquus (VMO)?

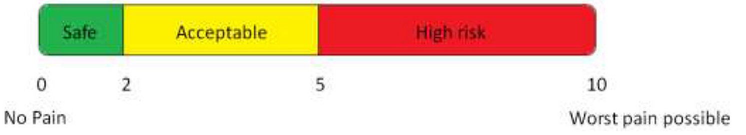
Retraining the vasti can reduce PFP and symptoms [63,64] and enhance VMO activation relative to vastus lateralis [65]. However, patients cannot activate the VMO in isolation, and no exercise appears to be preferential for the activation of the VMO. Therefore, for most patients, a graduated quadriceps-focussed exercise therapy program is likely to be effective, without paying specific attention to the VMO.

What are the critical elements of quadriceps-focussed exercise therapy?

Examples of quadriceps-focussed exercises include leg extensions, lunges, squats and step-ups (Fig. 3). During weight-bearing exercise, progressions can be made from minimal weight-bearing (using hand rails or other supports) to full weight-bearing (eventually including added loading) and through various knee flexion ranges. Importantly, exercises should be progressed with steadily increasing load and difficulty when possible. Progression can be partially based on the absence of significant pain (2–3 out of 10, see pain monitoring system) during exercises [2]. Further guidance on exercise prescription principles can be found in the American College of Sports Medicine guidelines [66].

Pain Monitoring System

A pain monitoring system allows pain to be recorded on a 10-cm numerical pain scale [2], helping to avoid pain-induced muscle inhibition and enhance exercise adherence.



Pain levels up to 5 out of 10, momentarily during exercise or immediately following exercise are acceptable, but not extending to the following morning.

What are the critical elements of hip-focussed exercise therapy?

Hip-focussed exercise therapy is associated with pain reduction in patients with PFP, potentially more so than quadriceps-focussed exercises in the initial stages of rehabilitation [67,68]. Starting with hip-focussed exercise before the addition of quadriceps-focussed exercise may be considered in those with more irritable symptoms, or when quadriceps-focussed exercise flares symptoms in the early stages of rehabilitation. Clinical experience suggests that hip- and quadriceps-focussed exercises should be combined in the long term, especially considering the likelihood of deficits in muscle

Fig. 3. Examples of quadriceps-focussed exercises for the management of patellofemoral pain.

strength in both areas. The principles for hip-focussed exercise therapy are the same as above, with exercises performed initially at the highest load possible and pain monitored throughout, particularly during weight-bearing progressions.

Neuromuscular activation, strength, endurance or power? What is best for patellofemoral pain?

Few studies have examined the different types of exercise on pain or other PFP symptoms [69]. It is possible that diminished treatment effects in the long term (i.e. a year or more after starting an exercise therapy program) could be related to inadequate consideration of the strength, endurance or power requirements in PFP rehabilitation. Evidence from a single multi-centre randomised controlled trial in the primary healthcare setting in Scandinavia suggests that a higher exercise therapy dose supervised by a physiotherapist over 12 weeks (3x/wk, 3 $\times$ 30 reps, 9 exercises, 60 min) was more effective than the equivalent exercise therapy intervention at a lower dose (3x/wk, 2 $\times$ 10 reps, 5 exercises, 20 min) [70].

Exercise therapy using resistance bands and body weight exercise may be appropriate early in PFP rehabilitation [68,71]. However, when considering accepted exercise prescription principles [66], progressing to gym-based rehabilitation (i.e. greater load) [66] and continuing programs for longer than the typical 8–12 weeks previously evaluated may be an important step that has been missing from clinical trials to date. Exercise therapy prescription should initially be tailored to prioritise addressing key deficits (see Fig. 2), and the program should develop in complexity over time to ensure all potential deficits are addressed.

Rethinking management approaches, beyond exercise-therapy

Is movement (e.g. running) retraining needed?

Retraining exercises could emphasise alignment of the lower limb (i.e. neutral hip rotation and adduction) during weight-bearing flexion tasks (e.g. lunge, step-up and step-down). For some patients, this may be important, as excessive hip internal rotation and adduction can be related to a 'dynamic valgus' movement pattern at the knee, which may contribute to the development or persistence of PFP [72]. However, retraining of dynamic alignment in these positions may not carry over into more functional tasks including walking and running [73]. Furthermore, the relationship of such patterns to the development or persistence of pain is unclear, particularly in men.

Running retraining

Running has received the most attention in research related to movement pattern retraining for PFP [74]. A recent review recommended running retraining should be considered for PFP, with limited evidence supporting the use of visual and verbal feedback to reduce hip adduction in female runners. Verbal instructions worthy of trialling include cues to 'open knees', 'widen stance' or 'engage the buttock muscles', whilst visual feedback could be provided through mirrors or video. Logically, the same cues and movement retraining approaches may also work for other tasks that people with PFP have difficulty with, such as stair negotiating, squatting and jumping. High-quality randomised controlled trials are needed to evaluate the efficacy of cues to reduce hip adduction during the various functional tasks people with PFP report pain in.

