The effect of an individualised functional retraining intervention on pain, function and biomechanics in participants with patellofemoral pain: a series of n of 1 trial

DOMINIQUE LEIBBRANDT, PhD1, QUINETTE LOUW, PhD1)

1) Division of Physiotherapy, Faculty of Medicine and Health Sciences, Stellenbosch University: Tygerberg 7505, South Africa

Abstract. [Purpose] To determine the effect of an individualised functional retraining intervention on pain, function, kinematics and self-reported recovery in participants with PFP. [Participants and Methods] Thirty-one participants with unilateral PFP between the ages of 14–40 were included. Data collection and treatment sessions were conducted at the Tygerberg 3D Motion Analysis Laboratory and Physiotherapy Clinic at the University of Stellenbosch Medical School in Cape Town, South Africa. Participants underwent motion analysis testing pre- and post-intervention and attended physiotherapy weekly for a 6-week individualised intervention. [Results] Thirty of the thirty-one participants (96.8%) demonstrated improved pain levels (NPRS) post intervention. Participants demonstrated a statistically significant improvement in function (AKPS) immediately post intervention and continued to improve with greater functional scores at 6-month follow up. Fifteen participants (48.4%) rated themselves as fully recovered on a 7-point Likert scale at 6-month follow up. Nineteen of the 31 participants (61.3%) demonstrated a clinically significant improvement in their priority kinematic outcome post intervention. [Conclusion] Individualised functional retraining may improve pain, function, kinematics and long-term recovery in participants with PFP presenting with kinematic contributing factors. Clinicians need to be educated on common biomechanical contributing factors and how to tailor treatment accordingly.

Key words: Anterior knee pain, Gait analysis, Individualised intervention

INTRODUCTION

Patellofemoral pain (PFP) is characterised by retropatellar or peripatellar pain during activities such as squatting, stair climbing and prolonged sitting that load a flexed knee joint1. It has an estimated prevalence of 19–31% in a young athletic population2. The causes of PFP are multifactorial and biomechanical factors may play an important role in its development3. Many of the proposed causes of PFP are likely to be associated with patient biomechanical dysfunction or poor dynamic stability during weight-bearing activities4. The impact of PFP is considerable as it hinders participation in sport, physical activity, work, and school5. In addition, it has the tendency to become chronic. As many as 50% of participants with PFP will still experience symptoms after 5–8 years6.

Conservative approaches, primarily physiotherapy, are preferred for the treatment of PFP. Surgical options such as lateral retinacular release, chondroplasties, proximal realignments and distal realignments should be considered a last resort thereafter7. In addition, surgery should only be considered when there are specific indications and the pathology is clearly defined8. At the recent Patellofemoral Pain Research Retreat in 2016, a document of current evidence-based treatment guidelines was...
According to this, current recommended treatment options include exercise therapy in the short, medium and long term; multimodal interventions in the short and medium term; and foot orthoses in the short term. The authors concluded that exercise should be considered the first choice of treatment due to the large body of evidence supporting it. This recommendation is supported by a high-quality systematic review that investigated the effect of exercise in the treatment of PFP. Despite the tendency of PFP to become chronic, the review showed that long-term evidence was limited. Three studies followed up on pain and functional outcomes 4–12 months post intervention. Of these, only one study measured self-reported long-term recovery at 12-month follow up. In this study, the exercise group was no more recovered than a control group that had not received an exercise intervention. It is unclear why exercise appears to improve pain and function in the short term, but recovery in the long term remains challenging. There is evidence that suggests that an individually tailored approach to exercise interventions improves patient outcomes in participants with other musculoskeletal conditions such as lower back pain. Therefore, further investigation of this approach in an PFP population is needed.

Since the 2015 Cochrane review, a prospective cohort study investigated the long-term effects of a multimodal individualised intervention for PFP. Thirty-seven participants with AKP received four treatments over a 4-week period, namely local interventions which focused on stretching the quadriceps; fourteen days of taping; fourteen more days of specialised lower limb movement and postural correction; followed by continued self-management. Subsequently a 3 year follow up yielded positive results with 73% pain-free and 27% having less pain than previously. Moreover, 82% returned to their sporting activities, while 54% took up new sports. Only 7% experienced a recurrence of PFP. The inclusion criteria for this study only required that patients had a 1-month duration of symptoms. Therefore, treatment success can be ascribed to early interventions and the effect of this intervention on persistent PFP remains unknown.

According to McMaster University’s hierarchy of evidence and the Oxford Centre for Evidence-Based Medicine, a n of 1 design can be regarded as level 1 evidence for treatment decisions as it enables the assessment of the intervention for a specific person. Recent studies have acknowledged the difficulty in applying the mean response (as assessed in an RCT) to a specific person. The selected methodological design attempts to address this problem by facilitating the translation of evidence into practice. This study will provide new information on potential risk factors associated with PFP and attempt to correlate biomechanics to functional and clinical outcomes through long-term follow up. To our knowledge no studies have assessed the effects of an individualised functional retraining intervention that targets specific biomechanical factors in participants with PFP. In addition, our study design is novel as we are using a series of n of 1 design. By using participants as their own controls, we are allowing for individual variation in aetiology and symptoms.

We hypothesise that an exercise intervention tailored to the individual can improve pain, function and kinematics in participants with PFP post-intervention compared to pre-intervention. The aims of this study are to determine the effect of an individualised functional retraining intervention on 1) lower limb kinematics and 2) short- and long-term pain and functional outcomes in 31 participants with PFP.

