Introduction
Patellofemoral pain syndrome (PFPS) is a multifactorial disorder with a variety of treatment options. The assortment of components that contribute to its pathophysiology can be categorized into local joint impairments, altered lower extremity biomechanics, and overuse. A detailed physical examination permits identification of the unique contributors for a given individual and permits the formation of a precise, customized treatment plan. This review aims to describe the latest evidence and recommendations regarding rehabilitation of PFPS. We address the utility of quadriceps strengthening, soft tissue flexibility, patellar taping, patellar bracing, hip strengthening, foot orthoses, gait reeducation, and training modification in the treatment of PFPS.

Abstract
Patellofemoral pain syndrome (PFPS) is a multifactorial disorder with a variety of treatment options. The assortment of components that contribute to its pathophysiology can be categorized into local joint impairments, altered lower extremity biomechanics, and overuse. A detailed physical examination permits identification of the unique contributors for a given individual and permits the formation of a precise, customized treatment plan. This review aims to describe the latest evidence and recommendations regarding rehabilitation of PFPS. We address the utility of quadriceps strengthening, soft tissue flexibility, patellar taping, patellar bracing, hip strengthening, foot orthoses, gait reeducation, and training modification in the treatment of PFPS.

Local Joint Impairments
Traditionally rehabilitation strategies have emphasized correction of abnormal patellofemoral kinematics and alignment by addressing structures at or crossing the knee joint, as these local structures have a direct effect on patellofemoral function, especially patellar tracking. Maltracking is defined classically by excessive lateral alignment of the patella within the trochlear groove and is thought to play a pivotal role in the development of PFPS. Strategies to address maltracking include quadriceps strengthening and improved flexibility of regional soft tissues (namely, the quadriceps, hamstrings, and iliotibial band). External methods, including taping and bracing, to resolve patellar maltracking have been investigated also.

Quadriceps strength
Strengthening of the quadriceps femoris has been the prevailing method of rehabilitation for PFPS, based on a strong association between PFPS and knee extension weakness. There is recent prospective evidence to suggest that healthy individuals with weak knee extensors are at increased risk of developing PFPS (9). Furthermore isolated strengthening of the quadriceps femoris complex consistently has shown success in treatment of PFPS (2,74,84).

The ideal approach to quadriceps strengthening may incorporate both open and closed kinetic chain exercises. In open kinetic chain exercises such as knee extensions, quadriceps muscle force and patellofemoral joint stress are greatest near full extension (31,73). Conversely in closed kinetic chain exercises such as lunges and leg presses, quadriceps muscle force and patellofemoral joint stress are highest near full flexion (31,73). Therefore integration of both forms of
exercise promotes strengthening throughout the arc of motion. Moreover open kinetic chain exercises (especially in the range of 90°–45°) may be better tolerated in the acute phases of PFPS when there is significant weakness or pain with weight bearing (31). In the long run, however, closed kinetic chain exercises with an emphasis on cocontraction of the hamstring and quadriceps muscles have proven overall superior to open kinetic chain exercises in improving function (2,84). Thus closed kinetic chain exercises should be incorporated to the rehabilitation program as early as a patient is able to tolerate (15).

**Table 1.**
Etiologic contributors to PFPS.

<table>
<thead>
<tr>
<th>Local Joint Impairments</th>
<th>Altered Lower Extremity Biomechanics</th>
<th>Training Errors/Overuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadriceps weakness</td>
<td>Hip abductor weakness</td>
<td>Increasing exercise too quickly</td>
</tr>
<tr>
<td>Impaired VM function</td>
<td>Hip external rotator weakness</td>
<td>Inadequate time for recovery</td>
</tr>
<tr>
<td>Soft tissue inflexibility</td>
<td>Excessive foot pronation</td>
<td>Excessive hill work</td>
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<tr>
<td>Quadriceps</td>
<td>Pes planus</td>
<td></td>
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<tr>
<td>Gastrocnemius</td>
<td>Excessive impact shock with heel strike</td>
<td></td>
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<tr>
<td>Iliotibial band</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamstring</td>
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</tbody>
</table>

