[CASE REPORT]

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Management of Patients With Patellofemoral Pain Syndrome Using a Multimodal Approach: A Case Series

Patellofemoral pain syndrome (PFPS) is a relatively common disorder encountered in the clinical setting, affecting an estimated 7% to 40% of adolescents and active young adults.[2,5] The diagnosis of PFPS is typically made based on the presence of anterior or retropatellar knee pain associated with prolonged sitting or with weight-bearing activities that load the patellofemoral joint, such as squatting, kneeling, running, and ascending and descending steps.[48] Because there currently exists no gold standard for diagnosis of PFPS, inclusion of the step-down test may increase the likelihood of diagnosis of PFPS from 40% to 65% (positive likelihood ratio, 2.34).[48] Once the diagnosis of PFPS has been established, the possibilities for interventions are numerous, but no general consensus exists as to the most efficacious treatment approach.[18] Current evidence-based treatment approaches include taping, strengthening of the hip musculature and quadriceps, manual therapy to the lower quarter, and fitting of foot orthoses.[17,35,43,47]

STUDY DESIGN: A case series of consecutive patients referred to physical therapy with patellofemoral pain syndrome (PFPS).

BACKGROUND: Physical therapists often treat patients with PFPS, yet there is currently no consensus as to the most effective management strategies. The purpose of this case series is to describe the outcomes of patients referred to physical therapy with PFPS who were treated with a multimodal approach.

CASE DESCRIPTION: Five patients were treated with a combination of thrust and nonthrust manipulation directed at the joints of the lower quarter, trunk and hip stabilization exercises, patellar taping, and foot orthotics. Outcome measures used to capture change in patient status included the Numeric Pain Rating Scale, the Kujala Anterior Knee Pain Scale, the Lower Extremity Functional Scale, and the Global Rating of Change.

OUTCOMES: Five patients (median age, 15 years; range, 14-50 years) with a median duration of knee pain for 8 months (range, 3-24 months) were included in this prospective case series. Four (80%) of the 5 patients demonstrated decreased pain and a clinically significant improvement in function. These gains in function were maintained at a 6-month follow-up.

DISCUSSION: Although a cause-and-effect relationship cannot be inferred from a case series, the outcomes achieved by the patients are consistent with studies incorporating manual physical therapy, exercise, patellar taping, and orthotic prescription to the management of conditions of the lower extremity. Further randomized controlled trials should be performed to determine the effectiveness of this multimodal approach for the management of individuals with PFPS.

LEVEL OF EVIDENCE: Therapy, level 4.
J Orthop Sports Phys Ther 2008;38(11):691-702. doi:10.2519/jospt.2008.2690

KEY WORDS: *knee, manual therapy, spine, orthotics, taping, pain, patellofemoral joint*

Treatment interventions for PFPS have previously targeted presumed altered patellofemoral joint biomechanics. One intervention often incorporated into the management of patients with PFPS is patellar taping.[17] Multiple studies have shown patellar taping to decrease pain[14,21] and, theoretically, to improve patellar tracking by changing vastus medialis obliquus (VMO) timing[13-16,20] with functional tasks. Overall pain has been shown to significantly decrease with taping and exercise compared to exercise alone.[73] Other researchers have shown that there is no difference in pain or patellar alignment with sham versus directional taping,[9,74,75] due, in part, to the poor reliability of assessing patellar mechanics.[71,74] Although the reliability of identifying the proper method of taping has been questioned,[71,74] there is evidence of its effectiveness for pain relief, specifically with the functional tasks of stair stepping and squatting.[14,21]

Exercise is another approach in the treatment of PFPS, which historically has targeted the improvement of the recruit-

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ment of the quadriceps and VMO. It is unknown if the VMO can preferentially be recruited with exercise or if VMO atrophy is an indication of total quadriceps atrophy.[12,51] Additionally, recent studies have shown that there is weakness of the gluteus medius, gluteus maximus, and hip external rotators,[34,58] and poor proprioceptive control[3,60] in patients with PFPS. It is still debated whether the most effective exercise for PFPS should be weight bearing or non-weight bearing. While a recent randomized controlled trial (RCT)[28] showed significant decreases in pain and increases in functional outcomes with both multiple-joint weight-bearing and single-joint non–weight-bearing exercises compared to a control group, the small sample size taken from a homogenous population could have predisposed the study to type 2 error and loss of statistical power. Boling et al[6] found that a program of weight-bearing therapeutic exercise targeting the quadriceps, gluteus medius, and proprioceptive control of the lower extremity decreased pain and improved function in patients with PFPS. In contrast to previous studies focusing solely on the VMO, Boling and colleagues[6] examined the recruitment of the gluteus medius in addition to the VMO to consider the lower extremity kinetic chain as a functional unit. Case reports have shown improvements with weight-bearing therapeutic exercises for the lower extremity, lending further support to a regional-interdependence approach.[47]

Manual physical therapy is also often used by physical therapists in the management of PFPS[1]; however, its use has received less attention in the literature than patellar taping and exercise. Patellar nonthrust manipulation, hip nonthrust manipulation, and lumbopelvic thrust manipulation are examples of manual therapy interventions investigated in this population.[10,21,35,62] In a recent RCT, transverse friction massage and sustained medial patellar nonthrust manipulation were shown to be more effective in relieving pain with a functional step-down task than no treatment in a control group.[65] Crossley et al,[21] in a recent RCT, demonstrated that patellar nonthrust manipulation combined with taping and exercise significantly relieved pain with stair descent. However, it has been reported that the direction of application of the patellar nonthrust manipulation may not be important, and patients who received thrust manipulation demonstrated greater pain pressure tolerance thresholds when compared to placebo.[59] Although this study lacked statistical power, the authors concluded patellar manipulation might be considered a useful intervention for pain relief.[59]

