Retrospective View of Patellofemoral Pain Classification Subcategories in a Marathon Runner: A Case Report

Angela Huber, PT, DPT, OCS

Physical Therapist, PT Services Rehabilitation, Ottawa, OH & Assistant Professor of Physical Therapy, University of Findlay Doctor of Physical Therapy Traditional and Weekend Programs, Findlay, OH

ABSTRACT

Background and Purpose: Long-distance running can create an overload on the knee, predisposing runners to patellofemoral pain syndrome (PFPS). The PFPS Clinical Practice Guidelines proposed 4 impairment/function-based classification subcategories to guide intervention, but not specifically for distance runners. The purpose of this case report was to apply clinical reasoning retrospectively in review of multimodal interventions in a marathon runner with PFPS. **Methods:** The patient was a 33-year-old male distance runner with PFPS. Multimodal intervention addressed the subcategories along with immediate patient-specific training education and gait retraining. **Findings:** The patient ran without pain after 4 visits. He completed 8 visits total and subsequently 6 months later completed a marathon without pain. **Clinical Relevance/Conclusion:** The findings of this case highlight immediate, patient-specific inclusion of training education and gait retraining supports early pain relief. Multimodal intervention from all 4 subcategories resulted in long-term pain relief and prevention of reinjury during a progressive increase in running mileage.

Key Words: gait, knee, running, training

BACKGROUND AND PURPOSE

Running-related injuries in distance runners range from 19.4% to 79.3%, with an incidence of knee injury ranging between 7.2% and 50%.[1] One author noted that during training in the year prior to a marathon, 54.8% of male runners suffered an injury with 79.6% of these injuries occurring during training sessions. In these training sessions, the knee is the most common injury site.[2] Runners have an increased risk of new injury after their initial injury, and marathon runners are at greater risk for running-related injuries due to high weekly mileage and high running frequency,[1,3] complicating prognosis for running participation.

Runners with patellofemoral pain (PFPS) have altered biomechanics[4-6] and may have multiple training factors associated with injury.[1,3] This complexity of evaluating a patient and considering multiple factors that influence PFPS is difficult and involves more than just evaluating mobility and measuring performance. In an attempt to resolve some of the complexity in treating a patient with PFPS, Willy et al published a Clinical Practice Guideline (CPG) for patellofemoral pain. Willy et al proposed 4 PFPS Impairment/Function-Based Classification Subcategories linked to the International Classification of Functioning, Disability, and Health Model. These subcategories include Overuse/Overload, Muscle Performance Deficits, Movement Coordination Deficits, and Mobility Impairments.[7]

Multimodal intervention is recommended in the treatment of PFPS, although, the best combination of interventions is yet to be determined.[7] Education regarding training should be an integral part of interventions[8] to match load expectations with soft tissue stress tolerance. Gait retraining reduces pain and improves biomechanics in injured runners with PFPS, but the best type and schedule of feedback, retraining dosage, and gait correction techniques of greatest priority are not well defined in the literature.[9] Video analysis using two-dimensional (2-D) video can elucidate group differences in kinematic variables during running,[10] and intra-rater reliability (k_w>.80) improves with clinician experience.[11] While video applications for devices are being used in the clinic, published clinical cases using 2-D video analysis are lacking.

Exercise prescription is an intervention priority for patients with PFPS. Combined proximal hip and knee targeted exercise have been shown to optimize pain and function in patients with PFPS.[12] Treating soft tissue structures that lack mobility in patients with PFPS is common in clinical practice. Authors have noted that specifically the hamstring, gastrocnemius, soleus, quadriceps, and iliotibial band lack flexibility in patients with PFPS.[13] However, the time commitment to achieve high mileage necessary to run a marathon provides a unique challenge to the implementation of exercise programs in the running athlete.

The purpose of this case report was to provide a physical therapy evaluation and multimodal intervention framework using shared decision-making[14] in an injured male distance runner training for his first marathon. The patient in this case presented with a new onset of PFPS before the publication of the Patellofemoral Pain Clinical Practice Guideline. Retrospective subcategorization following Impairment/Function-Based Classification of Patellofemoral Pain Syndrome is presented to provide a clinical reasoning framework for prioritization of evaluation and interventions. A patient-specific multimodal intervention approach was used to address multiple lower extremity pain locations and the patient-specific goal of running his first marathon was weighted into the plan of care decisions.

CASE DESCRIPTION

Patient History

The patient was a 33-year-old male runner with a chief complaint of left peripatellar knee pain, preceded by left anterior ankle pain, which was described as sharp during a half marathon 6 weeks before the initial evaluation. The patient ceased running for 2 weeks after his initial injury and then attempted to return to running over 4 weeks, but was limited by continuous sharp anterior and peripatellar left knee pain upon footstrike rated at 6/10 on the Numeric Pain Rating Scale (NPRS). The primary functional outcome measure used was the Patient-Specific Functional Scale (PSFS), which measures activity difficulty on an 11-point scale from 0 (unable to perform) to 10 (able to perform at the same level before injury).[15] The patient rated running at 1/10, jumping 7/10, and squatting 6/10. He also reported left knee stiffness after 4 hours of sitting during work. Since the injury, the patient continued with unmodified cross-fit classes 3 to 4 days a week. His past medical history consisted of infrequent migraines and low back pain with left radiculopathy. A lumbar magnetic resonance imaging confirmed central and left paracentral disc herniation/protrusion at the L5-S1 vertebral level with severe left lateral canal stenosis 2 years prior. At that time, the patient received 2 left L5-S1 transforaminal epidurals (Dexamethasone and Lidocaine) and one caudal epidural (Bupivacaine and Lidocaine). The patient, although unconcerned with the lumbar history, reported his left lower extremity numbness worsened after prolonged running. Care of this patient met the Health Insurance, Portability, and Accountability Act (HIPAA) requirements for the protection of health information.