**Table 2.**
Approach to PFPS management.

<table>
<thead>
<tr>
<th>Causative Element</th>
<th>Physical Examination Correlate</th>
<th>Management Considerations</th>
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</thead>
<tbody>
<tr>
<td>Local factors</td>
<td>Patellar malposition/maltracking</td>
<td>Patellar taping</td>
</tr>
<tr>
<td></td>
<td>Patella alta</td>
<td>Patellar bracing</td>
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<tr>
<td></td>
<td>Lateral patellar tilt</td>
<td>Correction of vasti activation imbalance</td>
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<td></td>
<td>Lateral patellar displacement</td>
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<tr>
<td>Soft tissue inflexibility</td>
<td>Tight iliotibial band</td>
<td>Stretching and foam roll</td>
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<tr>
<td></td>
<td>Tight quadriceps</td>
<td></td>
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<tr>
<td></td>
<td>Tight hamstring</td>
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</tr>
<tr>
<td></td>
<td>Tight gastrocnemius</td>
<td></td>
</tr>
<tr>
<td>Lower extremity biomechanics</td>
<td>Hip muscle weakness</td>
<td>Static hip abductor weakness, Dynamic knee valgum,</td>
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<tr>
<td></td>
<td>Static hip abductor weakness, Dynamic knee valgum,</td>
<td>Excessive adduction with</td>
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<td></td>
<td>Excessive adduction with SLS, and Contralateral pelvic drop with</td>
<td>Calf drop</td>
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<td></td>
<td>SLS, and Contralateral pelvic drop with single leg squat</td>
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<tr>
<td>Foot malposition</td>
<td>Excessive pronation contributing to increased femoral rotation</td>
<td>Foot orthosis</td>
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<tr>
<td>Gait</td>
<td>Ipsilateral hip adduction</td>
<td>Gait retraining</td>
</tr>
<tr>
<td></td>
<td>Contralateral pelvic drop</td>
<td></td>
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<tr>
<td></td>
<td>Excessive impact shock with heel strike</td>
<td></td>
</tr>
<tr>
<td>Training errors</td>
<td>Overly rapid exercise progression</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Overly intense exercise intensity for level of fitness</td>
<td>Relative rest</td>
</tr>
<tr>
<td></td>
<td>Inadequate recovery</td>
<td>Correct training errors</td>
</tr>
</tbody>
</table>

NA, not applicable.

**Vastus medialis strength**

Much attention has been given to the role of the vastus medialis (VM), and particularly the VM oblique (VMO), based on observations of reduced VMO volume and strength in individuals postsurgery, following injury, or with PFPS. The VMO fibers insert more distally and horizontally on the patella and are critical to providing dynamic medial patellar stability (30,32,44). Studies have found a significant correlation between VMO abnormalities (insertion level, fiber angle, and VMO volume) and patellofemoral pain (39,57). However three randomized controlled trials have compared attempts
at VMO strengthening to overall quadriceps strengthening using electromyographic feedback techniques, with unanimous results that negate any difference in short-term outcomes (26,74,88). Another study examined nine commonly used strengthening exercises and found that electromyographic activity was no different between the VMO and other muscles comprising the quadriceps complex (49). Therefore specific exercises to isolate the VMO for strengthening are not indicated. A well-rounded quadriceps strengthening program should correct any imbalance in strength between the quadriceps muscles.