Manual therapy interventions directed at regions proximal to the patellofemoral joint have also been found to decrease anterior knee pain.[10] Hip nonthrust manipulation was suggested as a useful intervention in a recent case report that described decreased pain and improved functional outcome measures after prolonged manual stretching of the hip followed by therapeutic exercise.[10] Suter and colleagues[62] found ipsilateral sacroiliac joint dysfunction with either positive palpation tests or provocation tests in each patient with PFPS in their study. The authors of this RCT found that thrust manipulation techniques directed at the lumbopelvic spine decreased quadriceps muscle inhibition in a PFPS population.[62] Other preliminary findings have demonstrated that patients with PFPS with asymmetrical hip rotation might respond rapidly and dramatically to lumbopelvic manipulation.[35] Iverson and colleagues[35] found that patients who exhibit asymmetrical hip internal rotation had an 80% probability of a successful outcome with lumbopelvic manipulation. These patients had at least a 50% or greater decrease in pain with a step-down test after a single treatment session.[35] Further research is needed to validate these findings.

Foot orthoses have been proposed to correct lower extremity malalignment and reduce patellofemoral stresses, thereby relieving patellofemoral pain. Literature supports the use of foot orthoses for patients who excessively pronate or have excessive tibial rotation, and custom orthotics have been found to significantly decrease pain and improve functional outcome scores in patients who excessively pronate and report anterior knee pain.[26,37] Thus foot orthoses may be a viable treatment intervention in certain subgroups of patients with PFPS.

Despite extensive research, there is still little consensus as to the most effective treatment strategy for the management of patients with PFPS. Although recent studies have indicated that specific interventions may be beneficial, these interventions have been studied in isolation or have targeted a single joint. Few studies have examined a more clinically based multimodal intervention directed toward the lower extremity as a functional unit. The purpose of this case series is to describe the management and outcomes of 5 patients with PFPS treated with manual physical therapy, patellar taping, orthotics, and exercise, using a regional-interdependence approach.

CASE DESCRIPTIONS

Five consecutive patients, referred to a single physical therapy outpatient clinic with a diagnosis of PFPS or anterior knee pain were screened for the eligibility criteria in this case series. All participants satisfied the inclusion criteria: 14 to 50 years of age, anterior knee pain with squatting, kneeling or ascending or descending stairs, pain with an eccentric-loading step test, and sufficient ability to read and understand English to complete the outcome questionnaires. Exclusion criteria for this study included prior knee surgery, patient refusal of manipulation techniques, radicular pain, positive clinical tests or imaging consistent with meniscal or ligamentous involvement, and a clinical exam consistent with nonmusculoskeletal etiology of symptoms. Each subject agreed to participate and provided informed consent. This study was approved by The Institutional Review Board at Franklin Pierce College. Patient privacy, patient consent, and compliance with HIPAA guidelines were maintained through the course of this case series.

Outcome Measures

The outcome measures utilized in this study included the Numeric Pain Rating Scale (NPRS), the Lower Extremity Functional Scale (LEFS), and the Kujala Anterior Knee Pain Scale (AKPS), and were collected at baseline, at 4 visits, at discharge, and at 6-month follow-up. Additionally, the Global Rating of Change Scale (GRC) was collected at discharge, and at 6-month follow-up.

Pain was measured using the NPRS. The NPRS has not been validated in patients with PFPS; however, it has been shown to have adequate reliability and validity in other populations with musculoskeletal disorders and requires a 2-point change to be clinically meaningful.[8,23] Similar to studies investigating the psychometric properties of the NPRS,[8] patients were asked to rate the average, lowest, and highest pain levels experienced over the last 24 hours on a 0-to-10 scale, with 0 representing no pain and 10 representing the worst pain imaginable. For this case series, highest pain levels are reported.

The LEFS and the AKPS have been utilized in clinical outcome studies and recommended for use with the PFPS population.[72] The LEFS is a 20-item functional assessment tool that rates the level of difficulty of functional tasks from 0 (extreme difficulty) to 4 points (no difficulty), yielding a maximum score of 80 points, with lower scores indicating more disability. The LEFS has been shown to have high test-retest reliability (ICC = 0.98)[72] and moderate responsiveness (area under the curve, 0.77; 95% CI: 0.57-0.97).[72] Moderate correlation between the LEFS and the Short Form-36 physical function subscale (r = 0.80) has demonstrated adequate validity in the PFPS population.[4] The minimal clinically important difference (MCID) of the LEFS has been reported to be 8 to 9 points in patients with PFPS.[4,72] The AKPS is a 13-item assessment tool with items differentially weighted for a maximum score of 100, with lower scores indicating greater disability.[40] The AKPS has also been shown to have high test-retest reliability (ICC = 0.95),[72] moderate responsiveness, and adequate validity, with moderate correlation with the visual analog scale (r = 0.74).[19] The minimal clinically important difference of the AKPS has been reported to be 10 to 13 points.[19,72]

The GRC is a 15-point scale of patient perception of improvement.[36] This outcome measure has been studied in patients with PFPS.[19,35] This scale is scored from −7 (a very great deal worse) to +7 (a very great deal better), with 3 points estimated as the MCID.[36] For this study, 3 points (somewhat better) was set a priori to show clinically important change.