Clinical impression #1

The initial clinical impression was a likely diagnosis of left PFPS due to overload with differential diagnosis of iliotibial band syndrome, patellar tendinitis, or meniscal tear. Anterior talocrural joint impingement was also suspected. International Classification of Function Activity Limitations included squatting, jumping, and running. Participation restrictions included an inability to participate in running in preparation for marathon completion and prolonged sitting discomfort brought on by work requirements. Personal factors that had the potential to negatively influence function included habitual training and high motivation to finish the marathon on a timeline set before injury. A positive personal factor included an established habit of regular physical activity.

Examination

A general clinic medical intake form along with the subjective interview confirmed no night pain, unexplained weight loss, or bowel and bladder changes. The past medical history revealed no current or past diagnosis related to the renal, immune, hepatic, cardiopulmonary, and endocrine systems. No integumentary impairments were noted by observation. The chronic numbness and tingling along with the history of disc herniation/protrusion indicated further lumbar screening was necessary. The primary system with impairment was the musculoskeletal system leading to detailed tests and measures. The patient ambulated with no antalgic or gait disturbance. Observation revealed no effusion or edema, although the patient reported mild left anterior knee swelling at the initial onset of symptoms. The patient exhibited bilateral pes planus, bilateral patella baja, normal left lower extremity Q angle of 7°, and neutral spinal posture in standing. Lumbar active range of motion was normal and repeated motion testing did not reproduce symptoms. Radicular symptoms, when present, followed a fifth vertebral dermatomal pattern but there was no sensory loss to light touch. The patient exhibited 5/5 bilateral knee manual muscle testing, but weakness at the lower abdominals, trunk extension, bilateral hip extension, and left greater than right hip abduction. Myotomes were 5/5 except at L3 and L4 as noted by bilateral hip extension and left greater than right hip abduction weakness. The patient's left knee lacked 2° of knee extension active range of motion and had a deficit of 5° of flexion active range of motion compared to the uninvolved knee. The left patellofemoral joint was hypomobile in the inferior and superior directions and the left talocrural joint was hypomobile in the posterior direction. The rectus femoris, iliopsoas, gastrocnemius, and hamstring flexibility were limited bilaterally. The straight leg raise test was negative bilaterally. No concordant pain was created with palpation of the left knee joint line, left iliotibial band, lumbar vertebrae, sacroiliac joint, or left knee and ankle ligamentous structures. The patient was mildly tender at the left patellar tendon. **Table 1** provides a detailed description of the test and measures results.

The initial clinical impression of PFPS indicated a need for thorough special testing and diagnostic criteria assessment to rule out other conditions. Meniscal Pathology Composite Score[16] revealed 4/5 negative findings; no history of catching or locking, a negative McMurray, negative joint line tenderness, and negative pain with forced hyperextension. Iliotibial band syndrome was no longer suspected due to the pain location and lack of tenderness at the iliotibial band. Due to left knee joint active range of motion limitations and edema within 12 hours of the onset of pain, a knee ligamentous screening was carried out. Knee valgus stress and Lachman tests for the medial collateral and anterior cruciate ligaments respectively, were negative for pain and laxity. No giving way or feeling of "pop" at injury onset was reported indicating a low likelihood for ligament damage.[17] Patellar tendinopathy was a possible diagnosis based on localized tenderness at the patellar tendon and aggravation with jumping activity during cross fit.[7] This patient was below the age of 40 and had isolated anterior knee pain, indicating a high likelihood of having PFPS (SP .93, +LR 8.70).[18] The patient's activity limitations mimicked the majority of patients with PFPS; difficulty with squatting (93.7%), running (90.8%), and prolonged sitting (54.4%).[19]

Movement coordination impairments were assessed to further gather information on functional movement quality, pain provocation, and for intervention planning. Left single leg squat revealed excessive hip internal rotation, hip adduction, and quadriceps dominance. See **Table 1** for details. Running gait analysis was performed using 2-D video analysis on a smartphone with freeware. Athletic tape was placed at the patient's fifth metatarsal head, lateral knee joint line, superior and inferior portions of the heel shoe counter, posterior superior iliac spine, and seventh cervical spinous process. Souza et al recommend further placement at the greater trochanter, anterior superior iliac spine, lateral malleoli, and midpoint of the calf.[20] However, that was not performed in this case due to time constraints. A warm-up consisting of a 5-minute treadmill run at a light self-selected speed was completed, and then speed was increased to a self-selected moderate intensity, and video was taken at a right angle laterally and posteriorly. The freeware was used to visualize angles looking for symmetry and abnormalities. Kinematic variables evaluated from a posterior view included base of support, heel eversion magnitude, foot progression angle, knee window, pelvic drop, and trunk side bending. From a lateral view, foot strike pattern, vertical displacement of the center of mass (vertical excursion), the tibial angle at loading response, foot inclination angle, a distance of heel to the center of mass, knee flexion at initial contact, hip extension during late stance, and trunk flexion was evaluated.[20] Cadence was determined by counting each right foot contact in 60 seconds at 2 separate time intervals and averaged. **Table 2** provides details on the related kinematic variables. Running gait analysis revealed a slow running cadence (162 steps per minute), asymmetrical forefoot strike pattern (left with greater dorsiflexion at initial contact), floating emphasized by excessive vertical excursion with a lack of hip extension, and asymmetrical pelvic drop (left greater than right). Informed consent was obtained for publication of photographs.