**VM activation and timing**

In addition to strength of the VMO, the timing of VM activation in relation to that of vastus lateralis (VL) has been implicated in multiple studies of PFPS (12,18,78,85). However this finding has not been consistent across all studies (11,64). Fortunately more recent research has helped to clarify the role of delayed VM activation in patellar maltracking. Vasti muscle activation may be quantified by either delay in VM activation when compared to the VL or the ratio of the magnitudes of normalized activations of the VL and VM muscles (VL/VM) (69). A novel diagnostic method by Pal et al. (55,56) has provided important breakthroughs in understanding the relationship between vasti muscle imbalance and patellar maltracking in patellofemoral pain patients. They defined a subset of individuals with patellar maltracking based on patellar tilt and bisect offset as measured from weight-bearing magnetic resonance imaging, and they found that within this group, the degree of maltracking was correlated with delay in VM activation. Furthermore when they combined their patients with and without patellar maltracking, no relationship between maltracking and vasti muscle imbalance was detected (55,56). In so doing, Pal et al. demonstrated the importance of accurate classification of individuals with PFPS into maltracking and normal tracking groups. One reason for the discrepancies observed in prior studies likely relates to the percentage of maltracking and normal tracking patients included in these studies; a study with a large number of maltrackers would conclude vasti muscle imbalance in patellofemoral pain patients, while a study with a large number of normal trackers would likely find no vasti muscle imbalance in patellofemoral pain patients. Indeed in a recent review article, Wong (86) hypothesized that the discrepancies between previous studies were due to lack of standardized methods for quantifying vasti muscle imbalance. Thus while controlled trials are lacking, it is logical to address deficits in VM activation delay and patellar maltracking within this subgroup of patellofemoral pain subjects with documented maltracking (abnormal tilt and/or abnormal bisect offset).

Pal et al. (56) have developed a cost-effective method for determination of vasti activation imbalance, based on the discovery of a strong correlation between the two vasti activation imbalance measures. Measurement of VM activation delay during functional tasks requires synchronization of EMG data with joint kinematics and ground reaction forces; VL/VM activation ratios can be obtained by simply placing surface electrodes on a patient while performing a functional task and is feasible in clinical settings.

Once vasti activation imbalance is recognized, several techniques may be effective to modify VM discrepancies. EMG biofeedback measures neuromuscular contractions and provides auditory or visual feedback signals designed to increase awareness and voluntary control of muscle activation. When combined with therapeutic exercise, EMG biofeedback aimed at increasing VMO activation while maintaining constant VL activity has been shown to improve VMO/VL activation ratios (53). Patellar taping, discussed in greater detail below, may likewise represent a useful adjuvant to augment temporal activation of the VMO (14,19).

**Soft tissue flexibility**

Stretching the muscles that surround the knee is another commonly employed technique in the management of PFPS. Inflexibility of both the rectus femoris and the gastrocnemius has been prospectively associated with development of PFPS (84). Cross-sectional studies likewise have observed a relationship of hamstring and iliotibial band tightness to the presence of PFPS (37,65). The iliotibial band, in particular, appears to play an essential role in patellar maltracking, with its derivative fibers comprising the strongest and most substantial layer of the lateral retinaculum. The transverse orientation of these fibers serves to resist medial displacement of the patella; however, when excessively tight, it may result in disproportionate lateral translation. Cadaveric studies support this notion, demonstrating increased lateral patellar shift and tilt with augmented iliotibial band loads (42,46). Furthermore among a small sample of patients, surgical release of iliotibial tract contracture has been shown to result in reduced lateral patellar subluxation and patellar tilt (87).

Generalized stretching protocols that encompass the quadriceps, hamstring, gastrocnemius, and iliotibial band have established benefit, especially when combined with an exercise program. In a randomized, controlled, single-blind trial, Moyano et al. (50) demonstrated significant reductions in pain among individuals managed with a stretching routine combined with strengthening or aerobic exercise. Proprioceptive neuromuscular facilitation stretching, in particular, a technique combining passive and isometric stretching, may yield enhanced pain control and function. However there is currently a paucity of research addressing isolated stretching protocols. Of the two controlled studies examining the role of isolated rectus femoris stretching in PFPS (45,58), only one showed significant clinical improvement (45). There are no randomized clinical trials that assess directed hamstring or iliotibial band stretching in the management of PFPS.

Although further investigation is necessary to identify whether specific muscles or stretches contribute more significantly to clinical improvement in PFPS, a stretching protocol aimed to reverse identified inflexibility of the quadriceps, gastrocnemius, hamstring, and/or iliotibial band is a valuable component of PFPS rehabilitation. Given the role of the iliotibial tract on patellar tracking, an emphasis on relieving iliotibial band tightness may prove particularly high yield, especially in individuals with concurrent maltracking and iliotibial band tightness on examination.