A number of other running retraining cues were also suggested to be worthy of consideration, including increasing step rate by 5–10% and transitioning from a rearfoot to a non-rearfoot strike [74]. Subsequent randomised trials supporting these strategies have mixed results. Small trials suggested transitioning to a non-rearfoot strike [75] or increasing step rate [76] led to significantly greater pain reductions when compared to a control intervention. However, a larger randomised trial indicated that running retraining, including an increased step rate of 7.5% and consideration to transitioning to non-rearfoot strike, if deemed necessary by the treating physiotherapist, added no benefit to education regarding load management [77]. Running retraining may be an important component for the running athlete who is struggling to run because of PFP, but further research is clearly needed to better understand optimal running retraining features and to identify which patients may or may not benefit from movement pattern and running retraining.

What about education for patellofemoral pain?

To date, most PFP research has focussed on exercise therapy and passive adjuncts, with less emphasis on patient education. Patient education is considered by international experts as critical to treat PFP despite a lack of evidence on its isolated effects [78]. A recent randomised trial completed by Esculier et al. [77] highlighted the clear importance of appropriate patient education in a running population with PFP. Particularly, neither eight weeks of hip- and quadriceps-focussed exercise therapy nor running retraining focussed on increasing step rate produced greater treatment effects than education regarding load management.

Effective education may allow self-management and optimise adherence to other interventions such as exercise therapy. Quality patient education for PFP should include load management, weight management when appropriate, understanding the potential value of treatments such as exercise-therapy and addressing any fear of movement [78]. Patient education might also play a critical role in ensuring that the patient has the skills and knowledge to progress their rehabilitation beyond the course of supervised physiotherapy treatment.

A paucity of research related to patient education and how to support behaviour change for individuals with PFP limits evidence-based guidance on what best-practice patient education might look like. In the absence of evidence, patient education should be tailored to the individual patient based on prior knowledge, needs and preferences. Multiple education-focussed consultations may be required to facilitate adequate knowledge gains (e.g. greater understanding of treatments supported by evidence, pain sensitisation and psychological influences on pain) or behaviour change (e.g. more optimal load management, participation in exercise therapy). Insight into how behaviour change and more active management might be supported is provided by knee osteoarthritis research, where clinicians are encouraged to tailor exercise prescription, consider environmental context and available resources, provide reassurance related to exercise pain and exercise participation and consider social supports (group exercise and family or friends partnering) [79]. Future research should investigate the effectiveness of behaviour change strategies that specifically target these factors in populations with PFP.

There are currently few published educational resources for people with PFP. However, Barton and Rathleff recently developed and published a leaflet based on syntheses of the literature and input from international experts and adapted the final version based on feedback from patients and clinicians [59] (see Fig. 4). This leaflet may support clinical practice but is not designed to replace individual consultation with a physiotherapist. Therefore, strong communication skills are still needed by the treating clinician including how to facilitate and support shared decision making [62].

Education related to pain

Current evidence suggests that central pain mechanisms may be a factor to consider in some, but not all, patients with PFP [15]. In a clinical setting, the following signs may suggest facilitated central pain mechanisms: 1) disproportionate pain, implying that the severity of pain and related reported or perceived disability are disproportionate to the nature and extent of the injury, 2) presence of diffuse pain distribution, allodynia and hyperalgesia.

Previous recommendations to assist in addressing central sensitisation [80] in chronic musculoskeletal pain can also be applied to PFP. These include pain neuroscience education and a cautious approach to initial exercise loads and progression to avoid symptom flaring, along with encouraging exercise of non-painful areas of the body [80]. The clinical implications of this are that rehabilitation may require more time. Additionally, it may also be important to avoid pain flares throughout the rehabilitation process and worth considering adjunctive interventions such as taping and orthoses, if effective. Following the proposed pain, monitoring system outlined earlier in this article may assist in the presence of central sensitisation. However, research is urgently needed to confirm the success (or otherwise) of such approaches.

KEY FACTORS AND TREATMENT OPTIONS
(See inside for greater details)

KEY BIOMECHANICAL FACTORS TO ADDRESS
1. Poor function and weakness of hip muscles
2. Poor function and weakness of thigh muscles
3. Too much foot roll (pronation)

KEY TREATMENT OPTIONS
1. Exercises to improve strength and function of the hip and thigh muscles
2. Taping of the knee cap to reduce pain in the short term
3. Foot orthotics if you have too much foot roll (pronation)

PRIORITIES TO MANAGE YOUR PATELLOFEMORAL PAIN
1. If you think you have patellofemoral pain, you should seek help as early as possible – this will improve your chances of a successful recovery.
2. There are many effective treatment options which you should discuss with your treating therapist.
3. Your recovery will be best if you actively participate in your rehabilitation.
4. Appropriately modifying your physical activity level is often the first step towards successful recovery.
5 Ensure you slowly and safely build up your physical activity levels **(Figure 5).**

100% 75% 50% 25%

Figure 5 Gradual and safe build up in physical activity levels

This information brochure has been created as part of a not for profit endeavour by Dr Christian Barton and Michael Rathleff.

MANAGING MY PATELLOFEMORAL PAIN

Patellofemoral pain (pain around, behind or under the knee cap) is very common, and affects both males and females of all activity levels. It often results in pain during simple daily activities such as walking, running, sitting, squatting and walking up and down stairs.