Clinical impression #2

Based on the initial evaluation findings, the health condition was determined to be PFPS due to overload/overuse. Patellar tendinopathy could not be ruled out as a secondary condition. Patellofemoral pain was supported by the patient's younger age, peripatellar pain location, concordant pain with squats, running, and prolonged sitting, and exclusion of other knee-related diagnoses. Retrospective reflection revealed the patient had characteristics of all Impair-

Table 1. Retrospective PFP Impairment/Function-Based Classification Subcategorization With the Patient's Initial Evaluation Findings and Interventions to Address the Subcategory

<table>
<tr><th>PFP Impairment/Function-Based Classification Subcategories</th><th colspan="3">Initial Evaluation Findings</th><th>Interventions</th></tr>
<tr><td rowspan="1">Overuse/overload without other impairment</td><td colspan="3">Onset of symptoms: increase loading magnitude at patellofemoral joint during half marathon competition</td><td>- Frequency: reduce lower extremity strength and plyometrics to 1-2 days a week, 1 rest day in between running sessions
- Intensity: pain-free running only, running between 60-70% estimated max HR zones
- Duration: flexible 10-20% weekly and longest run distance increase after achieving a 3 mile run without pain
- Type: begin with walk/run combination, home exercise program initiated and progressed as intervention advanced</td></tr>
<tr><td rowspan="8">Muscle performance deficits</td><td></td><td>Left</td><td>Right</td><td rowspan="8">- Spinal stabilization: small muscle neuromuscular recruitment progressed to global trunk strengthening
- Hip abduction, extension, and external rotation and knee resistance training open and close chained</td></tr>
<tr><td>Knee extension</td><td>5/5 crepitus</td><td>5/5</td></tr>
<tr><td>Knee flexion</td><td>5/5</td><td>5/5</td></tr>
<tr><td>Hip abduction</td><td>4/5</td><td>4+/5</td></tr>
<tr><td>Hip extension</td><td>3+/5</td><td>3+/5</td></tr>
<tr><td>Ankle all directions</td><td>5/5</td><td>5/5</td></tr>
<tr><td>Trunk extension</td><td colspan="2">4/5</td></tr>
<tr><td>Lower abdominals</td><td colspan="2">2-/5</td></tr>
<tr><td rowspan="6">Movement coordination deficits</td><td>Single leg squat</td><td colspan="2">Running gait analysis with 2-D video</td><td rowspan="6">- Gait training with phased feedback visits 1-3: Step cadence increase 10%, symmetrical strike, reduce vertical center of mass excursion
- Independently practice 1 minute every 10 minutes of running
- Squat and jump technique visit 3: Hip hinge, dynamic eccentric control with a reduction in hip internal rotation, adduction, and knee abduction</td></tr>
<tr><td>Excessive hip internal rotation</td><td colspan="2">Slow cadence – 162 steps</td></tr>
<tr><td>Excessive hip adduction</td><td colspan="2">Asymmetrical forefoot strike</td></tr>
<tr><td>Excessive knee abduction</td><td colspan="2">Lack of hip extension</td></tr>
<tr><td>Quad dominance</td><td colspan="2">Left > right pelvic drop</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td rowspan="6">Mobility impairments</td><td>Right</td><td colspan="2">Left</td><td rowspan="6">- Low-load long-duration static stretches daily and after aerobics with total end range time 60 seconds: hamstring, quadriceps, iliopsoas, gastrocnemius, and piriformis
- Quad sets until full knee extension active ROM
- Maitland Grade III-IV posterior talocrural joint mobilizations</td></tr>
<tr><td>Lack 35 hamstring 90/90</td><td colspan="2">Lack 25 hamstring 90/90</td></tr>
<tr><td>+ Thomas</td><td colspan="2">+ Thomas</td></tr>
<tr><td>Knee active ROM lack 2-133° capsular end feel</td><td colspan="2">Knee active ROM hyperextends 2-138°</td></tr>
<tr><td>+ Ely</td><td colspan="2">+ Ely</td></tr>
<tr><td colspan="3">Left patellar gliding – superior and inferior hypomobility</td></tr>
<tr><td colspan="5">Abbreviations: PFP, patellofemoral pain; ROM, range of motion</td></tr>
</table>

ment/Function-Based Classification Subcategories: Overuse/Overload (not in isolation), Movement Coordination Deficits, Mobility Impairments, and Muscle Performance Deficits.[7] Anterior ankle impingement was suspected based on the location of the pain at the anterior talocrural region provoked by maximum dorsiflexion movement, which likely resulted in joint stiffness, limited dorsiflexion, and edema from an impingement of either soft tissue or bony structures.[21]