TABLE 1 Patient Demographics at Baseline

Patient	Age (y)	Sex	BMI (kg/m^2)	Involved Knee	Symptom Duration (mo)
1	15	F	22.1	Bilateral	24.0
2	25	M	34.3	Bilateral	3.5
3	14	M	20.4	Right	8.0
4	15	M	20.1	Bilateral	18.0
5	50	F	44.9	Left	3.0

Examination

Patients completed the aforementioned questionnaires, followed by a standardized history and physical examination. All examinations and interventions were performed by the primary author (C.L.), who had 5 years of clinical practice. The subjective examination included screening for serious pathology and standardized interview questions. Patient demographic variables at baseline are shown in **TABLE 1**.

Physical Examination A postural examination was performed, which included an assessment of postural deviations of the subtalar joint, calcaneal varus/valgus, external tibial torsion, pelvic rotation, and symmetrical weight bearing.[39] All patients were also assessed dynamically for navicular drop during single-limb stance, as described by Piva and colleagues,[71] who found excellent reliability in bilateral stance (ICC = 0.93). A neurological examination to screen for pain of spinal origin was also performed on each patient, as pain was reported distal to the buttock.[33] Neurodynamic testing was assessed with a passive straight-leg raise.[66]

Muscle Length Examination All patients were assessed for flexibility of the hamstrings with the 90-90 hamstring length test.[45] If the individual lacked 20° of knee extension, the test was considered positive for hamstring muscle tightness.[63] Hamstrings tightness was also objectively measured during a passive straight-leg raise in supine, and quadriceps length was assessed in prone, using an inclinometer, as described by Piva et al.[52] Piva and colleagues[52] showed excellent reliability for measuring hamstrings and quadriceps length with an inclinometer (ICC = 0.91-0.92). Gastrocnemius length was assessed in standing.[76] For this study, the gastrocnemius length was considered decreased if the heel could not maintain contact with the floor without knee flexion during the test. This method has not been previously validated. Piriformis length was measured in prone with an inclinometer.[7,52] Iliopsoas length was assessed by a supine modified Thomas test, as described by Bullock-Saxton,[7] who found excellent intrarater reliability with measuring the length of the hip flexors (ICC = 0.98) and the internal and external rotators (ICC = 0.99) with an inclinometer. Because the iliotibial band has been purported to influence patellar mechanics,[30,56] the Ober's test was used to assess the iliotibial band length.[57] Reese and Bandy[57] studied the reliability of

Ober's test to assess iliotibial band length and found intraexaminer reliability to be excellent (ICC = 0.90).

Mobility and Strength Testing Measurements of knee and hip active range of motion (AROM) and passive range of motion (PROM) were assessed with a standard goniometer for flexion, extension, abduction, and adduction.[11] Knee PROM measurements with a standard goniometer have been shown to have excellent intrarater reliability (ICC = 0.98-0.99).[70] Rotational measures of the hip were assessed with an inclinometer, as previously stated.[7] Great toe extension and ankle dorsiflexion, measured with a standard goniometer, and calcaneal valgus and prone forefoot valgus were assessed as previously reported.[63] Manual muscle testing of the gluteal musculature and the quadriceps, hamstrings, and hip internal and external rotation was performed.[32] A patellar compression test[24] and assessment of passive accessory mobility of the lumbopelvic spine, hip, patellofemoral, and tibiofemoral joints were performed to identify impairments and guide direction of manipulation during treatment.[67] Abdominal recruitment was palpated as the participant was asked to perform the abdominal drawing-in maneuver, which has been shown on diagnostic ultrasound to preferentially activate the deep transverse abdominus.[64]

Patient 1

This patient was a 15-year-old female with bilateral knee pain of 2 years' duration, who reported pain with walking, squatting, running during soccer, and sitting less than 20 minutes. She rated the pain as a constant dull ache (5/10) with all activities. She had received physical therapy prior to this episode and reported that previous instruction in taping by a physical therapist did not alleviate the pain with activity or with the step-down test. The patient had previously acquired custom foot orthoses but refused to wear them due to experiencing no change in pain level with them after 2 years. On examination, she demonstrated calcaneal valgus in standing but no excessive pronation and less than 3-mm navicular drop in single-limb standing. Muscle length assessment demonstrated decreased hamstring, quadriceps, and hip flexor length and normal iliotibial band/tensor fascia lata length. Active and passive ROM of the knee was full and painless, but hip rotation was limited in internal rotation bilaterally, with a difference from side to side of 8°, and great toe extension was limited bilaterally. Passive joint accessory motion assessment revealed decreased inferior glide of both the hip and patella. Provocative testing elicited pain with the patellar compression test. Muscle testing revealed weakness in the gluteus medius and gluteus maximus, which was thought to influence the functional step-down test. Functional testing elicited increased pain with squatting, and the step-down test was painful and demonstrated visually perceived excessive internal rotation of the femur, internal tibial rotation, and subtalar pronation. Pain was not relieved with taping. This patient withdrew from the study and was unable to be contacted after the fourth treatment. Hence only short-term outcomes are presented for this individual.