Patellofemoral pain has many causes, and as such there are a lot of treatment options available. The information contained within this leaflet will help guide you on the most appropriate treatment for your knee pain. It is recommended you see an appropriately qualified health care professional to guide your treatment further.

WHAT MIGHT CAUSE MY KNEE PAIN?

Excessive loading or varied and rapid increases to physical activity which your knee cannot cope with **(Figure 1)** are thought to contribute to pain development. Poor biomechanics (movement) can also contribute, with the knee cap thought to move toward the outside of the knee **(Figure 2)**, stopping it from tracking normally in its groove. A number of factors can lead to this poor tracking **(Figure 3)**. There are numerous other contributing factors to patellofemoral pain including the structure of your knee, trauma, surgery and systemic disease, which you may wish to speak to your therapist about.

100% 75% 50% 25%

Figure 1 Varied and rapid increases to physical activity levels which can lead to patellofemoral pain

Figure 2 Illustrates abnormal tracking of the knee cap

Figure 3 Movement factors contributing to abnormal tracking of the knee cap.

1. **Pelvis** drops on opposite side, placing increased tension on the outside of the leg and pulling the knee cap outward.
2. **Hip** collapses inward and rolls under the knee cap due to poor function and weakness of the hip muscles.
3. **Thigh** muscles are weak or function poorly, meaning there is inadequate support for the knee and knee cap.
4. **Foot** rolls in too much, causing the shin and knee to collapse inward under the knee cap.

TREATMENT OPTIONS
(Good quality exercise rehabilitation is the key)

Exercise

WHAT EXERCISE PRINCIPLES ARE IMPORTANT?
1. Your therapist may suggest a period of rest before starting exercise again.
2 Exercises in sitting or lying at the beginning may help to get your hip and thigh muscles functioning without pain.
3. As soon as pain allows, exercises should be performed in standing postures which mimic everyday activities.
4. Your therapist should supervise you with any new exercises to ensure correct techniques.
5. Using mirrors and video recordings may help you to complete correct exercise techniques at home.
6. Exercises will not help unless you perform them with the correct technique and on a regular basis.

WHAT EXERCISES SHOULD I BE COMPLETING?
1. Weakness and poor function of the hip and thigh is common, so you will most likely need exercises to improve this.
2. Sometimes exercises for the foot or back are also required.
3. You may need to stretch your calf, hamstring or thighs.
4. Exercises should be progressed to activities you previously had pain with (squatting, stairs, running, etc.), ensuring good movement patterns during their completion. **(Figure 4 - example)**

Additional treatments

PAIN REDUCTION
1. Taping or strapping can relieve pain in the short term – your therapist can apply this or teach you how to do this.
2. Braces can also help relieve pain.
3. Foot orthotics sometimes reduce pain - your therapist will help you decide if they are appropriate, or refer you to someone who can.

4a. Poor control of hip and pelvis. 4b. Improved control of hip and pelvis.

Figure 4 Walking down stairs

HOW ELSE CAN MY THERAPIST HELP?
1. Guide you on your most appropriate exercises and other helpful treatments.
2. Answer questions related to your knee pain, and explain in greater detail the contents of this information leaflet where necessary.
3. Help you understand why you have knee pain, what factors have most likely caused your pain and how to modify your activity to improve your pain and recovery.
4. Provide manual therapy which may be important to improve pain and flexibility.

Fig. 4. Manage My Patellofemoral Pain education leaflet (Printable version downloadable here. http://bmjopensem.bmj.com/content/bmjosem/2/1/e000086/F1.large.jpg).

What about psychological considerations in the management of patellofemoral pain?

As discussed earlier, emerging evidence suggests that management of PFP requires consideration of biological/somatic contributors to pain and also psychological and social factors [14]. This is reflected in biopsychosocial models of pain, where psychological factors are hypothesised to have a mediating role on physical impairments, social/contextual factors, functional performance and ultimately physical activity/sports participation [81]. Therefore, researchers and clinicians are encouraged to consider psychosocial characteristics in the assessment and management of PFP. Generic tools such as the short-form Orebro Musculoskeletal Pain Questionnaire or Tampa Scale of Kinesiophobia are readily available and simple to implement and have been associated with PFP severity [15]. They provide a starting point for clinicians to identify potential candidates for whom more detailed assessment and management of psychological factors may be indicated. Incorporating management approaches that specifically address psychosocial impairments, such as self-efficacy and confidence, include goal setting, imagery and relaxation training [82]. Clinicians should be willing and able to facilitate referral in the instance of more extreme psychological response in relation to PFP. Given emerging evidence of psychological features of PFP, there is a need to develop and implement well-designed intervention studies that target improvement of psychological outcomes to assist patients with PFP to recover successfully.

What about adjunctive treatments for patellofemoral pain?