**Patellar taping**

A variety of taping methods have been proposed with the tailored McConnell taping technique representing the standard...
in management of PFPS. The McConnell method aims to control patellar tilt, glide, and/or spin based on physical examination findings (20). Studies have found increased tolerance to knee joint loading, increased VMO activity, and improved onset of the VMO in relation to the VL muscles utilizing this method (14,19,63,68). Alterations in patellofemoral kinematics have been demonstrated also (22). Taping performed under dynamic magnetic resonance imaging reveals inferior shift of the patella, thereby increasing the patellofemoral contact area within the trochlea (22). Taping also may lateralize the patella partially in individuals with baseline medial displacement and medialize the patella in individuals with baseline lateral displacement, again improving patellofemoral contact area (22). This increase in contact area is theorized to contribute to pain reduction in PFPS by producing a wider distribution of forces across the patella and possibly relieving contact in sensitive areas (62).

McConnell taping shows promise in providing enhanced pain relief and function particularly when combined with exercise (45,79). Whittingham et al. (79) investigated pain and functional outcomes among three treatment groups: McConnell taping combined with exercise, placebo taping combined with exercise, and exercise alone. While pain improved across all groups by 4 wk, both pain and function scores were significantly better in the group managed with a combination of McConnell taping and exercise. In an effort to further delineate the impact of taping, Mason et al. (45) evaluated the effect of quadriceps strengthening, quadriceps stretching, and McConnell taping in isolation and in combination. Improvements in pain and strength were demonstrated for all intervention groups in isolation, but more significant and pervasive improvements were observed when the three modalities were combined. A recent meta-analysis further concluded that there is moderate evidence to support incorporation of tailored taping into a rehabilitation program for PFPS, particularly for early pain reduction (7).

**Patellar bracing**

Bracing has been explored similarly for its role in patellar stabilization and management of PFPS. As with taping, bracing has been shown to modify patellofemoral kinematics (27,62). Medially directed patellofemoral stabilization braces, and to a lesser degree, simple knee support sleeves, contribute to reduced lateral translation of the patella (27). Medially directed braces also may reduce patellar tilt (27). These alterations are more apparent in a subset of individuals who have baseline abnormal kinematics when compared to controls (27). However it is recognized that the impact of braces on patellar lateralization and tilt is limited, and alignment is not restored to normal with bracing alone (27,62). Patellofemoral contact area, on the other hand, does appear to increase substantially with the application of a medially directed brace and may be a driving factor in associated pain reduction (62).

The clinical effect of knee braces on patellofemoral pain has been investigated with varying results. There are few prospective randomized clinical trials evaluating the impact of bracing. Immediate pain reduction following application of a brace has been reported (62). Longer-term benefits in a small population also have been demonstrated (1). Arazpour et al. (1) found a nearly 60% reduction in pain with the use of bracing and additionally ascertained gains in walking speed and step length. Despite this, others have failed to uncover a therapeutic benefit to bracing (48). This may represent inappropriate patient selection (normal patellar kinematics) or variability in the type of brace employed. Although further studies are needed to clarify the outcomes and most appropriate subpopulations for brace utilization, a properly fitted patellar stabilization brace represents a potential adjunct to a physical therapy program, particularly in those patients with documented patellar maltracking, and is a reasonable alternative to patellar taping.

**Altered Lower Extremity Biomechanics**

While addressing local joint impairments remains an integral component of PFPS rehabilitation, there is expanding evidence to support the influence of lower extremity kinematics in the development of PFPS. Aberrations that result in excessive internal rotation of the femur in particular appear to increase patellofemoral stress. Studies utilizing dynamic magnetic resonance imaging suggest excessive internal femoral rotation, rather than patellar rotation, as giving rise to lateral patellar tracking and increased patellofemoral joint stress (59,70). These kinematic changes more likely are to be seen during more demanding tasks such as single-limb squat, running, single-limb jumping, and single-limb drop landing (24,71,80,81).