Patient 2

This patient was a 25-year-old male with bilateral knee pain of 3.5 months' duration, who reported pain with running, ascending and descending steps, squatting, and sitting greater than 20 minutes. He rated the most painful activities as 7/10 at worst and reported pain as 0/10 at rest. Postural assessment revealed bilateral subtalar pronation with navicular drop greater than 3 mm and bilateral calcaneal valgus in standing. ROM assessment revealed normal knee ROM, limited hip internal rotation ROM, with a side-to-side difference of 20°, excessive ankle dorsiflexion of 20° bilaterally, and limited great toe extension less than 50° bilaterally. Muscle length assessment revealed decreased flexibility of the hamstrings, quadriceps, iliotibial band complex, and hip flexors. Muscle testing demonstrated weakness of the gluteus medius and maximus, which was also demonstrated by the inability to functionally squat without loss of balance backwards. Provocative patellar compression testing was negative; however, passive accessory motion assessment demonstrated limited inferior glide of the patella and limited caudal hip glide bilaterally. The step-down test was provocative for pain bilaterally, and excessive internal hip rotation, internal tibial rotation, and subtalar joint pronation were noted with poor eccentric control of the lower extremity, as described in previous reports.[47,53] Taping did not relieve pain with the step-down test.

Patient 3

This patient was a 14-year-old male who reported right anterior knee pain of 8 months' duration with running during soccer, squatting, and descending stairs. He rated the most painful activity, running, as 6/10 at worst and had 1/10 pain at rest. Assessment of posture revealed tibial varum and genu varum bilaterally, subtalar joint supination in relaxed stance, and no navicular drop in single-limb stance. Active ROM of the knee was normal but painful with overpressure into flexion, and hip internal rotation was limited with capsular end feel, with a difference side to side of 20°. He had limited great toe extension and bilateral ankle dorsiflexion to 10° limited by a muscular stretch. Muscle strength testing showed decreased gluteus medius and maximus strength, which was further demonstrated during the step-down test. Muscle length testing revealed shortness of the hamstrings, gastrocnemius, and iliotibial band complex bilaterally. Provocative testing reproduced pain with the patellar compression test, and passive accessory motion revealed limited superior glide of the patellofemoral joint, limited caudal glide of the hip, and limited anteromedial glide of the fibula on the tibia with knee flexion.

Patient 4

This patient was a 15-year-old male who complained of bilateral anterior knee pain of 18 months' duration, aggravated by sitting less than 20 minutes, running,

TABLE 2 Treatment

Patient	Manual Therapy	Exercise	Stretching	Patellar Taping	Orthotics
1	• Bilateral lumbopelvic thrust manipulation • Caudal hip nonthrust manipulation • Inferior patellar nonthrust manipulation	• NWB exercises visits 1-3 and HEP • WB exercises visit 4 and HEP	• Hamstrings • Hip flexors • Quadriceps	None	None
2	• Bilateral lumbopelvic thrust manipulation • Caudal hip nonthrust manipulation • Inferior patellar nonthrust manipulation	• NWB exercises visits 1-3 • WB exercises visits 4-11 and HEP	• Hamstrings • Hip flexors • Quadriceps • Hip external rotators	None	Custom orthoses, visit 10
3	• Right lumbopelvic thrust manipulation • Caudal hip nonthrust manipulation • Superior patellar nonthrust manipulation • Posterior-to-anterior proximal tibiofibular thrust manipulation	• NWB exercises visits 1-3 • WB exercises visits 4-11 and HEP	• Gastrocnemius • Hamstrings • Piriformis • Gluteals • Iliotibial band complex	Medial glide patellar taping visits 1-4	None
4	• Bilateral lumbopelvic thrust manipulation • Caudal hip nonthrust manipulation • Inferior patellar nonthrust manipulation	• NWB exercises visits 1-2 • WB exercises visits 3-8 and HEP	• Gastrocnemius • Hamstrings • Hip flexors • Iliotibial band complex	None	None
5	• Left lumbopelvic thrust manipulation • Caudal hip nonthrust manipulation • Inferior patellar nonthrust manipulation • Posterior-to-anterior proximal tibiofibular thrust manipulation	• NWB exercises visits 1-5 • WB exercises visits 6-14 and HEP	•Iliotibial band complex • Piriformis	Medial glide patellar taping visits 1-4	Off-the-shelf or-thoses, visit 12

Abbreviations: HEP, home exercise program; NWB, non-weight bearing; WB, weight bearing.

squatting, and descending steps, which he rated as 2/10 at worst and 1/10 with rest. He had been wearing bilateral patellar stabilization braces for 12 months with little relief. Static posture exam showed bilateral navicular drop greater than 3 mm, forefoot abduction, bilateral genu varus, and bilateral tibial external rotation. ROM testing for the knee was normal, but the left hip exhibited limited internal rotation with a side-to-side difference of 18°. Ankle dorsiflexion was also limited bilaterally, and great toe extension was limited bilaterally. Muscle length testing showed decreased bilateral hamstring and gastrocnemius length and decreased right hip flexor and iliotibial band length. Consistent with the other patients, the gluteal muscles were identified to be weak with manual muscle testing. Patellar compression elicited pain bilaterally, and passive accessory motion testing revealed decreased inferior glide of the patella and limited caudal glide of the hip. Functionally, this patient had pain with squatting and during a step-down test. Patellar taping had no effect on the pain with the step-down test.