PARTICIPANTS AND METHODS

Approval for this study was given by the Health Research Ethics Committee (HREC) of Stellenbosch University, under ethics number N13/05/038. Informed consent was obtained for all included participants.

The study was conducted using a series of single-participant design with each participant acting as his or her own control. The population comprised 31 participants between the ages of 14–40 with unilateral PFP, residing in the Cape Metropitan. Our sample size was determined from a priori power analysis for a single-group pre-test post-test design and the effect size using pilot data on a sub-sample of eight participants. A two-tailed Wilcoxon-signed rank test was used as the data was abnormally distributed. Assuming that alpha=0.05, power=0.95 and effect size=0.75, we needed a sample size of n=27. We recruited 31 participants to allow for drop out.

An evidence-based screening tool was developed specifically for this study (Appendix A) to ensure standardised diagnosis and exclusion of other pathologies. This checklist was based on an up-to-date evidence synthesis on systematic reviews. An initial screening was done at recruitment. Potential participants were asked to complete a short, screening questionnaire via email, containing the subjective indicators required for the diagnosis of PFP. Participants were considered based on age, area of pain, duration of pain, aggravating factors and previous medical history. Sixty-seven participants inquired and of these 31 met the subjective criteria. The most common reason for exclusion was age (>40 years old).

Individuals who met the criteria in the preliminary screening were booked for a testing session at the 3D Motion Analysis Laboratory at the Tygerberg campus of Stellenbosch University. At the first session written informed consent was obtained and all participants were screened based on the objective criteria described in the evidence-based diagnostic checklist. All 31 participants met the criteria and could therefore proceed to the 3D motion analysis assessment. VICON-specific anthropometric measurements that were obtained prior to the motion analysis included: height, mass, leg length, knee diameter and ankle diameter.

A fast, accurate, reliable and high-resolution motion-capturing 3D device, the T10 VICON Analysis (LTD) (Oxford, UK) T10 system was used to obtain the 3D movement analysis data. Retro-reflective markers with a diameter of 9.5 mm were applied. The standard plug-in gait model was used, providing the angle output sought in the current study. Nexus 1.8 software was used for preliminary marker reconstruction, labelling and processing of data. All marker placements were done by an
experienced researcher (DL), to reduce marker bias. Gap filling was performed using the standard Woltring filter supplied by Vicon. Segment and joint kinematics were calculated using the PIG-model and filtered with a 4th-order Butterworth filter at a 34 10 Hz cut-off frequency. Data was exported to MATLAB to extract the joint kinematics of the lower limbs.

Participants were required to attend gait analysis sessions at week 1, week 2, and week 8. Gait analysis was used to screen for kinematic factors associated with PFP that could be targeted with treatment, as there are well-established normative values for these outcomes. The normative dataset is based on gait data from healthy, pain-free participants walking at a self-selected speed tested in the Tygerberg motion analysis laboratory.

Testing was repeated on three occasions. Sessions 1 and 2 were to establish the test-retest reliability of the kinematic outcomes and to quantify measurement error. Session 3 was done post intervention to determine the effects of the intervention. Therefore, the duration of the entire testing period was eight weeks. Function was measured using the anterior knee pain scale (AKPS) and was assessed pre- and post-intervention on the same day as the gait analysis assessment to evaluate the subjective impact of the treatment on the patient’s function and daily activities. The validity and reliability of the AKPS has been established in an PFP population31). The AKPS was followed up at three months, one month after the end of the intervention period, and again at six months. The AKPS can be found attached as Appendix B. The testing procedure and timing of outcome measures can be seen in Fig. 1.

The intervention has been described according to the template for intervention description and replication (TIDieR) checklist22). Individualised functional retraining is an approach to exercise that targets participant-specific biomechanical risk factors by focusing on correcting a dysfunctional movement pattern rather than addressing a specific muscle group. Experts in the field23) recommend incorporating movement pattern retraining as part of the exercise plan for participants with PFP, as it is unclear whether specific muscle group strengthening translates to improved movement performance24). A progressive exercise database adapted from a recent textbook on functional rehabilitation25) was created to assist with the choice of exercises. Two exercise database spreadsheets were created. The first focused on components of walking and was used to choose exercises for weeks 1–3. The second focused on components of squatting and was used to choose exercises for weeks 4–6. Functional retraining during these exercises focused on the specific kinematic factor exhibited by the patient. The exercises were ranked according to three levels of difficulty within task and area. Exercises were progressed according to the following principles: bilateral before unilateral, stable surface before unstable surface, and body weight before loading26). Examples of proximal and local focused exercises at different levels of difficulty from the database are available as supplementary file 1 (online only).

Participants were required to exclusively attend the Tygerberg Physiotherapy Gym weekly for six weeks for individual supervised treatment sessions. The progress of the exercises was assessed weekly and adjusted as needed. Examples of the individually tailored exercises over the 6-week period can be seen as supplementary online data. The therapist’s instructions to the patient as well as criteria for progression has been described in detail in a previous study26).

The participants were required to do the exercises at home three times a week apart from their weekly supervised treatment sessions because published reports suggest that supervision is beneficial in the early phases of rehabilitation to monitor technique. However, participants should be motivated to independency as quickly as possible27).