**Hip strength**

Deficits in hip muscle performance, particularly the external rotators and abductors including gluteus maximus and medius, could result in internal rotation of the femur during dynamic lower limb functions and consequent increased patellofemoral compressive forces. Multiple studies have established a correlation between hip external rotator and abductor weakness in women with PFPS (8,38). Altered neuromuscular activity of gluteus medius and maximus also has been associated with PFPS (51).

Recent experience corroborates the incorporation of hip strengthening in the management of PFPS, especially for the female population. In 2008, Nakagawa et al. (51) published the first randomized controlled trial investigating the utility of a hip strengthening protocol. This study demonstrated that the addition of hip abduction and external rotation strengthening exercises to a traditional rehabilitation program of patellar mobilization and quadriceps strengthening results in less pain and improved gluteus medius neuromuscular activation (51). Since that time, four additional randomized controlled trials investigating female patients with PFPS have supported hip strengthening further in reducing patellofemoral pain and optimizing function (25,34,35,41). Importantly when compared to knee stretching and strengthening alone, the addition of targeted hip exercise appears to provide significantly more lasting benefits at 1 year and minimize risk of pain relapse (35). Thus targeted hip muscle strengthening is encouraged for PFPS rehabilitation, particularly in women who demonstrate static or dynamic evidence of hip weakness and medial femoral collapse on physical examination. Exercises should address the gluteus medius and maximus specifically. Gluteus medius may be targeted with side-lying abduction and single-limb squats. Gluteus maximus is best recruited using front planks with hip
extension and gluteal squeezes. Side planks effectively target both gluteus maximus and medius (10).

Foot position
Observational studies have demonstrated an association between excessive foot pronation and PFPS (3,67). The precise manner by which excessive pronation may result in increased patellofemoral stress has not been elucidated; however Tiberio (76) theorized one possible mechanism through compensatory internal rotation of the femur. In normal gait, the subtalar joint is supinated at heel strike. During early contact, the foot pronates and the tibia internally rotates. Once the foot reaches midstance and the foot is in full contact with the ground, the subtalar joint again supinates and the tibia follows, externally rotating, in order to move the knee into extension. However in situations of excessive pronation, the subtalar joint remains in a pronated position at midstance, preventing the tibia from externally rotating. Tiberio proposed that to compensate and promote knee extension, the femur internally rotates on the tibia (the so-called compensatory internal rotation of the femur). This then results in lateral tracking of the patella, thereby increasing patellofemoral strain. Although not proven, this model has become accepted widely and provides a plausible rationale for the apparent relation between overpronation and PFPS. However Reischl et al. (66) have reported that the magnitude of foot pronation does not predict the magnitude of tibia or femur rotation. As such, patients need be evaluated on an individual basis to determine whether abnormal foot mechanics are contributing to a kinematic pattern that could explain the presence of patellofemoral symptoms.

Historically results utilizing foot orthoses to correct excessive pronation in the management of PFPS have been mixed; however there is a growing body of literature to support the use of foot orthoses. The predominance of recent studies implement semirigid orthoses. Instead of rigid materials, semifirm materials that absorb shock and provide medial longitudinal arch support without hindering the natural pronation mechanism of the foot are recommended (61).

Positive effects in both pain reduction and functional performance have been reported immediately following use (6) and over a period of time up to 3 months (5,40). In a recent randomized clinical trial comparing the efficacy of foot orthoses to flat inserts or physical therapy, prefabricated orthoses did appear superior to flat inserts according to participants’ perception in the short-term management of PFPS (16). Outcomes were no different between the orthosis group and physical therapy. Furthermore the combined use of a foot orthosis with physical therapy did not portend any additional gains in pain or function at follow-up. It is worth noting that participants of this study were not screened for lower extremity mechanics including foot posture. The failure to detect an advantage, particularly in the combined group, may reflect inclusion of individuals for whom an orthosis would be less likely beneficial. Several predictors for response to foot orthoses have been identified including lower baseline pain levels, increased midfoot mobility (change in midfoot width between non-weight bearing and weight bearing), reduced ankle dorsiflexion, and use of less supportive shoes (4,77). In addition it has been suggested that those who report immediate pain reduction with an orthosis when performing a single-leg squat are more likely to benefit from one (4).