Patient 5

This patient was a 50-year-old female with left anterior knee pain of 3 months' duration when sitting less than 20 minutes, walking, squatting, or ascending/descending stairs. She rated the pain at worst as 8/10 with activity and as 0/10 with rest. Static posture exam revealed forefoot abduction, bilateral calcaneal valgus, left genu recurvatum, and uneven pelvic landmarks, revealing left anterior pelvic torsion. In single-limb stance, the navicular drop was greater than 3 mm, with associated ipsilateral pelvic drop. Range-of-motion testing for the knee was limited into end range flexion, with pain elicited with overpressure, and right hip internal rotation was limited, with a 15° difference between sides. Ankle dorsiflexion was within normal limits at 18° bilaterally; however, great toe extension was limited bilaterally. Muscle length testing revealed decreased iliotibial band length on the left, and the 90-90 hamstring length test was negative, with greater than 90° bilaterally measured with the straight-leg raise. Provocative testing of the left patellofemoral joint was positive for patellar compression, and passive accessory motion revealed limited hip caudal glide, anteromedial tibiofibular glide, and inferior patellar glide. Muscle testing of the gluteus maximus, medius, and quadriceps were judged to be weak, and this was demonstrated during the step-down test. Functional testing with the step-down test elicited pain, and she demonstrated ipsilateral pelvic drop, hip internal rotation, genu valgus, and subtalar pronation. As demonstrated in other studies,[14] taping relieved the anterior knee pain during the step-down test, and this patient continued to tape for the first 3 weeks of treatment.

Description and Rationale of Selected Techniques

Manual Techniques Based upon the clinical assessment of the patient and using clinical reasoning with supporting evidence, treatment interventions were administered using an impairment-based model (**TABLE 2**). We recognize that there is no reported validity or reliability for determining which manual technique would be the most effective

TABLE 3 Exercise Description*

Non–Weight-Bearing Exercises	Description
1. Abdominal isometric bracing in hook lying	1. Patient in hook lying and asked to draw lower abdomen inward toward the spine to hold an isometric contraction for 10 s per repetition
a. Abdominal bracing with heel slide	a. Abdominal bracing as above, while sliding heel away from gluteals
b. Abdominal bracing with bent knee lifts	b. Abdominal bracing as above, while performing hip and knee flexion
c. Abdominal bracing with straight-leg raise	c. Abdominal bracing as above, while performing a straight-leg raise
2. Bridging	2. Patient in hook lying and asked to perform abdominal bracing, while lifting gluteals from the table
3. Side-lying clamshells	3. Patient in side lying, with hip and knees flexed to 45°. Patient lifts uppermost knee toward the ceiling, while keeping the feet together
4. Quadruped upper extremity shoulder flexion and lower extremity hip extension	4. Patient in quadruped and asked to perform abdominal bracing, while simultaneously lifting opposite upper and lower extremity
5. Quadruped lower extremity abduction and extension	5. Patient in quadruped and asked to perform abdominal bracing, while simultaneously abducting and extending hip with knee in flexion
Weight-Bearing Exercises	**Description**
1. Double-leg press	1. Patient on Total Gym machine and asked to simultaneously flex hip and knee to squat bilaterally
2. Single-leg press	2. Patient on Total Gym machine and asked to simultaneously flex hip and knee to squat unilaterally
3. Eccentric step-downs from step	3. Patient standing on small 10-cm step, facing forward, and asked to eccentrically lower opposite heel from the step, progressed by raising height of step
4. Eccentric side step-downs from step	4. Patient standing on small 10-cm step, facing side, and asked to eccentrically lower opposite heel from the step, progressed by raising height of step
5. Hip abduction sidestepping, with resistive band at ankles	5. Patient standing, with resistive band wrapped around ankles, and asked to slightly flex knees and hips, while sidestepping against resistance
6. Squats	6. Patient standing and asked to simultaneously flex knees and hips to perform partial squat, progressed by performing deeper squats
7. Lunge	7. Patient standing with one lower extremity in front of the other and asked to flex hip and knee of forward most lower extremity to perform a lunge
8. Clock balance and reach†	8. Patient standing on affected lower extremity with knee slightly flexed. Patient asked to reach with opposite heel directly in front of the affected lower extremity (12:00) and then to reach forward and to the side (1:00) and so forth in a circle†
Stretches	**Description**
1. Supine piriformis stretch	1. Patient in supine, with affected knee flexed and crossed over the other. Stretch was performed by gently pulling affected knee toward opposite shoulder
2. Supine gluteus figure-four stretch	2. Patient in supine, with affected knee flexed and ankle crossed over the other knee. Stretch was performed by gently pushing knee downward
3. Standing hamstrings stretch	3. Patient in standing, with knee extended and hip flexed, with foot resting on step. Stretch was performed by leaning forward to stretch hamstring, while maintaining anterior pelvic tilt
4. Standing quadriceps stretch	4. Patient in standing, with knee flexed and hip in neutral. Stretch was performed by pulling heel toward gluteal
5. Standing iliotibial band/tensor fascia lata stretch	5. Patient in standing, with affected lower extremity behind other lower extremity, with knee and hip extended. Stretch was performed by leaning away from the affected lower extremity
6. Standing gastrocnemius/soleus stretch	6. Patient in standing, with affected lower extremity behind other lower extremity, with knee and hip extended. Stretch was performed by flexing foremost knee, while keeping rearmost heel on the floor

** Exercises were commenced after manual therapy treatment and prescribed for home once they were performed correctly in the clinic. Exercises were individualized for each patient and performed 1-2 times per day.*
†Adapted from Loudon et al.[44]

in this patient population; however, these techniques have been reported as interventions in prior studies and have been shown to have clinical success with the PFPS population.[35,59,65] The treating therapist based the selection of manual technique upon the individual patient's impairments and techniques shown to be beneficial in other studies. Thrust and nonthrust manipulation directed at the lumbopelvic spine, hip, patellofemoral, and proximal tibiofemoral joints was performed if a restriction with joint mobility was noted in that treatment session. Treatment progression for each patient and technique was based on frequent reassessment within and between sessions of joint accessory motion and patient response to particular interventions.[38,46] Test-retest assessment was used because it is believed that within-session changes would be predictive of a positive outcome.[46] Posterior-to-anterior tibiofibular thrust manipulation was applied to the proximal tibiofibular joint and resulted in immediate increases in pain-free flexion in patients 3 and 5. Each patient demon-