The clinician asked patients to complete a weekly pain monitoring and exercise compliance diary at each treatment session (Appendix C). The treatment sessions were administered by one of two experienced musculoskeletal physiotherapists (DL and MM).

The data was initially analysed for each individual participant by describing measures of central tendency (means) and variation expressed (standard deviations) of pelvic, hip, knee and ankle kinematics, at baseline and post-intervention. The 2-standard deviation (SD) band method was used to determine which participants obtained clinically meaningful improvements in their priority kinematic factor28). This method has been previously used to analyse single-participant design data as it accounts for individual variability29). The two standard deviation band method is based on the computation of the deviation for the pre-intervention baseline data. Once the standard deviation is computed for the baseline data, bands are drawn on the graph that contain scores within two standard deviations from the mean. If the mean post-intervention data points fall outside of the 2SD band the change in kinematics is considered clinically significant30).

The pain and functional outcome scores were used to determine who improved, whose condition was unchanged or whose worsened. The data was categorised according to severity of pain and level of functional impairment. A χ² test established categorical changes following treatment and at 3- and 6-month follow up. Stata version 13 was used for data analysis.

Primary outcomes included priority kinematic factor identified for each participant based on decision-making algorithm using gait analysis as a screening tool (Appendix D). This algorithm was developed specifically for the study and is based on a systematic review of the evidence31), pain ratings using the numeric pain rating scale (NPRS) over the 8-week testing period and 3- and 6-month follow up (post-intervention period), functional scores using the AKPS at week 1, week 8 and 3-month and 6-month follow up (post-intervention period), and self-reported long-term recovery on a 7-point Likert scale at 6-month follow up (post-intervention period).

RESULTS

Thirty-one participants (13 males, 18 females) with unilateral PFP (20 left-sided, 11 right-sided) were included in this
The average age was 30 (range 14–40; SD=8.4), height (mean=170.1 cm; SD=10.4 cm) and weight (mean=77.5 kg; SD=25.7 kg). The average duration of symptoms was 16.5 months and 64% of the participants had tried previous treatment such as massage, taping, pain medication and strength training. Participant characteristics are depicted in Table 1.

The weekly pain diary using the NPRS showed that 30 of the 31 participants (96.8%) demonstrated improved pain levels (NPRS) post-intervention (8 weeks). Table 2 shows the changes in pain severity based on NPRS scores throughout the follow-up period. The percentage of participants in each category differed significantly pre-versus post-intervention $X^2(4, N=31)=12.4, p=0.02$. These positive changes reflected a significantly greater percentage of participants in the “pain-free” and “mild” pain categories post-intervention.

There were no significant changes between pain categories post-intervention (8 weeks) compared to the 3-month follow up $X^2(4, N=31)=8.1, p=0.9$ and 6-month follow up indicating that the effects were maintained but not improved. The same applied at the 6-month follow up compared to the post-intervention showing that the treatment effects were maintained in the long term $X^2(4, N=31)=3.7, p=0.4$. Pain diary results for each participant throughout the treatment period are available online only as supplementary file 2.

Self-reported long-term recovery was measured on a 7-point Likert scale at the 6-month follow up as seen below in Fig. 213). The measurements ranged from fully recovered to worse than before. If participants regarded themselves as having recovered well or having recovered completely, they were classified as “recovered”. Those who were “not recovered”, identified as worse than before or as minimally recovered13, 32). Fifteen participants (48.4%) rated themselves as fully recovered, whereas only one participant (AKP12) rated herself as not recovered. The remaining 48.4% reported being “partially recovered” with scores of between 3 and 5.

The test retest reliability of the kinematic outcomes was established in a previous study33). A comparison of session 1 and

---

### Table 1. Sample description (affected side, age, gender, height and mass)

| Sample size | Affected leg | Average age (years) | Average height (cm) | Average mass (kg) | Average BMI (kg/m$^2$) |
|-------------|--------------|---------------------|---------------------|------------------|------------------------|
| Males with PFP | 13 Left | 31.5 | 176.9 | 85.62 | 27.4 |
| Females with PFP | 5 Right | 8.7 | 8.2 | 24.19 | 6.0 |
| All participants | 18 Left | 29.22 | 165.3 | 65.56 | 24.3 |
| | 6 Right | 7.9 | 11.6 | 23.98 | 6.1 |
| | 31 Left | 30.2 | 170.2 | 77.50 | 26.8 |
| | 11 Right | 8.4 | 10.5 | 25.70 | 6.1 |

### Table 2. Proportion of participants in different categories of pain severity (NPRS) throughout the follow-up period

| Categories | Actual scores (NPRS) | Pre-intervention | Post-intervention | 3-month follow up | 6-month follow up |
|------------|----------------------|-----------------|-------------------|------------------|------------------|
| 0 | 0 (pain-free) | 0 (0%) | 18 (50.1%) | 18 (50.1%) | 18 (50.1%) |
| 1 | 1–3 (mild) | 12 (38.7%) | 10 (32.3%) | 12 (38.7%) | 11 (35.5%) |
| 2 | 4–6 (moderate) | 15 (48.4%) | 3 (9.6%) | 1 (3.2%) | 2 (6.5%) |
| 3 | 7–9 (severe) | 4 (12.9%) | 0 (0%) | 0 (0%) | 0 (0%) |