There are no specific criteria to identify those individuals who warrant a trial of an orthosis in the management of PFPS. Nevertheless it is reasonable to trial a foot orthosis simultaneously, or after an appropriate course of physical therapy, in individuals with excessive pronation on dynamic examination. If an over-the-counter orthosis is not sufficient, a custom orthosis with a stiffer medial heel wedge may be indicated (33,61).

The majority of research on the foot has focused on the rearfoot. However due to reported findings of increased foot mobility in individuals with PFPS, future research may be better served by focusing more on the midfoot. Prospective evaluation of the foot’s association with PFPS is needed also (60).

Gait
Gait patterns that demonstrate excessive hip adduction (9,52), femoral internal rotation (9,71), and excessive pronation during dynamic activities (67) have been implicated in the development of PFPS. Souza and Powers (71) also reported that isotonic hip extension endurance was a significant predictor of peak hip rotation during running, suggesting that impaired hip muscle performance may underlie the abnormal hip kinematics thought to contribute to PFPS. It is interesting that targeted hip strengthening regimens, while improving strength, may not affect these associated gait impairments necessarily (29,83). Failure to correct these dynamic patterns may result in suboptimal clinical outcomes. Several researchers have addressed this problem through case series incorporating various feedback mechanisms, including visual feedback from an instrumented treadmill (21), real-time hip adduction measurements (54), adoption of a forefoot strike pattern (13), and direct mirror feedback (82), and all report both biomechanical and clinical success. Thus while these methods of gait retraining show great promise, prospective and controlled studies are needed to evaluate these techniques further in the prevention and treatment of PFPS.

Increased peak ground reaction forces also have been implicated also in the development of PFPS in runners (75). Efforts to reduce forces through gait modification have been undertaken. Heiderscheit et al. (36) performed biomechanical evaluations in healthy runners through modification of step rate and demonstrated that a higher step rate is associated with a decreased foot inclination angle, step length, center of mass vertical excursion, and horizontal distance from center of mass and heel at initial contact. A subsequent follow-up study associated a 14% force reduction at the patellofemoral joint with a 10% increase in step rate (43). It stands to reason that methods aimed at reducing ground reaction and transmitted patellofemoral forces, such as reducing step length, are a reasonable approach to managing PFPS; however additional trials are necessary to confirm this notion.

Training Errors
The likely role of tissue homeostasis in the development of patellofemoral pain has been described by Dye (28). He maintains that altered tissue homeostasis may occur under
any circumstance that supersedes the so-called envelope of function or load acceptance capacity of the joint. This includes not only gross structural abnormalities but also repetitive, lower magnitude loads (supraphysiologic overload) to the patellofemoral joint. While not sufficient to produce immediately evident structural damage, these repetitive stresses over time result in loss of osseous and periosseous soft tissue homeostasis as manifested by peripatellar synovitis and inflammation of the fat pad tissues (28). Thus lack of significant findings on physical examination (i.e., normal patellar mechanics and normal lower extremity function) may suggest training errors and overuse resulting in supraphysiologic overload. This overuse is seen often in an athletic population. In such cases, the training program should be evaluated for obvious errors, including increasing exercise intensity too quickly, inadequate time for recovery, and excessive hill work (33). Initial management should emphasize activity modification to a pain-free level (28).

Conclusion

It is becoming increasingly apparent that PFPS is a multifactorial condition that mandates a comprehensive yet individualized approach to treatment. A rehabilitation program should incorporate quadriceps strengthening and be tailored further according to identified deficiencies in patellofemoral kinematics, lower extremity biomechanics, and training. Based on an individual’s constitution, additional strategies that may prove valuable include enhanced muscle flexibility, patellar bracing or taping, hip strengthening, foot orthoses, and gait modification. Training errors and overuse must be addressed also.

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References