While the largest evidence supports exercise therapy, prefabricated foot orthoses are effective as a standalone treatment to reduce pain in the short term, and adjunctive treatments (such as foot orthoses, patellar taping or patellar mobilisations) may be used in combination with exercise therapy [61]. Foot orthoses may be used as an alternative to exercise therapy if this is a more suitable option (e.g. patient preference, concerns about adherence to exercise) or as an addition to exercise therapy, especially if patients are struggling to complete their exercise with acceptable level of pain.

Are different approaches needed for adolescents with patellofemoral pain?

Considering that adolescent pain may transition into adulthood, education and treatment for PFP may need to start in adolescence when complaints seem to emerge. Adolescent PFP should not be expected to spontaneously recover. Some literature suggests that symptom duration is longer in adolescents than in adults [42]. Though, adherence to supervised exercise therapy seems particularly challenging in this patient population, and therefore, more research seems necessary to determine effective management of pain in this subgroup of patients with PFP.

Summary

Patellofemoral pain is one of the most common musculoskeletal conditions affecting young and middle-aged active adults and presents frequently to sports medicine and general practitioners. It affects an individual's ability to perform routine daily activities (stairs, squat and run) and has a tendency to persist in a substantial proportion of individuals. Although the exact aetiology of PFP is not fully understood, the best available evidence suggests that abnormal loading of the PFJ, driven to a large extent by deficits in quadriceps strength, is a hallmark feature contributing to the incidence and persistence of PFP. Despite its prevalence, chronicity and impact, PFP remains one of the most challenging musculoskeletal conditions to manage. This is reflected by a lack of evidence-based clinical guidelines. International consensus and current evidence recommends exercise therapy, focussed on hip and knee muscle strengthening, as a cornerstone of management to reduce PFP. Importantly, exercise therapy should be tailored to the individual and progressed with increasing load and difficulty, wherever possible, based on the absence of significant pain during exercises. Because greater pain severity and longer symptom duration are predictive of poor prognosis, early effective management may be the key to limiting the long-term impact of PFP. Rethinking management approaches beyond exercise therapy to incorporate movement retraining, education and psychosocial aspects provides potential avenues to enhance outcomes for patients with PFP. Future research needs to help identify whether certain management and preventative approaches are more effective for different subgroups of patients with, or at risk of, PFP to reduce the burden of this common and recalcitrant condition.

Practice points

- A wide range of PFP incidence and prevalence rates have been reported, with the highest rates typically observed in military populations, women and adolescent athletes.
- PFP is not self-limiting – persistent symptoms for up to 20 years are common.
- Quadriceps weakness (total population) and greater hip abduction strength (adolescents only) are the only risk factors for PFP, with at least moderate evidence from systematic reviews.
- International consensus recommends exercise therapy (hip and quadriceps focussed) as the cornerstone of PFP management.
- Effective exercise prescription involves
  - o Targeting the intervention to the capacity and needs of the patient.
  - o Progression of the type and load to match the patient capacity and needs.
  - o Sufficient engagement of the patient and adherence to the program.
- Patient education is critical and could include managing expectations, load management, ensuring self-management, importance of adherence and strategies to address fears and anxiety.
- Sharing the decisions between clinician and patient regarding interventions is vital.

Research agenda

- There is a need to identify subgroups of patients with PFP, considering structural, biological, biomechanical and psychosocial factors to improve understanding of the pathogenesis of PFP to guide the development of targeted treatments.
- Longitudinal studies are needed to confirm the possible relationship between PFP and the development of PFOA.
- The emerging appreciation of psychological and central pain processing features of PFP emphasises the need to evaluate potential psychological risk factors to inform targets for new preventative trials.
- Future research is required to confirm the mechanisms underpinning the development of PFP in different subgroups of adolescents.
- There is a need for more research to determine effective management of pain in the subgroup of adolescent patients with PFP.
- Further research is needed to evaluate the possible benefits of greater progression and duration of exercise therapy programs on long-term outcomes.
- Further research is needed to better understand optimal running retraining features and to identify which patients may or may not benefit from movement pattern and running retraining.
- Further research is needed to understand the benefits of optimising patient education on short- and long-term outcomes.

Conflicts of interest statement

All authors declare no conflict of interest.

Consent

Written informed consent was obtained for the publication of Fig. 3. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

Acknowledgements

AGC is a recipient of a National Health and Medical Research Council (NHMRC) of Australia Early Career Fellowship (Neil Hamilton Fairley Clinical Fellowship (APP1121173)). CJB is a recipient of a Medical Research Future Fund (MRFF) Translating Research Into Practice (TRIP) Fellowship (APP1150439).