### Table 3. Proportion of participants in different categories of functional impairment (AKPS) throughout the follow-up period

| Categories | Actual scores AKPS (100) | Pre-intervention | Post-intervention | 3-month follow up | 6-month follow up |
|------------|--------------------------|-----------------|-------------------|------------------|------------------|
| 1 | <60 (severe functional impairment) | 2 (6.5%) | 0 (0%) | 0 (0%) | 0 (0%) |
| 2 | 60–79 (moderate functional impairment) | 21 (67.7%) | 6 (19.4%) | 4 (12.9%) | 3 (9.7%) |
| 3 | 80–99 (minor functional impairment) | 8 (25.8%) | 24 (77.4%) | 20 (64.5%) | 19 (61.3%) |
| 4 | 100 (No functional impairment) | 0 (0%) | 1 (3.2%) | 7 (22.6%) | 9 (29%) |

---

13. Figure 2: Image or diagram

21. Previous study: Reference to a previous study with specific details
43

kinematic data, tested one week apart with no intervention in between revealed that all outcomes obtained were acceptable to excellent test-retest reliability scores for both measures of relative reliability (ICC=0.78–0.9) and measures of absolute reliability (SEM=0.9 −4.2 degrees). Hip frontal plane and ankle sagittal plane outcomes were the most reliable with the lowest measurement error. Hip transverse plane outcomes were least reliable and demonstrated the highest measurement error.

Results for participant’s priority kinematic factor are summarised in Table 4. Detailed individual findings can be found online only as supplementary file 3. Of the 31 participants, 20 (64.5%) showed clinically significant changes post-intervention compared to pre-intervention. Of these 19 (61.3%) improved (positive change) and one (3.2%) worsened (negative change). Ten participants (32.3%) showed no significant change in their priority kinematic factor following treatment. There were no significant differences between genders with 11/18 (61%) of females and 8/13 (61%) of males showing clinically meaningful improvements. The 25 adult participants aged 20–40 did slightly better than the six adolescents, with 64% and 50% improving respectively. However, a bigger adolescent group is required to draw further conclusion.

DISCUSSION

The results of this study showed that most participants demonstrated improvements in self-reported pain and function following an individualised functional retraining intervention. The effect of the intervention on average pain levels had improved one month later (3-month follow up). As had the average functional scores (AKPS) with 96.8% of the participants reporting clinically significant improvements in function. Given that the participants had all experienced PFP for longer than three months at the time of recruitment, it is possible that central mechanisms were involved. This can be classified as sub-acute going on chronic pain. Therefore, function could be a more important indicator of treatment success than pain. These findings concur with a recent high-quality systematic review that exercise is effective in improving short-term pain and function. In the current study, the participants demonstrated improved pain levels in the medium term at 3 months following completion of the intervention and these were maintained in the long term at 6-month follow up. In terms of functional outcomes, the participants showed improved functional scores at 3 months and they reported that their functional scores had continued to improve at 6-month follow up.
There is limited and low-quality long-term evidence for the effect of exercise in the treatment of PFP. One study found that proprioceptive neuromuscular facilitation (PNF) and aerobic exercise interventions resulted in significantly reduced pain and significant improvements in function in participants with PFP at 4 months post intervention. The effects of these two intervention groups were equal and demonstrated greater improvements in all outcomes than a third group that only received stretching. However, this was not followed up at 6 or 12 months post intervention. Another study did a long-term follow up for four different treatment groups 1) exercise, taping and education, 2) exercise and education, 3) taping and education and 4) education only. The exercise intervention focused on eccentric strengthening of the lower limb extensors and participants received 6 sessions over a 3-week period. At 12-month follow up, the exercise groups showed significantly greater improvements in pain compared to the other groups. However, the long-term functional scores were equal. This shows that reductions in pain do not necessarily result in improvements in function. The reasons for this are unclear, however it is possible that a 3-week intervention period was insufficient to address functional impairment in the participants. It is also possible that participants did not continue with self-management after the treatment period especially if pain had decreased. The findings of the current study showed improvements in pain and function at a 6-month follow up; however, it is unclear how this compares to other exercise interventions and if the effects would be maintained at 12 months or even a few years later. These limitations should be addressed in future research.

A major challenge in the treatment of PFP is that participants tend to improve with exercise but don’t recover fully. The 6-month follow up showed that half of the participants (48.6%) recovered fully and half reported being partially recovered. This is similar to findings from a previous exercise intervention study that found that 43% had recovered at 3-month follow up and 62% at 12-month follow up. Exercise interventions need to prevent reoccurrence; therefore, one needs to ascertain what inhibits full recovery. In the current study, one of these factors could be compliance with continued self-management after the 6-week supervised exercise period, as this was not measured.

Several recent studies have established which patients are most likely to experience favourable outcomes with different conservative treatment approaches. A longer duration of symptoms (>4 months) will most likely result in a poor outcome. Other prognostic factors include older age, greater usual pain severity and lower baseline AKPS score. One study found that females respond better than males to exercise therapy. Kinematic differences may exist between genders. These factors include increased dynamic measures of knee valgus angle, hip internal rotation angle and decreased dynamic measures of knee flexion angle compared to males. Females may have decreased hip strength compared to pain-free controls and thus exercise that strengthens hip muscles might be more beneficial for women than for men. We identified males and females with hip kinematic risk factors and found no significant differences between the genders with both benefiting equally from hip-focused interventions.