Intervention

A multimodal intervention approach initially targeted interventions that could be subcategorized into Overuse/Overload, lower extremity Movement Coordination Impairments, and Mobility Deficits. Training modifications included an initial walk and run interval progression until 3 miles of continuous pain-free running was achieved, followed by a weekly mileage increase of 10% to 20% as tolerated. The patient was advised to reduce cross-fit lower extremity strengthening and plyometrics to 1-2 days a week. Final training education emphasized running between 60% and 70% of estimated heart rate maximum to manage intensity while mileage increased. Focus shifted to exercise that could be subcategorized as interventions addressing Muscle Performance Deficits as the pain subsided, and as the patient demonstrated increased independence with movement coordination retraining and educational training load concepts 2 weeks into treatment. Intervention details can be found retrospectively organized according to PFPS Classification Subcategories in **Table 1**. The patient preferred to focus intervention on his recent knee and ankle injuries due to his desire to return to marathon training. However, neurologic symptoms were monitored for change while progressing into higher running loads, lower extremity neurodynamic glides were initiated, and asymmetrical lower

Table 2. Two-Dimensional Video Analysis of Running Kinematic Variables for the Patient in This Case Report

Video analysis view	Gait cycle	Kinematic variable	Initial evaluation results	Results at 8-week follow-up
Posterior	Mid stance	Base of support Normal or scissoring	Normal	Normal
Posterior	Mid stance	Heel eversion magnitude Normal, excessive, limited	*Excessive	**Normal
Posterior	Mid stance	Foot progression angle Normal, excessive out toe, in toe	*Excessive toe out right Normal left	***Excessive toe out right Normal left
Posterior	Mid stance	Knee window Closed window, open window	Open Window	Open Window
Posterior	Mid stance	Pelvic drop Normal, excessive	*Left excessive Right normal	***Left excessive Right normal
Lateral view	Initial contact	Strike pattern Forefoot, midfoot, or rearfoot	*Forefoot bilateral (left more than right)	** Symmetrical midfoot strike
Lateral view	Initial contact	Foot inclination angle	N/A	
Lateral view	Distance of heel at initial contact to the center of mass	Vertical to anterior superior iliac spine, anterior to anterior superior iliac spine	Vertical to anterior superior iliac spine	Vertical to anterior to superior iliac spine
Lateral view	Loading response	Tibial angle Extended, vertical, flexed	Vertical	Vertical
Lateral view	Mid stance	Knee flexion ➢ or = 40, < 40	➢ 40°	➢ 40°
Lateral view	Mid stance	Trunk lean Normal, Reduced flexion, Excessively Flexed	Normal	Normal
Lateral View	Late Stance	Hip Extension Normal, Limited, Compensatory lumbar lordosis	*Limited	**Normal
Lateral View	Floating	Vertical Excursion Excessive, Normal	*Excessive	**Normal
Step Cadence			*162 steps per minute	**176 steps per minute

*Abnormal findings
**Findings that changed after intervention
***Findings that did not change with intervention

extremity and trunk muscle length and weakness deficits were addressed with exercise intervention.

The patient was seen for 6 visits during the first 4 weeks of the 8-week plan of care. The visit frequency was reduced as the patient's symptoms resolved, compliance was maintained, and self-directed training increased. The 2 final visits were completed during the last 4 weeks.