References

[1] 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.
[2] Thomee R, Augustsson J, Karlsson J. Patellofemoral pain syndrome: a review of current issues. Sports Med 1999;28(4):245–62.
[3] Powers CM, Witvrouw E, Davis IS, Crossley KM. Evidence-based framework for a pathomechanical model of patellofemoral pain: 2017 patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester, UK: part 3. Br J Sports Med 2017;51(24):1713–23.
[4] Lankhorst NE, Bierma-Zeinstra SM, van Middelkoop M. Factors associated with patellofemoral pain syndrome: a systematic review. Br J Sports Med 2013;47(4):193–206.
[5] Lankhorst NE, Bierma-Zeinstra SM, van Middelkoop M. Risk factors for patellofemoral pain syndrome: a systematic review. J Orthop Sports Phys Ther 2012;42(2):81–94.
[6] Dye SF. The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. Clin Orthop Relat Res 2005;(436):100–10.
[7] van der Heijden RA, de Kanter JL, Bierma-Zeinstra SM, Verhaar JA, van Veldhoven PL, Krestin GP, et al. Structural abnormalities on magnetic resonance imaging in patients with patellofemoral pain: a cross-sectional case-control study. Am J Sports Med 2016;44(9):2339–46.
[8] van der Heijden RA, Oei EH, Bron EE, van Tiel J, van Veldhoven PL, Klein S, et al. No difference on quantitative magnetic resonance imaging in patellofemoral cartilage composition between patients with patellofemoral pain and healthy controls. Am J Sports Med 2016;44(5):1172–8.
[9] van der Heijden RA, Poot DHJ, Ekinci M, Kotek G, van Veldhoven PLJ, Klein S, et al. Blood perfusion of patellar bone measured by dynamic contrast-enhanced MRI in patients with patellofemoral pain: a case-control study. J Magn Reson Imag 2018;48(5):1344–50.
[10] Collins NJ, Oei EHG, de Kanter JL, Vicenzino B, Crossley KM. Prevalence of radiographic and MRI features of patellofemoral osteoarthritis in young and middle-aged adults with persistent patellofemoral pain. Arthritis Care Res 2019. https://doi.org/10.1002/acr.23726 [Epub ahead of print].
[11] Ho KY, Hu HH, Colletti PM, Powers CM. Recreational runners with patellofemoral pain exhibit elevated patella water content. Magn Reson Imaging 2014;32(7):965–8.
[12] van der Heijden RA, Rijndertse MM, Bierma-Zeinstra SMA, van Middelkoop M. Lower pressure pain thresholds in patellofemoral pain patients, especially in female patients: a cross-sectional case-control study. Pain Med 2018;19(1):184–92.
[13] Rathleff MS, Rathleff CR, Stephenson A, Mellor R, Matthews M, Crossley K, et al. Adults with patellofemoral pain do not exhibit manifestations of peripheral and central sensitization when compared to healthy pain-free age and sex matched controls - an assessor blinded cross-sectional study. PLoS One 2017;12(12), e0188930.
[14] Vicenzino B, Maclachlan L, Rathleff MS. Taking the pain out of the patellofemoral joint: articulating a bone of contention. Br J Sports Med 2019. https://doi.org/10.1136/bjsports-2017-098803 [Epub ahead of print].
[15] Maclachlan LR, Collins NJ, Matthews MLG, Hodges PW, Vicenzino B. The psychological features of patellofemoral pain: a systematic review. Br J Sports Med 2017;51(9):732–42.
[16] Selfe J, Janssen J, Callaghan M, Witvrouw E, Sutton C, Richards J, et al. Are there three main subgroups within the patellofemoral pain population? A detailed characterisation study of 127 patients to help develop targeted intervention (TIPPs). Br J Sports Med 2016;50(14):873–80.
[17] Smith BE, Selfe J, Thacker D, Hendrick P, Bateman M, Moffatt F, et al. Incidence and prevalence of patellofemoral pain: a systematic review and meta-analysis. PLoS One 2018;13(1), e0190892.
[18] Dey P, Callaghan M, Cook N, Sephton R, Sutton C, Hough E, et al. A questionnaire to identify patellofemoral pain in the community: an exploration of measurement properties. BMC Muscoskelet Disord 2016;17:237.
[19] Fairbank JC, Pynsent PB, van Poortvliet JA, Phillips H. Mechanical factors in the incidence of knee pain in adolescents and young adults. J Bone Joint Surg Br 1984;66(5):685–93.
[20] Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scand J Med Sci Sports 2010;20(5):725–30.
[21] Weiss BD. Nontraumatic injuries in amateur long distance bicyclists. Am J Sports Med 1985;13(3):187–92.
[22] Molgaard C, Rathleff MS, Simonsen O. Patellofemoral pain syndrome and its association with hip, ankle, and foot function in 16- to 18-year-old high school students: a single-blind case-control study. J Am Podiatr Med Assoc 2011;101(3):215–22.
[23] Noehren B, Hamill J, Davis I. Prospective evidence for a hip etiology in patellofemoral pain. Med Sci Sports Exerc 2013;45(6):1120–4.
[24] Ramskov D, Barton C, Nielsen RO, Rasmussen S. High eccentric hip abduction strength reduces the risk of developing patellofemoral pain among novice runners initiating a self-structured running program: a 1-year observational study. J Orthop Sports Phys Ther 2015;45(3):153–61.
[25] Thijs Y, Van Tiggelen D, Roosen P, De Clercq D, Witvrouw E. A prospective study on gait-related intrinsic risk factors for patellofemoral pain. Clin J Sport Med 2007;17(6):437–45.