Nineteen participants showed clinically significant changes in their priority kinematic factor, targeted with functional exercises. Eleven demonstrated no significant change and one participant (AKP18) worsening of his main kinematic factor identified in session 1. The reason for this is unclear as the participant reported a full recovery, with no pain (0/10 on the AKPS) and full function (100% on AKPS) at the 6-month follow up. The participant was a trail runner and reported decreased pain and significant improvements in function in participants with PFP at 4 months post intervention. The effects of other prognostic factors were the same if the participants were followed up at 6 to 12 months post intervention. It is unclear if an individualised exercise approach might influence the findings. However, it is clear that targeting kinematics is just one component of individualised treatment. Activity modification and load management is vital and should be included in an individualised treatment plan.

Our results suggest that an individualised approach to exercise may be beneficial in reducing short-term pain and improving short-, medium- and long-term function in participants with PFP. Kinematics during gait may also improve in patients presenting with kinematic contributing factors. In order to provide individualised interventions more research needs to be done using an n of 1 design. The vision of this study is to move away from an approach whereby all patients receive the same intervention and to move towards an individualised approach that addressed participant-specific impairments.

A limitation of the current study is that the gait analysis re-assessment was only done immediately post intervention. Future research should include a biomechanical reassessment at the long-term follow up to establish whether the biomechanical results were maintained or improved and how this relates to long-term pain and function. Another limitation is that the kinematic factors that were identified are based on cross-sectional studies and therefore we cannot establish if they are factors predictive of PFP or rather effects of the pain. The current intervention is only relevant for participants with PFP presenting...
with kinematic risk factors and cannot be generalised to all participants with PFP. If we are trying to achieve a holistic person-centred approach to treatment, an individually tailored treatment approach based only on biomechanics is insufficient as it only addresses one aspect of the biopsychosocial model of treatment. Future research should develop ways to tailor treatment to the individual taking into consideration the interplay of physical, biological, psychological and social factors.\(^{14}\)

In conclusion, most participants (64.5\%) demonstrated clinically meaningful improvements in their priority kinematic outcome post intervention. The effects of the intervention were maintained in the long term and half of the participants reported that they had recovered fully at 6 months post intervention. Future research should investigate factors preventing individuals with PFP from full long-term recovery.

**Funding and conflict of interest**

The authors wish to acknowledge that this work was funded by the National Research Foundation (NRF) of South Africa (Grant number CSUR13090332637). The authors declare that they have no financial or personal relationships or conflicts of interest that may have inappropriately influenced them in writing this article.

**REFERENCES**

1) Østerås B, Østerås H, Torstensen TA, et al.: Dose-response effects of medical exercise therapy in patients with patellofemoral pain syndrome: a randomised controlled trial. Physiotherapy, 2013, 99: 126–131. [Medline] [CrossRef]

2) Rathleff CR, Roos EM, Olesen JL, et al.: Prevalence and severity of patellofemoral pain among adolescents—a population-based study. International Patellofemoral Research Retreat, 2013.

3) Witvrouw E, Callaghan MJ, Stefanik JJ, et al.: Patellofemoral pain: consensus statement from the 3rd International Patellofemoral Pain Research Retreat held in Vancouver, September 2013, 48: 411–441. [Medline] [CrossRef]

4) Rabelo ND, Lima B, Reis AC, et al.: Neuromuscular training and muscle strengthening in patients with patellofemoral pain syndrome: a protocol of randomised controlled trial. BMC Musculoskeletal Disorder, 2014, 15: 157–167. [Medline] [CrossRef]

5) Lankhorst NE, van Middelkoop M, Crossley KM, 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, 2013, 47: 227–233. [Medline] [CrossRef]

6) Collins NJ, Bierma-Zeinstra SM, Crossley KM, et al.: Prognostic factors for patellofemoral pain: a multicentre observational analysis. Br J Sports Med, 2013, 47: 881–886. [Medline] [CrossRef]

7) McCarthy MM, Strickland SM: Patellofemoral pain: an update on diagnostic and treatment options. Curr Rev Musculoskeletal, 2013, 6: 188–194. [Medline] [CrossRef]

8) Post WR, Dye SF: Patellofemoral pain: an enigma explained by homeostasis and common sense. Am J Orthop, 2017, 46: 92–100. [Medline]

9) Crossley KM, van Middelkoop M, Callaghan MJ, et al.: 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: 844–852. [Medline] [CrossRef]

10) Van Der Heijden RA, Lankhorst NE, Van Linschoten R, et al.: Exercise for treating patellofemoral pain syndrome: an abridged version of Cochrane systematic review. Eur J Phys Rehabil Med, 2016, 52: 110–133. [Medline] [CrossRef]

11) Clark DI, Downing N, Mitchell J, et al.: Physiotherapy for anterior knee pain: a randomised controlled trial. Ann Rheum Dis, 2000, 59: 700–704. [Medline] [CrossRef]

12) Moyano FR, Valenza MC, Martin LM, et al.: Effectiveness of different exercises and stretching physiotherapy on pain and movement in patellofemoral pain syndrome: a randomized controlled trial. Clin Rehabil, 2013, 27: 409–417. [Medline] [CrossRef]

13) van Linschoten R, van Middelkoop M, Berger MY, et al.: Supervised exercise therapy versus usual care for patellofemoral pain syndrome: an open label randomized controlled trial. BMJ, 2009, 339: b4074. [Medline] [CrossRef]

14) Falla D, Hodges PW: Individualized exercise interventions for spinal pain. Exerc Sport Sci Rev, 2017, 45: 105–115. [Medline] [CrossRef]

15) Keays SL, Mason M, Newcombe PA: Three-year outcome after a 1-month physiotherapy program of local and individualized global treatment for patellofemoral pain followed by self-management. Clin J Sport Med, 2016, 26: 190–198. [Medline] [CrossRef]

16) McMaster University hierarchy of evidence: https://research-handbook.mcmaster.ca/ebm/hierarchy_evidence.htm

17) Oxford University Centre for Evidence Based Medicine levels of evidence: http://www.cebm.net/index.aspx?o=5653

18) Elamin MB, Montori VM: The hierarchy of evidence: from unsystematic clinical observations to systematic reviews. Neurology. New York: Springer, 2012, pp 11–24.