TABLE 4 Description of Manual Therapy Techniques*

Technique	Description
Thrust lumbopelvic manipulation 	All participants in this case series received lumbopelvic manipulation on the first 2 visits to the side ipsilateral to the knee pain. For patients with bilateral knee pain, this technique was performed on both sides. Participants were positioned in sidebending toward, and rotated away from, the painful side, and a high-velocity short-amplitude posterior thrust was delivered through the anterior superior iliac spine. Cavitation was noted during the technique and, if there was no click noted, the participant was repositioned and the technique was attempted again. Up to 2 thrust manipulations were attempted per side for the first 2 treatment visits
Inferior and superior patellar nonthrust manipulations 	All participants in this case series received patellar nonthrust manipulations, with both sustained hold and oscillations in the direction of restriction. With the participant in supine or long sitting, the painful knee was placed in 15° of flexion and the patella cupped by the examiner's hand. A superior or inferior gliding force was then applied until the restrictive barrier was achieved and either an oscillation or sustained hold was applied at the end range
Caudal hip nonthrust manipulation 	Caudal hip nonthrust manipulation was performed when hip was noted to be hypomobile with a capsular end feel. For this technique, the participant was lying supine, with hip and knee flexed to 90°, with a belt placed just distal to the hip joint. Graded oscillatory manual force was then applied inferiorly by the therapist to impart a distraction force through the hip joint. The caudal force was performed to the first barrier of resistance, as needed, at each treatment session for each participant
Proximal tibiofibular nonthrust manipulation 	For this technique, the patient was lying supine, with hip flexion at 90° and knee flexion to 90°. The treating therapist provided counterforce posterior to the fibular head, as the knee was flexed toward 120°. If excessive resistance was assessed, a low-amplitude, high-velocity thrust was performed through the tibia to increase flexion and cavitation was noted

strated asymmetrical hip rotation, and 4 of 5 patients had a 15° or larger asymmetry (range, 8°-20°) between sides; each participant received lumbopelvic manipulation. Recent evidence has shown hip internal rotation asymmetry to be the strongest predictive factor for successful response to lumbopelvic manipulation.[35] Patients with hip internal rotation asymmetry greater than 14° who received this technique increased the likelihood of successful response from 45% to 80%.[35] The manual physical therapy techniques that were most commonly used in this case series are described in **TABLE 4**.

Exercise Progression Each patient presented with weakness of the hip abductors, extensors, and external rotators, as well as poor neuromuscular control of the lower extremity in the step-down test.[44] All 5 patients also demonstrated difficulty recruiting deep abdominal muscles, indicating the need for lumbopelvic stabilization intervention, similar to previous reports.[47] Following the manual physical therapy interventions, all patients were taught lumbopelvic stabilization exercises, with focus on the transverse abdominus, hip extensors, and hip abductors (**TABLE 3**).[47,49] Patients were initially taught stabilization exercises in non-weight bearing until they were able to complete 2 sets of 10 repetitions with-

TABLE 5 Individual Results for Pain and Disability Measures

Measure/Patient	Evaluation	Visit 4	Discharge	6 mo
Worst pain reported*				
1	5/10	5/10		
2	7/10	1/10	3/10	2/10
3	6/10	2/10	1/10	0/10
4	2/10	2/10	0/10	2/10
5	8/10	8/10	3/10	0/10
Anterior Knee Pain Scale†				
1	34	48		
2	85	97	93	93
3	69	95	100	100
4	69	70	84	87
5	31	37	78	89
Lower Extremity Functional Scale‡				
1	53	46		
2	71	77	75	72
3	59	71	77	80
4	58	61	68	76
5	28	44	61	69
Global rating of change§				
1			0 (4th visit)	
2			0	0
3			6	7
4			4	3
5			6	7

* *Pain was reported by the patient on a 10-point scale (NPRS), recording the worst pain felt over the last 24 hours, with 0 representing no pain and 10 the worst pain imaginable.[8]*
† *The Anterior Knee Pain Scale scores are calculated as percentages ranging from 0 to 100, with higher scores indicating greater function.[40]*
‡ *The Lower Extremity Functional Scale scores are raw scores out of 80 points, with higher scores indicating greater function.[72]*
§ *The Global Rating of Change scores are raw scores ranging from −7 (a very great deal worse) to 7 (a very great deal better).[36]*

out substitution. At that point, exercises were progressed to weight-bearing exercises (**TABLE 3**).[6,28,44] Proprioception exercises with visual feedback were included in a weight-bearing step-down task because proprioception has been shown to be decreased in patients with PFPS.[3,60] Lower extremity stretching for the hamstrings, gastrocnemius, quadriceps, iliopsoas, and iliotibial band complex were prescribed if muscle length deficits were observed on clinical examination (**TABLE 3**). These stretches were held for 30 seconds each for 3 repetitions daily, and the patient was instructed to continue these exercises at home after discharge.

Taping Intervention During the subjective examination, all participants reported pain with descending stairs. During the physical exam, all participants completed a functional step-down test[48] as a comparative sign for a successful response to patellar taping.[14,17] If the participant had pain during the step-down test, patellar taping was applied in a medial direction (**FIGURE**), and the step-down test was repeated. Clinical decision making for taping as an intervention for each respective case was guided by alleviation of pain during the step-down test.[44] Patients 3 and 5 had alleviation of pain with patellar taping during the step-down test and were instructed in patellar taping for the first 3 weeks.