[26] Lankhorst NE, van Middelkoop M, Crossley KM, Bierma-Zeinstra SM, Oei EH, Vicenzino B, et al. Factors that predict a poor outcome 5-8 years after the diagnosis of patellofemoral pain: a multicentre observational analysis. Br J Sports Med 2016;50(14):881–6.
[27] Nimon G, Murray D, Sandow M, Goodfellow J. Natural history of anterior knee pain: a 14- to 20-year follow-up of nonoperative management. J Pediatr Orthop 1998;18(1):118–22.
[28] 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(5):1122–30.
[29] Stathopulu E, Baildam E. Anterior knee pain: a long-term follow-up. Rheumatology 2003;42(2):380–2.
[30] Rathleff MS, Rathleff CR, Olesen JL, Rasmussen S, Roos EM. Is knee pain during adolescence a self-limiting condition? Prognosis of patellofemoral pain and other types of knee pain. Am J Sports Med 2016;44(5):1165–71.
[31] Collins NJ, Bierma-Zeinstra SM, Crossley KM, van Linschoten RL, Vicenzino B, van Middelkoop M. Prognostic factors for patellofemoral pain: a multicentre observational analysis. Br J Sports Med 2013;47(4):227–33.
[32] Matthews M, Rathleff MS, Claus A, McPoil T, Nee R, Crossley K, et al. Can we predict the outcome for people with patellofemoral pain? A systematic review on prognostic factors and treatment effect modifiers. Br J Sports Med 2017;51(23):1650–60.
[33] Crossley KM. Is patellofemoral osteoarthritis a common sequela of patellofemoral pain? Br J Sports Med 2014;48(6):409–10.
[34] Mills K, Hunter DJ. Patellofemoral joint osteoarthritis: an individualised pathomechanical approach to management. Best Pract Res Clin Rheumatol 2014;28(1):73–91.
[35] Thomas MJ, Wood L, Selfe J, Peat G. Anterior knee pain in younger adults as a precursor to subsequent patellofemoral osteoarthritis: a systematic review. BMC Muscoskelet Disord 2010;11:201.
[36] Culvenor AG, Oiestad BE, Holm I, Gunderson RB, Crossley KM, Risberg MA. Anterior knee pain following anterior cruciate ligament reconstruction does not increase the risk of patellofemoral osteoarthritis at 15- and 20-year follow-ups. Osteoarthritis Cartilage 2017;25:30–3.
[37] Peat G, Duncan RC, Wood LR, Thomas E, Muller S. Clinical features of symptomatic patellofemoral joint osteoarthritis. Arthritis Res Ther 2012;14(2):R63.
[38] Farrokhi S, Keyak JH, Powers CM. Individuals with patellofemoral pain exhibit greater patellofemoral joint stress: a finite element analysis study. Osteoarthritis Cartilage 2011;19(3):287–94.
[39] Kannus P, Natri A, Paakkala T, Jarvinen M. An outcome study of chronic patellofemoral pain syndrome. Seven-year follow-up of patients in a randomized, controlled trial. J Bone Joint Surg Am 1999;81(3):355–63.
[40] Neal BS, Lack SD, Lankhorst NE, Raye AD, Morrissey DH, Van Middelkoop M. Risk factors for patellofemoral pain: a systematic review and meta-analysis. Br J Sports Med 2019. https://doi.org/10.1136/bjsports-2017-098890 [Epub ahead of print].
[41] Rathleff MS, Roos EM, Olesen JL, Rasmussen S. Exercise during school hours when added to patient education improves outcome for 2 years in adolescent patellofemoral pain: a cluster randomised trial. Br J Sports Med 2015;49:406–12.
[42] Rathleff MS, Vicenzino B, Van Middelkoop M, Graven-Nielsen T, Van Linschoten RL, Hölmich P, et al. Patellofemoral pain in adolescence and adulthood: same same, but different? Sports Med 2015;45(11):1489–95.
[43] Anderson AF, Dome DC, Gautam S, Awh MH, Rennirt GW. Correlation of anthropometric measurements, strength, anterior cruciate ligament size, intercondylar notch characteristics to sex differences in anterior cruciate ligament tear rates. Am J Sports Med 2001;29(1):58–66.
[44] Cronström A, Creaby MW, Nae J, Ageberg E. Gender differences in knee abduction during weight-bearing activities: a systematic review and meta-analysis. Gait Posture 2016;49:315–28.
[45] Carter CW, Micheli LJ. Training the child athlete: physical fitness, health and injury. Br J Sports Med 2011;45:880–5.
[46] Rathleff CR, Baird WN, Olesen JL, Roos EM, Rasmussen S, Rathleff MS. Hip and knee strength is not affected in 12-16 year old adolescents with patellofemoral pain - a cross-sectional population-based study. PLoS One 2013;8(11), e79153.
[47] Culvenor AG, Collins NJ, Vicenzino B, Cook JL, Whitehead TS, Morris HG, et al. Predictors and effects of patellofemoral pain following hamstring-tendon ACL reconstruction. J Sci Med Sport 2015;19(7):518–23.
[48] Spindler K, Kuhn J, Freedman K, Matthews C, Dittus R, Harrel F. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring: does it really matter? A systematic review. Am J Sports Med 2004;32(8):1986–95.
[49] Biau DJ, Tournoux C, Katsahian S, Schranz PJ, Nizard RS. Bone-patellar tendon-bone autografts versus hamstring autografts for reconstruction of anterior cruciate ligament: meta-analysis. Br Med J 2006;332(7548):995–8.
[50] Li S, Chen Y, Lin Z, Cui W, Zhao J, Su W. A systematic review of randomized controlled clinical trials comparing hamstring autografts versus bone-patellar tendon-bone autografts for reconstruction of the anterior cruciate ligament. Arch Orthop Trauma Surg 2012;132(9):1287–97.
[51] Herrington L, Wrapson C, Matthews M, Matthews H. Anterior cruciate ligament reconstruction, hamstring versus bone-patellar tendon-bone grafts: a systematic literature review of outcome from surgery. Knee 2005;12(1):41–50.
[52] Culvenor AG, Cook JL, Collins NJ, Crossley KM. Is patellofemoral joint osteoarthritis an under-recognised outcome of anterior cruciate ligament reconstruction? A narrative literature review. Br J Sports Med 2013;47(2):66–70.
[53] Culvenor AG, Lai CCH, Gabbe BJ, Makdissi M, Collins NJ, Vicenzino B, et al. Patellofemoral osteoarthritis is prevalent and associated with worse symptoms and function after hamstring tendon autograft ACL reconstruction. Br J Sports Med 2014;48(6):435–9.
[54] Culvenor AG, Schache AG, Vicenzino B, Pandy MG, Collins NJ, Cook JL, et al. Are knee biomechanics different in those with and without patellofemoral osteoarthritis after anterior cruciate ligament reconstruction? Arthritis Care Res 2014;66(10):1566–70.
[55] Culvenor AG, Collins NJ, Guermazi A, Cook JL, Vicenzino B, Khan KM, et al. Early knee osteoarthritis is evident one year following anterior cruciate ligament reconstruction: a magnetic resonance imaging evaluation. Arthritis Rheum 2015;67(4):946–55.
[56] Myer GD, Ford KR, Di Stasi SL, Barber Foss KD, Micheli LJ, Hewett TE. High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament injury (ACL) in girls: is PFP itself a predictor for subsequent ACL injury? Br J Sports Med 2014;49:118–22.