19) Greenhalgh T: How to implement evidence-based healthcare. Oxford: John Wiley & Sons, 2017, pp 10–29.

20) Elahar Y, Fujimoto H, Miyazaki S, et al.: Comparison of the performance of 3D camera systems II. Gait Posture, 1997, 5: 251–255. [CrossRef]

21) Watson CJ, Propps M, Ratner J, et al.: Reliability and responsiveness of the lower extremity functional scale and the anterior knee pain scale in patients with anterior knee pain. J Orthop Sports Phys Ther, 2005, 35: 136–146. [Medline] [CrossRef]

22) Hoffmann TC, Glasziou PP, Boutron I, et al.: Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. BMJ, 2014, 348: g1687. [Medline] [CrossRef]

23) Barton CJ, Lack S, Hemmings S, et al.: The ‘Best practice guide to conservative management of patellofemoral pain’: incorporating level 1 evidence with expert clinical reasoning. Br J Sports Med, 2015, 49: 923–934. [Medline] [CrossRef]

24) Wouters I, Almonroeder T, Dejarlais B, et al.: Effects of a movement training program on hip and knee joint frontal plane running mechanics. Int J Sports Phys Ther, 2012, 7: 637–646. [Medline]

25) Liebenson C: Functional training handbook. Philadelphia: Lippincott Williams & Wilkins, 2014, pp 355–361.
26) Leibbrandt DC, Louw QA: Targeted functional movement retraining to improve pain, function, and biomechanics in subjects with anterior knee pain: a case series. J Sport Rehabil, 2018, 27: 218–223. [Medline] [CrossRef]

27) Papadopoulos K, Stanisopoulos D, Ganchev D: A systematic review of reviews in patellofemoral pain syndrome. Exploring the risk factors, diagnostic tests, outcome measurements and exercise treatment. Sports Med Open, 2015, 9: 7–17. [CrossRef]

28) Romeiser Logan L, Hickman RR, Harris SR, et al.: Single-subject research design: recommendations for levels of evidence and quality rating. Dev Med Child Neurol, 2008, 50: 99–103. [Medline] [CrossRef]

29) Jones F, Mandy A, Partridge C: Changing self-efficacy in individuals following a first time stroke: preliminary study of a novel self-management intervention. Clin Rehabil, 2009, 23: 522–533. [Medline] [CrossRef]

30) Tamminga JS, Martin KS, Miller EW: Single-subject design study of 2 types of supramalleolar orthoses for young children with down syndrome. Pediatr Phys Ther, 2012, 24: 278–284. [Medline] [CrossRef]

31) Leibbrandt D, Louw Q: Kinematic factors associated with anterior knee pain during common aggravating activities: a systematic review. Phys Ther Rev, 2017, 22: 34–47.

32) Rathleff MS, Petersen KK, Arendt-Nielsen L, et al.: Impaired conditioned pain modulation in young female adults with long-standing patellofemoral pain: a single blinded cross-sectional study. Pain Med, 2016, 17: 980–988. [Medline]

33) Leibbrandt DC, Louw QA: The test retest reliability of gait outcomes in subjects with anterior knee pain. J Bodyw Mov Ther, 2018, 22: 476–481. [Medline] [CrossRef]

34) Rathleff MS, Roos EM, Olesen JL, et al.: Lower mechanical pressure pain thresholds in female adolescents with patellofemoral pain syndrome. J Orthop Sports Phys Ther, 2013, 43: 414–421. [Medline] [CrossRef]

35) Witvrouw E, Werner S, Mikkelsen C, et al.: Clinical classification of patellofemoral pain syndrome: guidelines for non-operative treatment. Knee Surg Sports Traumatol Arthrosc, 2005, 13: 122–130. [Medline] [CrossRef]

36) Lack S, Barton C, Vicenzino B, et al.: Outcome predictors for conservative patellofemoral pain management: a systematic review and meta-analysis. Sports Med, 2014, 44: 1703–1716. [Medline] [CrossRef]

37) Lankhorst NE, van Middelkoop M, van Trier YD, et al.: Can we predict which patients with patellofemoral pain are more likely to benefit from exercise therapy? A secondary exploratory analysis of a randomized controlled trial. J Orthop Sports Phys Ther, 2015, 45: 183–189. [Medline] [CrossRef]

38) Matthews M, Rathleff MS, Claus A, 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: 1650–1660. [Medline] [CrossRef]

39) Boling M, Padua D, Marshall S, et al.: Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scand J Med Sci Sports, 2010, 20: 725–730. [Medline] [CrossRef]

40) Prins MR, van der Wurff P: Females with patellofemoral pain syndrome have weak hip muscles: a systematic review. Aust J Physiother, 2009, 55: 9–15. [Medline] [CrossRef]

41) Hreljac A, Ferber R: A biomechanical perspective of predicting injury risk in running. Int J Sports Med, 2006, 7: 98–108.