Orthotic Intervention Foot orthoses were recommended for patients demonstrating excessive pronation of the subtalar joint, operationally defined as a drop of greater than 3 mm with functional movement. Patients 3 and 5 both demonstrated excessive pronation with walking and with the step-down test, and, therefore, received foot orthoses. The orthoses were hypothesized to decrease excessive subtalar joint pronation and tibial rotation, and to decrease chronic overloading of the patellofemoral joint.[26,42] The mechanism by which orthotics affects patellofemoral pain is beyond the scope of this paper; however, this lends further support to a regional interdependence approach of affecting patellar pain by modifying foot mechanics.

OUTCOMES

A total of 7 consecutive patients referred to physical therapy with anterior knee pain were screened for eligibility criteria for this study. One patient was excluded due to the mechanism of injury being a traumatic event, and the other patient was excluded due to time commitments. All 5 patients in this case series exhibited anterior knee pain with ascending and descending steps, squatting, and a positive step-down test.[48] Three of the 5 patients had bilateral symptoms. One patient discontinued treatment after the fourth treatment and her data are reported as such. The age range was 14 to 50 years, and the median duration of symptoms was 8 months (range, 3-24 months). The median number of physical therapy visits was 11 treatments (range, 8-14) over a 6- to 14-week period. Participants were discharged from treatment once the patient met the goals set at the initial examination or reported 0/10 pain on the NPRS with activity or return to sport.

Four of 5 patients demonstrated a clinically significant improvement in pain and functional status measured by the outcome tools. Individual results

FIGURE. Taping with medial patellar glide.

for the LEFS, AKPS, and NPRS at baseline, fourth treatment, discharge, and 6-month follow-up are shown in **TABLE 5**. The median baseline pain was moderate for worst pain reported in the past 24 hours (median, 6 points; range, 2-8 points). At the fourth treatment, the median change of the worst pain reported on the NPRS from baseline did not surpass the MCID of 2 points (median, 0 points; range, 0-6 points). Patients 1, 4, and 5 did not experience a change in pain from baseline to the fourth treatment. However, by discharge, overall worst pain reported on the NPRS decreased, and every individual patient had surpassed the MCID of 2 points (median, 5 points; range, 2-5 points). Patients 2, 3, and 5 reported a change greater than 2 points on the NPRS at 6-month follow-up (median, 6 points; range, 0-8 points).

The median score at baseline for the AKPS indicated moderate disability (median, 69%; range, 31%-85%). Patients 1 and 5 reported severe disability at baseline, with scores less than 35% (**TABLE 5**). However, at the fourth treatment, the median improvement in disability measured by the AKPS surpassed the MCID of 10% (median, 12%; range, 1%-26%) and continued to increase by discharge (median, 23%; range, 8%-47%). Patients 3, 4, and 5 demonstrated an increase in function greater than 15% at discharge and 6-month follow-up (median, 25%; range, 8-58). Individual scores are listed in **TABLE 5**.

The median score of the LEFS at baseline indicated moderate disability (median, 58; range, 28-71). At treatment 4, patient 2 reported worsening disability, with a negative change in score of 7 points, correlating with no change in patient status. The median improvement in disability on the LEFS from baseline to the fourth treatment did not surpass the MCID of 9 points (median, 6 points; range, −7 to 16 points). However, at discharge the median improvement in disability on the LEFS surpassed the MCID (median, 14 points; range, 4-33 points). This trend of improved disability continued at 6 months, and the median improvement in disability on the LEFS was 20 points (range, 1-41 points) at the 6-month follow-up. Patient 2 did not show significant changes in the LEFS and may have demonstrated a ceiling effect, with an initial score of 71. Individual results are reported in **TABLE 5**.

The individual patient-reported functional improvements collected at discharge and at the 6-month follow-up were followed by the treating therapist. Patient 1 did not complete treatment beyond the fourth session and rated her symptoms as "about the same" (0) on the GRC. By discharge, patients 2 and 5 had returned to exercise programs, and patients 3 and 4 had returned to playing competitive soccer. They did not seek further treatment at the 6-month follow-up. Individual results for the GRC are listed in **TABLE 5**.

DISCUSSION

THIS CASE SERIES DESCRIBES THE outcomes and management of 5 patients with PFPS using manual therapy, exercise, taping, and orthotic prescription. Four (80%) of 5 patients experienced a successful outcome, as measured by surpassing the MCID on outcome instruments within a median of 11 visits (range, 4-14) over a median of 9 weeks (range, 2-14 weeks).

The theory of regional interdependence explores the biomechanical link between the lumbopelvic region, hip, knee, and foot.[68] Several authors[27,29,69,74] have questioned some of the current clinical methods of assessing and treating PFPS. Suspicion regarding this approach stems from studies that primarily focus on static alignment tests.[29,55,69] Studies of multiple factors of lower limb alignment investigating the Q-angle,[29,55] patella alta,[69] iliotibial band length,[30] and recruitment of the VMO[12,31,50] have failed to completely account for patellofemoral pain. Furthermore, pain reports are not necessarily correlated with radiographic findings. A relationship between static patellar positioning and degenerative findings on radiographs has not been shown in asymptomatic subjects.[22,41]

It is likely that PFPS may be the result of a dynamic dysfunction of the interaction between the lumbopelvic region, hip, knee, and foot. Studies have examined the dynamic relationship between the hip and knee and the foot and knee, and have found impairments in hip internal rotation in patients with PFPS.[54] This relationship has been examined in weight-bearing activities with excessive hip internal rotation during the step-down test, affecting patellofemoral mechanics.[55] Weight-bearing dynamic studies have led to the hypothesis that increased contralateral pelvic drop, hip internal rotation and adduction, and tibial internal rotation increase the valgus alignment of the knee, resulting in suboptimal mechanics of the patellofemoral joint during the step-down test in patients with PFPS.[53] These studies call into question the relevancy of the static tests and measures, and suggest that our clinical decisions for treatment interventions should be guided by a dynamic assessment of the lower extremity as a functional unit.