[57] Coppack RJ, Etherington J, Wills AK. The effects of exercise for the prevention of overuse anterior knee pain: a randomized controlled trial. Am J Sports Med 2011;39(5):940–8.
[58] Webster KE, Hewett TE. A meta-analysis of meta-analyses of anterior cruciate ligament injury reduction training programs. J Orthop Res 2018;36(10):2696–708.
[59] Barton CJ, Rathleff MS. Managing My Patellofemoral Pain': the creation of an education leaflet for patients. BMJ Open Sport Exerc Med 2016;2, e000086.
[60] Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. Br J Sports Med 2013;47(8):495–502.
[61] Collins NJ, Barton CJ, Van Middelkoop M, 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(18):1170–8.
[62] Barton CJ, Crossley KM. Sharing decision-making between patient and clinician: the next step in evidence-based practice for patellofemoral pain? Br J Sports Med 2016;50(14):833–4.
[63] Crossley K, Bennell K, Green S, Cowan S, McConnell J. Physical therapy for patellofemoral pain. A randomised, double-blinded , placebo controlled study. Am J Sports Med 2002;30(6):857–65.
[64] 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.
[65] Cowan SM, Bennell KL, Hodges PW. Therapeutic patellar taping changes the timing of vasti muscle activation in people with patellofemoral pain syndrome. Clin J Sport Med 2002;12:339–47.
[66] Medicine ACoS. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009;41(3):687–708.
[67] Crossley KM, van Middelkoop M, Callaghan MJ, Collins N, Rathleff MS, Barton CJ. 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). Br J Sports Med 2016;50(14):844–52.
[68] 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(21):1365–76.
[69] Lack S, Neal B, De Oliveira Silva D, Barton C. How to manage patellofemoral pain – understanding the multifactorial nature and treatment options. Phys Ther Sport 2018;32:155–66.
[70] 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(2):126–31.
[71] van der Heijden RA, Lankhorst NE, van Linschoten R, Bierma-Zeinstra SM, van Middelkoop M. Exercise for treating patellofemoral pain syndrome. Cochrane Database Syst Rev 2015;1:CD010387.
[72] Crossley K, Cook J, Cowan S, Culvenor A, Docking S, Rathleff M, et al. Anterior knee pain. In: Brukner PDCB, Cook J, Crossley K, et al., editors. Brukner & Khan's clinical sports medicine. fifth ed. Sydney: McGraw Hill Education; 2017. p. 769–804.
[73] Willy RW, Davis IS. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. J Orthop Sports Phys Ther 2011;41(9):625–32.
[74] Barton CJ, Bonanno DR, Carr J, Neal BS, Malliaras P, Franklyn-Miller A, et al. Running retraining to treat lower limb injuries: a mixed-methods study of current evidence synthesised with expert opinion. Br J Sports Med 2016;50(9):513–26.
[75] Roper JL, Harding EM, Doerfler D, Dexter JG, Kravitz L, Dufek JS, et al. The effects of gait retraining in runners with patellofemoral pain: a randomized trial. Clin Biomech 2016;35:14–22.
[76] Bonacci J, Hall M, Saunders N, Vicenzino B. Gait retraining versus foot orthoses for patellofemoral pain: a pilot randomised clinical trial. J Sci Med Sport 2018;21(5):457–61.
[77] Esculier JF, Bouyer LJ, Dubois B, Fremont P, Moore L, McFadyen B, et al. Is combining gait retraining or an exercise programme with education better than education alone in treating runners with patellofemoral pain?A randomised clinical trial. Br J Sports Med 2018;52(10):659–66.
[78] Barton CJ, Lack S, Hemmings S, Tufail S, Morrissey D. The 'best practice guide to conservative management of patellofemoral pain': incorporating level 1 evidence with expert clinical reasoning. Br J Sports Med 2015;49(14):923–34.
[79] Dobson F, Bennell KL, French SD, Nicolson PJA, Klaasman RN, Holden NA, et al. Barriers and facilitators to exercise participation in people with hip and/or knee osteoarthritis: synthesis of the literature using behavior change theory. Am J Phys Med Rehab 2016;95:372–89.
[80] Nijs J, Meeus M, Cagnie B, Roussel NA, Dolphens M, Van Oosterwijck J, et al. A modern neuroscience approach to chronic spinal pain: combining pain neuroscience education with cognition-targeted motor control training. Phys Ther 2014; 94(5):730–8.
[81] Wiese-Bjornstal DM, Smith AM, Shaffer SM, Morrey MA. An integrated model of response to sport injury: psychological and sociological dynamics. J Appl Sport Psychol 1998;10:46–69.
[82] Schwab Reese LM, Pittsinger R, Yang J. Effectiveness of psychological intervention following sport injury. J Sport and Health Sci 2012;1:71–9.
[83] Coburn SL, Barton CJ, Filbay SR, Hart HF, Rathleff MS, Crossley KM. Quality of life in individuals with patellofemoral pain: a systematic review including meta-analysis. Phys Ther Sport 2018;33:96–108.
[84] Barton CJ, Lack S, Malliaras P, Morrissey D. Gluteal muscle activity and patellofemoral pain syndrome: a systematic review. Br J Sports Med 2013;47:207–14.
[85] Barton CJ, Levinger P, Menz HB, Webster KE. Kinematic gait characteristics associated with patellofemoral pain syndrome: a systematic review. Gait Posture 2009;30:405–16.
[86] Hart HF, Barton CJ, Khan KM, Riel H, Crossley KM. Is body mass index associated with patellofemoral pain and patellofemoral osteoarthritis? A systematic review and meta-regression and analysis. Br J Sports Med 2017;51:781–90.
[87] Neal BS, Barton CJ, Gallie R, PO'Halloran P, Morrissey D. Runners with patellofemoral pain have altered biomechanics which targeted interventions can modify: a systematic review and meta-analysis. Gait Posture 2016;45:69–82.