42) Esculier JF, Bouyer LJ, Dubois 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: 659–666. [Medline] [CrossRef]
Appendix A. Checklist for diagnosis of patellofemoral pain

**Subjective information:**

|                         | YES | NO |
|-------------------------|-----|----|
| Age (must be yes)       |     |    |
| 14–40                   |     |    |
| Area (must be yes)      |     |    |
| Front of knee or retropatella |     |    |
| Chronicity              |     |    |
| Longer than 3 months    |     |    |
| Aggravated by (must be yes for 2 or more of the following) |     |    |
| Squatting               |     |    |
| Prolonged sitting       |     |    |
| Stairs (ascending or descending) |     |    |
| Kneeling                |     |    |
| Excluded if any of the below known |     |    |
| Previous lower limb surgery |     |    |
| History of trauma       |     |    |
| Rheumatological conditions |     |    |
| Known intra-articular pathology: ligament and osteoarthritis |     |    |
| Patellar instability    |     |    |
| Knee effusion           |     |    |
| Patella subluxation/ dislocation |     |    |
| Fat pad impingement/ bursitis |     |    |
| Osgood Sclatter         |     |    |

**OBJECTIVE TESTS:**

Symptom reproduction with (must be positive for at least 1 of the following activities)

|                         |     |    |
|-------------------------|-----|----|
| Squatting               |     |    |
| Kneeling                |     |    |
| Ascending or descending stairs |     |    |

Positive for at least one of the following

|                         |     |    |
|-------------------------|-----|----|
| Patella compression test |     |    |
| Patella tilt test       |     |    |
(Minimum 2/3) positive for combination of

| Procedure                        | Result  |
|----------------------------------|---------|
| Squatting                        |         |
| Isometric quads                  |         |
| Palpation of patella borders     |         |

Excluded if positive for

| Test                              | Condition    |
|-----------------------------------|--------------|
| Lachmen’s Test6–8)                | ACL          |
| Posterior Drawer Test6–8)         | PCL          |
| Valgus Stress Test6–8)            | MCL          |
| Varus Stress test6, 8)            | LCL          |
| McMurray’s Test6, 8)              | MENISCUS     |
| Patellar Ballotment Test5)        | Effusion     |

**REFERENCES**

1) Haim A, Yaniv M, Dekel S, et al.: Patellofemoral pain syndrome: validity of clinical and radiological features. Clin Orthop Relat Res, 2006, 451: 223–228. [Medline] [CrossRef]
2) Näslund J, Näslund UB, Odenbring S, et al.: Comparison of symptoms and clinical findings in subgroups of individuals with patellofemoral pain. Physiother Theory Pract, 2006, 22: 105–118. [Medline] [CrossRef]
3) Cook C, Hegedus E, Hawkins R, et al.: Diagnostic accuracy and association to disability of clinical test findings associated with patellofemoral pain syndrome. Physiother Can, 2010, 62: 17–24. [Medline] [CrossRef]
4) Sweitzer BA, Cook C, Steadman JR, et al.: The inter-rater reliability and diagnostic accuracy of patellar mobility tests in patients with anterior knee pain. Phys Sportsmed, 2010, 38: 90–96. [Medline] [CrossRef]
5) Nijs J, Van Geel C, Van der auwera C, et al.: Diagnostic value of five clinical tests in patellofemoral pain syndrome. Man Ther, 2006, 11: 69–77. [Medline] [CrossRef]
6) Benjaminse A, Gokeler A, van der Schans CP: Clinical diagnosis of an anterior cruciate ligament rupture: a meta-analysis. J Orthop Sports Phys Ther, 2006, 36: 267–288. [Medline] [CrossRef]
7) Day RJ, Fox JE, Paul-Taylor G: Neuromusculoskeletal clinical tests: a clinician’s guide. Elsevier Health Sciences. 2009.
8) Malanga GA, Andrus S, Nadler SF, et al.: Physical examination of the knee: a review of the original test description and scientific validity of common orthopedic tests. Arch Phys Med Rehabil, 2003, 84: 592–603. [Medline] [CrossRef]
Appendix B. Anterior knee pain scale

ANTERIOR KNEE PAIN (Sheet code____________________)

Name: ___________________________ Date: ________________

Age: ___________ Knee: L/R

Duration of symptoms: ______ years _______ months

For each question, circle the latest choice (letter), which corresponds to your knee symptoms.