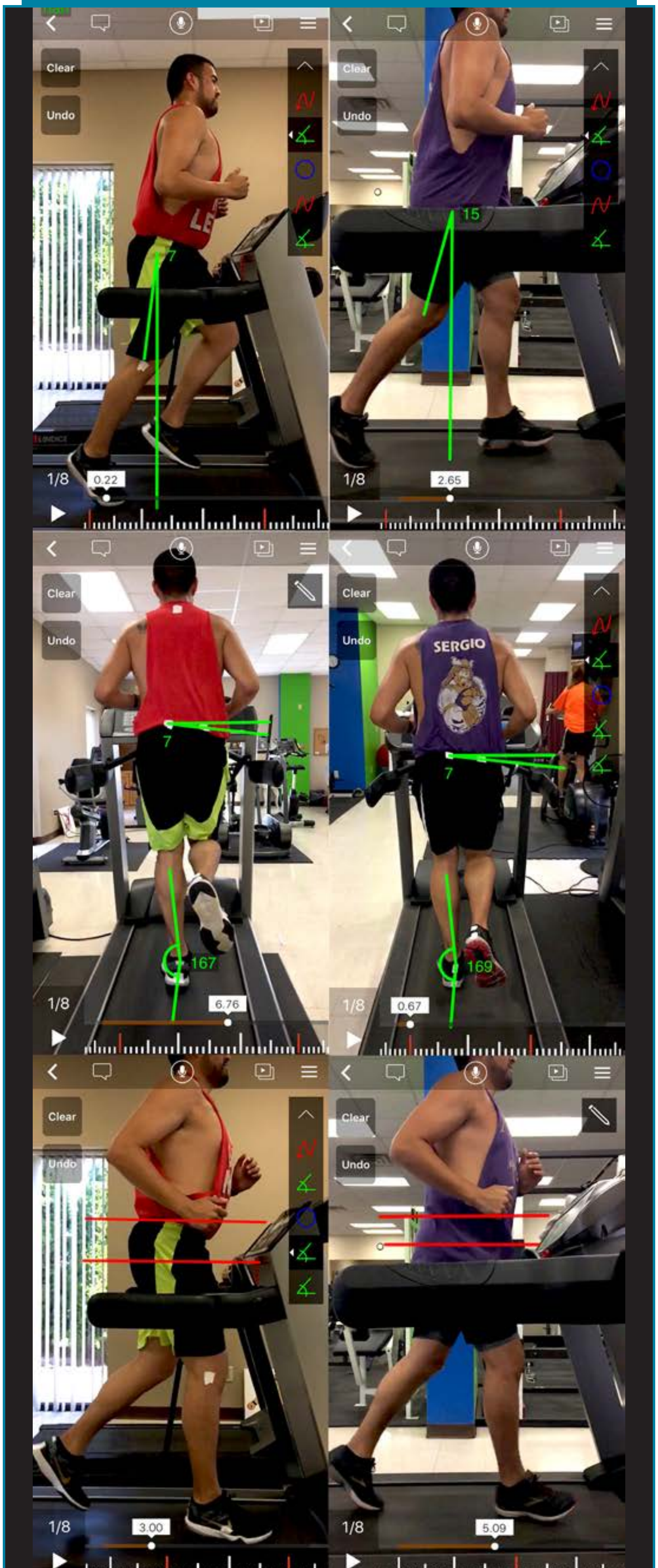
Outcome

The patient was able to achieve his primary goal of returning to running without knee pain after 4 treatment sessions. At discharge and a 6-month phone follow-up, the patient improved beyond the minimal detectable change of 2.5 points[15] on the PSFS for all activities. He scored a 10 on the PSFS for running (initially 1), jumping (initially 7), and squatting (initially 6). The PSFS has high test-retest reliability (r=0.84.).[15] The patient no longer complained of pain with prolonged sitting, and scored beyond the minimally clinically important difference of 1 point or 15% on the NPRS[22] at the knee and ankle, rating all activity a 0/10 at discharge and 6-month follow-up (6/10 initially).

Two-dimensional video analysis at discharge revealed an increase in hip extension at late stance, 176 steps per minute cadence, symmetrical midfoot strike, and reduced vertical excursion. The posterior view revealed no changes in asymmetrical pelvic drop. See **Table 2** for details of all kinematic variables. See **Figure 1** for video analysis images.

Education on training modification resulted in the patient's ability to create a long-term marathon training program with minor suggestions for alterations. However, he did experience hamstring tendon discomfort when initially progressing to a longer running distance. The patient finished his first marathon pain-free and was training for his second with no reoccurrence of injury at a 6-month follow-up. The hamstring soreness resolved with a reduction in stretching intensity. The patient felt what helped him most was changing his running form and performing a consistent low load duration stretching program included in the initial home exercise program. He believed the strengthening exercises helped him maintain his new running form and improved his running performance. The patient remained engaged with his home exercise program 4 days a week.

Figure 1. Two-Dimensional Video Analysis



Images at evaluation on the left in descending order (hip extension, pelvic drop, vertical excursion). Images at discharge on the right in descending order (hip extension, pelvic drop, vertical excursion).

DISCUSSION

This case report provides an example of a comprehensive evaluation using shared decision-making and multimodal interventions in a male with PFPS training for his first marathon. This patient case was complicated by a personal goal that included high loading athletic activity, secondary diagnosis of anterior talocrural joint impingement, and medical history of chronic lumbar radiculopathy provoked by prolonged running. However, despite these complicating factors and the PFPS provoked by overuse/overload this patient rehabilitated while progressing the cumulative load expected during marathon training. Perhaps, more importantly, the patient in this case retained intervention benefits despite continued long-distance training and competition.

Retrospective clinical reasoning presented in this case suggests that a PFPS Classification System may help clinicians prioritize impairments into subcategories: Overload/Overuse, Muscle Performance, Mobility Deficits, and Motor Coordination including gait retraining. Based on the results of this case and past studies, combining interventions is optimal. What specific combination of interventions is best for patients with PFPS is yet unknown.[7] Subcategorization may provide a means to guide intervention decisions in a patient-specific multimodal manner to enhance outcomes. Due to the retrospective nature of this clinical reasoning report, classification of subcategories was dependent on tests and measures commonly used in the clinic, but not necessarily supported by evidence. The dynamic valgus Lateral Step-Down Test and frontal plane valgus during single-leg stance is recommended to identify coordination deficit.[7] In this case, the quality of functional movement was assessed by the clinician without an objective measure. Measuring for a 10° change in frontal plane valgus during the single-leg squat would have added validity to the identification of the Movement Coordination Deficit Subcategory. Manual muscle testing was used in this case to Subcategorize Muscle Performance Impairments, but isokinetic dynamometry is recommended to identify weakness.[7,23] The Hip Stability Isometric Test identifies posterolateral hip weakness and is a reliable and valid test.[24] Using the Foot Posture Index provides a composite score observing 3 body planes,[25] giving clinicians greater confidence in making decisions regarding intervention strategies related to Mobility Deficits, such as an orthotic prescription that was not considered in this case. Future research is needed to prospectively subcategorize patients using recommended tests and measures described in the PFPS Clinical Practice Guidelines.