[88] Drew BT, Redmond AC, Smith TO, Penny F, Conaghan PG. Which patellofemoral joint imaging features are associated with patellofemoral pain? Systematic review and meta-analysis. Osteoarthritis Cartilage 2016;24:224–36.
[89] Bonanno DR, Murley GS, Munteanu SE, Landorf KB, Menz HB. Effectiveness of foot orthoses for the prevention of lower limb overuse injuries in naval recruits: a randomised controlled trial. Br J Sports Med 2018;52:298–302.
[90] Schwellnus MP, Jordaan G, Noakes TD. Prevention of common overuse injuries by the use of shock absorbing insoles. Am J Sports Med 1990;18(6):636–41.
[91] Milgrom C, Finestone A, Schlamkovitch N, Wosk J, Laor A, Voloshin A, et al. Prevention of overuse injuries of the foot by improved show shock attenuation: a randomized prospective study. Clin Orthop Relat Res 1992;281:189–92.
[92] Van Tiggelen D, Witvrouw E, Roget P, Cambier D, Danneels L, Verdonk R. Effect of bracing on the prevention of anterior knee pain - a prospective randomized study. Knee Surg Sports Traumatol Arthrosc 2004;12:434–9.
[93] BenGal S, Lowe J, Mann G, Finsterbush A, Matan Y. The role of the knee brace in the prevention of anterior knee pain syndrome. Am J Sports Med 1997;25(1):118–23.
[94] Brushøj C, Larsen K, Albrecht-Beste E, Nielsen MB, Loye F, Holmich P. Prevention of overuse injuries by a concurrent exercise program in subjects exposed to an increase in training load: a randomized controlled trial of 1020 Army recruits. Am J Sports Med 2008;36(4):663–70.
[95] Pope RP, Herbert RD, Kirwan JD, Graham BJ. A randomized trial of preexercise stretching for prevention of lower-limb injury. Med Sci Sports Exerc 2000;32(2):271–7.
[96] Cumps E, Verhagen EA, Duerinck S, Deville A, Duchene L, Meeusen R. Effect of a preventive intervention programme on the prevalence of anterior knee pain in volleyball players. Eur J Sport Sci 2008;8(4):183–92.