The ability to affect knee pain through exercise interventions directed toward proximal or distal joints emphasizes a regional-interdependence exercise approach to the lower extremity. Powers and colleagues[47,53,55] have identified a direct kinematic relationship between the hip and PFPS during weight-bearing exercise, while other researchers have shown improved function and decreased pain with strengthening exercises directed at the hip and lumbopelvic region.[6,10,34,47] Mascal and colleagues[47] described both weight-bearing and non–weight-bearing exercise directed at multiple joints, including the hip and pelvis in 2 case reports. Similar to these studies, the weight-bearing and non–weight-bearing exercises chosen in this case series were directed toward neuromuscular control of the hip, pelvis, and knee. Each patient in this case series demonstrated lumbopelvic and hip weakness, similar to other reports in the literature.[34,58] Robinson and Nee[58] recently found a limb asymmetry of 23% less hip abduction strength, 29% less hip extension strength, and 14% less hip external rotation strength in females with PFPS. These findings are similar to those of Ireland and colleagues,[34] who found 26% less hip abduction and 36% less hip external rotation strength in females with PFPS than in asymptomatic controls. These studies underline a paradigm shift occurring in treatment of PFPS targeting interventions at the entire lower extremity.

Patients with PFPS have been shown in previous studies to have poor dynamic motor control during a step-down test.[47,53] Proprioception in these patients has also been shown to be impaired, with patients unable to assess knee flexion angle.[3] Similar to these studies,[47,53] the patients in this case series demonstrated poor lower extremity mechanics with decreased awareness of knee position sense during the step-down test. Pain with the step-down test was used as a comparative sign in the assessment of these patients and was the key factor of clinical reasoning for not only patellar taping but also weight-bearing proprioceptive exercises to re-educate the motor control pattern during the step-down test. Each patient performed the step-down as a weight-bearing exercise and reported that decreased pain and eccentric control improved. Due to the fact that improved motor control took several weeks for an observable change, it is difficult to separate the effect of the lumbopelvic and quadriceps strengthening on gain of eccentric motor control.

Although this case series cannot be used to show a cause-and-effect relationship between the manipulation techniques and the outcomes of the patients, the idea of affecting symptoms associated with PFPS through thrust and nonthrust manipulation of adjacent joints is intriguing and has been previously explored in the literature.[61,62] Suter and colleagues[61,62] investigated the relationship between manipulation of the sacroiliac joint and weakness of the quadriceps in a cohort of patients with PFPS and found decreased quadriceps muscle inhibition after sacroiliac joint manipulation. The mechanism by which manipulation affects pain response of an adjacent joint is not well understood but has been proposed to occur by either mechanical or neurophysiological mechanisms.[61,62] As in previous studies, 80% of the patients in this case series demonstrated asymmetric hip internal rotation greater than 14°, which could indicate a mechanical link.[35] However, the decrease in pain in the patients in this case series after manipulation was accompanied by an improvement in ability to recruit the lumbopelvic stabilizers, which may support a previously proposed neurophysiological mechanism.[25] This neurophysiological hypothesis could be further investigated using ultrasound imaging of the deep abdominals and assessment of the H-reflex following manipulation of the lumbar spine, hip, or patellofemoral joint. The results of this case series lend further support to a regional-interdependence approach of manual therapy for PFPS.

Limitations of this report include the fact that no blinding occurred with patients or the investigator, as a single treating therapist completed all examinations and interventions. However, the treating therapist had no influence on the self-reported functional outcome measures. Due to the lack of a gold standard for diagnosis of PFPS, common signs and symptoms were used as a basis for clinical diagnosis. Thus, the presence of concurrent knee pathologies, such as fat pad irritation or patellar tendonitis, could not be fully excluded. As previously mentioned, we cannot infer a cause-and-effect relationship from a case series. Despite the limitations, this case series describes positive outcomes for patients with PFPS.

Future research should investigate and validate predictive factors for successful outcomes with a regionally interdependent approach, including lumbopelvic manipulation, orthotic management, taping, and neuromuscular reeducation of the lower quarter. A multimodal approach may be warranted, considering the results of this case series. The mechanism of lumbopelvic manipulation has been studied briefly but should be investigated further for effects on the quadriceps and lumbopelvic stabilizers in the PFPS population. It should also be noted that thrust manipulation versus nonthrust manipulation should be studied to determine if different clinical outcomes occur with one technique versus the other.

CONCLUSIONS

This case series describes the management and outcomes of patients with PFPS treated with manual therapy, exercise, taping, and orthotics. Four (80%) of 5 patients demonstrated a decrease in pain and an increase in functional ability over a median 11 sessions course of care, and these gains were maintained at 6-month follow-up. Future studies, in the form of well-designed clinical trials, should investigate the regional interdependence of the lower quarter and spine with management of patellofemoral pain. ◉

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