What is lacking from this case is the successful management of lumbar radiculopathy while running loads continued. This plan of care followed patient preferences by maintaining a primary focus on eliminating knee and ankle pain with prolonged running but may have missed important lumbar findings and lumbar outcome measures to identify change. The patient did report a reduction in radiculopathy intensity with the inclusion of neurodynamic gliding procedures recommended for chronic low back pain with radiating symptoms,[26] but this incomplete improvement is consistent with a lack of research directing the management of chronic low back pain with radiating symptoms in runners. A randomized controlled trial by Cai et al[27] noted that lower limb, lumbar extensor exercise, and lumbar stabilization exercise all improved pain levels in recreational runners, with lower limb exercise having the largest effect. Recreational runners in this study did not have radiating systems, rather localized back pain, unlike this case study patient. Asking the patient to discontinue running was not advised secondary to the literature supporting that running does not degrade disc pathology. Mitchell et al found middle-aged endurance runners that had the greatest weekly mileage had a less age-related decline in lumbar intervertebral discs.[28] Due to minimal change with intervention, a referral was indicated.

This case describes a patient with PFPS with a mechanism of injury being Overload/Overuse, thus providing training modification is consistent with the literature.[8] However, recommending a loose 10% to 20% increase based on fitness and symptoms challenged the common practice recommendation of increased duration/distance of 10% at most. Buist et al found implementing a 10% graded training program did not correlate with injury prevention, although this study was completed on novice runners.[29] A systematic review by Damsted et al reported increased injury risk if running mileage progressed more than 30% or if one or more of the following was changed: velocity, and/or distance, and/or frequency.[30] Ramskey et al reported types of injury are not associated with specific progressions of either intensity or training volume.[31] Clinical reasoning led the physical therapist to quantify intensity with heart rate monitoring while the mileage was being increased, to prevent training-related injury in this patient case due to paralleled volume and intensity continuously ramping up to marathon distance. Cross-fit lower extremity strengthening and plyometrics frequency was reduced in this case to prevent detrimental kinematic changes that result from muscle fatigue while this patient-focused on increasing mileage for marathon training.[32]

Video analysis was easily incorporated into the evaluation and plan of care for this patient. Kinematic variables were rated as normal versus abnormal as described by Souzza et al[20] due to a lack of consensus on ideal kinematic joint angles with running. Due to a lack of consensus on feedback protocols and frequency of gait retraining,[9,33] the video feedback sessions were limited by schedule matching with the physical therapist. Two sessions using 2-D video and verbal feedback were completed and then phased to one verbal feedback session less than 20 minutes duration within the first 2 weeks of treatment. A final video assessment and feedback session was completed on the last visit to reemphasize positive gains in running form. The remaining visits were delivered by a physical therapy assistant under the plan of care direction and intraprofessional communication. This case provides an example of how neuromuscular reeducation using 2-D video feedback could be considered in the multimodal plan of care.

Patient-specific gait retraining was targeted on reducing the vertical center of mass displacement (vertical excursion) and equalizing bilateral dorsiflexion range of motion upon forefoot strike by equalizing landing sound which was not part of the PFPS Clinical Practice Guideline recommendations, although, increasing step cadence was.[7] Wille et al recognized vertical excursion as a kinematic variable component of subsets estimating peak vertical ground reaction force, peak knee extensor moment, and braking impulse.[34] Therefore, vertical excursion is a reasonable kinematic variable to modify during gait retraining. However, increasing step rate reduces vertical excursion[35] so focusing cues on reducing floating characterized by excessive vertical excursion may not have been necessary for this patient. Increasing step cadence has the potential to change strike patterns in heel strike runners to either midfoot or forefoot strike.[36] This patient was unique because he had a forefoot strike that adapted to a midfoot strike with an increase in cadence. A study by Kasmer et al[37] found that of 1991 marathon runners, 93.67% were heel strikers, 5.07% were midfoot strikers, 0.71% split strikers, and only 0.55% were forefoot strikers. It is possible runners change strike pattern as training distance increases such as was seen with this case. Further investigations are warranted to determine if runners with a natural forefoot or midfoot strike adapt to heel strike with a change in running distance, such as seen in marathon training. It is unclear if the outcomes in this case, specifically new midfoot strike pattern, increase in hip extension, and decreased vertical excursion was a direct result of one or a combination of patient-specific gait retraining cues.

Hip abduction and extension weakness were identified in patients with PFPS.[6,7] Combined hip and knee resistance exercises in open and closed chain positions[12,27] are recommended in the literature and were used to address hip abduction and extension weakness in this case (see **Table 1** for manual muscle testing results). Despite the hip resistance exercises, the patient's pelvic drop in the frontal plane that was noted on 2-D video gait analysis did not improve as suggested in the literature.[38] Perhaps the lack of neuro reeducation focusing on the timing of muscle recruitment and functional movement during the specific activity of running limited improvements in gait quality. The intensity of the resistance program was not prescribed as a percentage of a 1 repetition maximum, therefore, may not have maximized muscle performance. The workload demand placed on an individual's hip during running cannot be quantified clinically, therefore, the ideal training workload is also difficult to quantify. Typical hip abduction resistance exercises do not mimic the function of running, therefore, do not follow the concept of specificity of training. Future studies investigating optimal dosing parameters, optimal exercises mimicking the demands on the hip during running, and neuro reeducation may be warranted to optimize exercise prescription in distance runners with PFPS.