1. Limp
   (a) None (5)
   (b) Slight or periodic (3)
   (c) Constant (0)

2. Support
   (a) Full support without pain (5)
   (b) Painful (3)
   (c) Weight bearing impossible (0)

3. Walking
   (a) Unlimited (5)
   (b) More than 2 km (3)
   (c) 1-2 km (2)
   (d) Unable (0)

4. Stairs
   (a) No difficulty (10)
   (b) Slight pain when descending (8)
   (c) Pain both when descending and ascending (5)
   (d) Unable (0)

5. Squatting
   (a) No difficulty (5)
   (b) Repeated squatting painful (4)
   (c) Painful each time (3)
   (d) Possible with partial weight bearing (2)
   (e) Unable (0)

6. Running
   (a) No difficulty (10)
   (b) Pain after more than 2 km (8)
   (c) Slight pain from start (6)
   (d) Severe pain (3)
   (e) Unable (0)

7. Jumping
   (a) No difficulty (10)
   (b) Slight difficulty (7)
   (c) Constant pain (2)
   (d) Unable (0)

8. Prolonged sitting with the knees flexed
   (a) No difficulty (10)
   (b) Pain after exercise (8)
   (c) Constant pain (6)
   (d) Pain forces to extend knees temporarily (4)
   (e) Unable (0)

9. Pain
   (a) None (10)
   (b) Slight and occasional (8)
   (c) Interferes with sleep (6)
   (d) Occasionally severe (3)
   (e) Constant and severe (0)

10. Swelling
    (a) None (10)
    (b) After severe exertion (8)
    (c) After daily activities (6)
    (d) Every evening (4)
    (e) Constant (0)

11. Abnormal painful kneecap (patellar) movements (subluxations)
    (a) None (10)
    (b) Occasionally in sports activities (6)
    (c) Occasionally in daily activities (4)
    (d) At least one documented dislocation (2)
    (e) More than two dislocations (0)

12. Atrophy of thigh
    (a) None (5)
    (b) Slight (3)
    (c) Severe (0)

13. Flexion deficiency
    (a) None (5)
    (b) Slight (3)
    (c) Severe (0)
Appendix C. Weekly pain and exercise compliance diary

| Date | Time | Description of pain | 0-10 | What eased pain | Other comments (pain, mood, activities, medication, etc.) | Exercise Compliance Diary: Recorded at same time and day once a week |
|------|------|---------------------|------|----------------|----------------------------------------------------------|--------------------------------------------------------------------|
|      |      |                     |      |                |                                                          | Time |
|      |      |                     |      |                |                                                          | Date |
|      |      |                     |      |                |                                                          |      |
Appendix D. Evidence-based algorithms for screening during gait

**MUST CONSIDER**
- Evidence based on at least 2 cross-sectional studies with significant and consistent findings

**MAYBE CONSIDER**
- Evidence based on 1 cross-sectional study with a significant finding

**DO NOT CONSIDER**
- Evidence based on at least 2 cross-sectional studies with inconsistent findings

**NOT CURRENTLY CLINICALLY RELEVANT**
- Evidence based on at least one cross-sectional study with insignificant findings

---

**Hip:**
- Reduced peak hip internal rotation$^{12}$
- Delayed timing of peak rear-foot eversion $^{12,20}$

**Knee:**
- Early timing of peak hip internal rotation$^{12}$
- Increased hip add angle at peak knee extensor moment$^{18}$
- Reduced hip adduction at peak knee extensor moment during fast walking$^{18}$

**Ankle and foot:**
- Increased rear-foot eversion at heel strike$^{11}$
- Increased overall ankle dorsiflexion ROM$^{18}$
- Increased peak ankle dorsiflexion during fast walking$^{18}$

**Walking: Evidence from cross-sectional studies**

Key: F=female, S=small effect size, M=medium effect size, L=large effect size
ALGORITHM REFERENCES

1) Barton CJ, Levinger P, Webster KE, et al.: Walking kinematics in individuals with patellofemoral pain syndrome: a case-control study. Gait Posture, 2011, 33: 286–291. [Medline] [CrossRef]

2) Powers CM, Perry J, Hsu A, et al.: Are patellofemoral pain and quadriceps femoris muscle torque associated with locomotor function? Phys Ther, 1997, 77: 1063–1075, discussion 1075-1078. [Medline] [CrossRef]

3) Levinger P, Gilheard W: Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking. Gait Posture, 2007, 25: 2–8. [Medline] [CrossRef]

4) Salsich GB, Long-Rossi F: Do females with patellofemoral pain have abnormal hip and knee kinematics during gait? Physiother Theory Pract, 2010, 26: 150–159. [Medline] [CrossRef]

5) Powers CM, Heino JG, Rao S, et al.: The influence of patellofemoral pain on lower limb loading during gait. Clin Biomech (Bristol, Avon), 1999, 14: 722–728. [Medline] [CrossRef]

6) Nadeau S, Gravel D, Hébert LJ, et al.: Gait study of patients with patellofemoral pain syndrome. Gait Posture, 1997, 5: 21–27. [CrossRef]

7) Levinger P, Gilheard W: The heel strike transient during walking in subjects with patellofemoral pain syndrome. Phys Ther Sport, 2005, 6: 83–88. [CrossRef]

8) Barton CJ, Levinger P, Crossley KM, et al.: The relationship between rearfoot, tibial and hip kinematics in individuals with patellofemoral pain syndrome. Clin Biomech (Bristol, Avon), 2012, 27: 702–705. [Medline] [CrossRef]

9) Powers CM, Chen PY, Reischl SF, et al.: Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain. Foot Ankle Int, 2002, 23: 634–640. [Medline] [CrossRef]

10) Heino Brechter J, Powers CM, Powers CM: Patellofemoral stress during walking in persons with and without patellofemoral pain. Med Sci Sports Exerc, 2002, 34: 1582–1593. [Medline] [CrossRef]

11) Powers CM, Landel R, Perry J: Timing and intensity of vastus muscle activity during functional activities in subjects with and without patellofemoral pain. Phys Ther, 1996, 76: 946–955; discussion 956–967. [Medline] [CrossRef]