CLINICAL APPLICATIONS

Evaluating and treating lower extremity injuries in the running population is a challenge for clinicians due to multiple impairments of body function and structure and high risk of reinjury. Patient-specific multimodal interventions are a vital part of managing the care of the running population who are prone to multiple site injuries, and long-term outcomes of combined intervention are needed to guide management. Viewed retrospectively, PFPS Classification Subcategories have the potential to provide a framework for clinical reasoning to guide evaluation and intervention priorities in distance runners with PFPS. Gait retraining using 2-D video analysis has the potential to enhance outcomes in runners training at marathon distances where joint loading and soft tissue stress is central to participation.

ACKNOWLEDGEMENTS

I thank Alyssa Kreinbrink, PTA (P.T. Services Rehabilitation Inc.) for providing physical therapy intervention to the patient in this case. I thank Dr. Scott Van Zant (University of Findlay) and Dr. Nicole Schroeder (University of Findlay) for comments on the manuscript.

REFERENCES

1. van Gent RN, Siem D, van Middelkoop M, van Os AG, Bierma-Zeinstra SM, Koes BW. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *Br J Sports Med*. 2007;41(8):469-480. doi:10.1136/bjsm.2006.033548
2. Van Middelkoop M, Kolkman J, Van Ochten J, Bierma-Zeinstra SM, Koes B. Prevalence and incidence of lower extremity injuries in male marathon runners. *Scand J Med Sci Sports*. 2008;18:140-144. doi: 10.111/j.1600-0838.2007.00683.x
3. Van der Worp MP, ten Haaf DS, van Cingel R, de Wijer A, Nijhuis-van der Sanden MW, Staal JB. Injuries in runners; A systematic review on risk factors and sex

differences. *Plos One*. 2015;10(2). doi: 10.1371/journal.pone.0114937
4. Dierks TA, Manal KT, Hamill J, Davis I. Lower extremity kinematics in runners with patellofemoral pain during prolonged runners. *Med Sci Sports Exerc*. 2011;43(4):693-700. doi: 10.1249/MSS.0b013e3181f744f5
5. Neal BS, Barton CJ, Gallie R, O'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. doi: 10.1016/j.gaitpost.2015.11.018
6. 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):1713-1723. doi: 10.1136/bjsports-2017-098717
7. Willy R, Hoglund L, Barton C, et al. Patellofemoral pain. Clinical practice guidelines linked to the International Classification of Functioning, Disability and Health from the Academy of Orthopaedic Physical Therapy of the American Physical Therapy Association. *J Orthop Sports Phys Ther*. 2019;49(9):CPG1-CPG95. doi:10.2519/jospt.2019.0302
8. 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 randomized clinical trial. *Br J Sports Med*. 2018;52(10):659-666. doi: 10.1136/bjsports-2016-096988
9. Agresta C, Brown A. Gait retraining for injured and healthy runners using augmented feedback: A systematic literature review. *J Orthop Sports Phys Ther*. 2015;45(8):576-84. doi: 10.2519/jospt.2015.5823
10. Dingenen B, Malliaras P, Janssen T, Ceyssens L, Vanelderen R, Barton CJ. Two-dimensional video analysis can discriminate differences in running kinematics between recreational runners with and without running-related knee injury. *Phys Ther Sport*. 2019;38:184-191. doi: 10.1016/j.ptsp.2019.05.008
11. Pipkin A, Kotecki K, Hetzel S, Heiderscheit B. Reliability of a qualitative video analysis for running. *J Orthop Sports Phys Ther*. 2016;46(7):556-561. doi: 10.2519/jospt.2016.6280
12. Lack S, Barton C, Sohan O, Crossley K, Morrissey D. Proximal muscle rehabilitation is effective for patellofemoral pain: a systematic review with meta- analysis. *Br J Sports Med*. 2015;49:1365-1376. doi:10.1136/bjsports-2015-094723
13. Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther*. 2005;35:793-801. https://doi.org/10.2519/jospt.2005.35.12.793 2
14. 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):833-834. doi: 10.1136/bjsports-2015-095607
15. Chatman AB, Hyams SP, Neel JM, et al. The Patient-Specific Functional Scale: measurement properties in patients with knee dysfunction. *Phys Ther*. 1997;77(8):820-829. doi: 10.1093/ptj/77.8.820
16. Lowery DJ, Farley TD, Wing DW, Sterett WI, Steadman JR. A clinical composite score accurately detects meniscal pathology. *Arthroscopy*. 2006;22(11):1174-1179. doi: 10.1016/j.arthro.2006.06.014
17. Logerstedt DS, Scalzitti D, Risberg MA, et al. Knee stability and movement coordination impairments: knee ligament sprain revision 2017. Clinical practice guidelines linked to International Classification of Functioning Disability and Health from the Orthopaedic Section of the American Physical Therapy Association. *J Orthop Sports Phys Ther*. 2017;47(11):A1-A47. doi:10.2519/jospt.20170303
18. Décary S, Frémont P, Pelletier B, et al. Validity of combining history elements and physical examination tests to diagnose patellofemoral pain. *Arch Phys Med Rehabil*. 2018;99:607-614.e1. doi: 10.1016/j.apmr.2017.10.014
19. Papadopoulos K, Stasinopoulos D, Ganchev D. A systematic review on patellofemoral pain syndrome. Exploring the risk factors, diagnostic tests, outcome measurements and exercise treatment. *Open Sports Med J*. 2015;9:7-17. doi:10.2174/1874387001509010007
20. Souza RB. An evidence based videotaped running biomechanics analysis. *Phys Med Rehabil Clin N Am*. 2016;27(1):217-236. doi: 10.1016/j.pmr.2015.08.006
21. Lavery KP, McHale KJ, Rossy WH, Theodore G. Ankle impingement. *J Orthop Surg Res*. 2016;11(1):97. doi:10.1186/s13018-016-0430-x
22. Salaffi F, Stancati A, Silbertstri CA, Ciapetti A, Grassi W. Minimal clinically important changes in chronic musculoskeletal pain intensity measured on a numerical rating scale. *Eur J Pain*. 2004;8(4):283-291. doi: 10.1016/j.ejpain.2003.09.004
23. Van Cant J, Pineux C, Pitance L, Feipel V. Hip muscle strength and endurance in females with patellofemoral pain: a systematic review with meta-analysis. *Int J Sports Phys Ther*. 2014;9:564-582.
24. Almeida GPL, das Neves Rodrigues HL, de Freitas BW, de Paula Lima PO. Reliability and validity of the Hip Stability Isometric Test (HipSIT): a new method to assess hip posterolateral muscle strength. *J Orthop Sports Phys Ther*. 2017;47:906-913. doi.org/10.2519/jospt.2017.7274 5
25. Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: The Foot Posture Index. *Clin Biomech (Bristol, Avon)*. 2006;21(1):89-98. doi: 10.1016/j.clinbiomech.2005.08.002
26. Delitto A. George S. Dillen L, et al. Low back pain. Clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopaedic Section of the American Physical Therapy Association. *J Orthop Sports Phys Ther*. 2012;42(4):A1-A57. doi: 10.2519/jospt.2012.0301
27. Cai C, Yang Y, Kong PW. Comparison of lower limb and back exercises for runners with chronic low back pain. *Med Sci Sports Exerc*. 2017;49(12):2374-2384. doi: 10.1249/MSS.0000000000001396
28. Mitchell UH, Bowden JA, Larson RE, Belavy DL, Owen PJ. Long-term running in middle-aged men and intervertebral disc health, a cross-sectional

pilot study. *PloS One*. 2020;15(2):e0229457. doi: 10.1371/journal.pone.0229457
29. Buist I, Bredeweg SW, van Mechelen W, Lemmink KA, Pepping GJ, Diercks RL. No effect of a graded training program on the number of running-related injuries in novice runners: a randomized controlled trial. *Am J Sports Med*. 2008;36(1):33-39. doi: 10.1177/0363546507307505
30. Damsted C, Glad S, Nielsen R, et al. Is there evidence for an association between changes in training load and running-related injuries? A systematic review. *Int J Sports Phys Ther.* 2018;13(6):931-942. doi: 10.26603/ijspt20180931
31. Ramskov D, Rasmussen S, Sorensen H, et al. Progression in running intensity or running volume and the development of specific injuries in recreational runners: run clever, a randomized trial using competing risks. *J Orthop Sports Phys Ther*. 2018;48(10):740-748. doi: 10.2519/jospt.2018.8062
32. Dierks TA, Manal KT, Hamill J, Davis I. Lower extremity kinematics in runners with patellofemoral pain during prolonged runs. *Med Sci Sports Exerc*. 2011;43(4):693-700. doi: 10.1249/MSS.0b013e3181f744f5
33. Davis IS, Tenforde AS, Neal BS, Roper JL, Willy RW. Gait Retraining as an intervention for patellofemoral pain. *Curr Rev Musculoskelet Med*. 2020;13(1):103-114. doi:10.1007/s12178-020-09605-3
34. Wille C, Lenhart R, Wang S, Thelen DG, Heiderscheit BC. Ability of sagittal kinematic variables to estimate ground reaction forces and joint kinetics in running. *J Orthop Sports Phys Ther*. 2014;44(10):825-830. doi: 10.2519/jospt.2014.5367
35. Heiderscheit BC, Chumanov ES, Mechalski MP, Wille CM, Ryan MB. Effects of step rate manipulation on joint mechanics during running. *Med Sci Sports Exerc*. 2011;43(2):296-302. doi: 10.1249/MSS.0b013e3181ebedf4
36. Allen DJ, Heisler H, Mooney J, Kring R. The effect of step rate manipulation on foot strike pattern of long distance runners. *Int J Sports Phys Ther*. 2016;11(1):54-63.
37. Kasmer ME, Liu XC, Roberts KG, Valadao JM. Foot-strike pattern and performance in a marathon. *Int J Sports Physiol Perform*. 2013;8(3):286-292. doi: 10.1123/ijspp.8.3.286
38. Snyder KR, Earl JE, O'Connor KM, Ebersole KT. Resistance training is accompanied by increases in hip strength and changes in lower extremity biomechanics during running. *Clin Biomech (Bristol, Avon)*. 2009;24(1):26-34. doi: 10.1016/j.clinbiomech.2008.09.009

Thank you for being a member of the Academy of Orthopaedic Physical Therapy.

We appreciate you and thank you for your membership!