

PETER MALLIARAS, BPhysio (Hons), PhD^{1,2} • JILL COOK, PhD^{1,3} • CRAIG PURDAM, MSportsPhysio³⁻⁵
EBONIE RIO, BPhysio (Hons), MSportsPhysio, PhD^{1,3}

Patellar Tendinopathy: Clinical Diagnosis, Load Management, and Advice for Challenging Case Presentations

Anterior knee pain in athletes can be caused by a number of anatomical structures. Patellar tendinopathy, one source of anterior knee pain, is most commonly characterized by pain localized to the inferior pole of the patella and load-related pain that increases with the demand on the knee extensors, notably in activities that store and release energy in the patellar tendon.³³ Patellar tendinopathy is debilitating and can result in prolonged absence

and potentially retirement from sports participation. Cook et al¹⁶ found that more than one third of athletes presenting for treatment for patellar tendinopathy were unable to return to sport within 6 months, and it has been reported that 53% of athletes with patellar tendinopathy were

forced to retire from sport.⁵²

Patellar tendinopathy is primarily a condition of relatively young (15-30 years old) athletes, especially men, who participate in sports such as basketball, volleyball, athletic jump events, tennis, and football, which require repetitive loading of the patellar tendon.⁵⁷ The power needed



for jumping, landing, cutting, and pivoting when participating in these sports requires the patellar tendon to repetitively store and release energy.² Energy storage and release (similar to a spring) from the long tendons of the lower limb are key features for high performance while reducing the energy cost of human movements.^{2,76} Repetition of this spring-like activity over a single exercise session,⁵¹ or with insufficient rest to enable remodeling between sessions,⁸¹ can induce pathology and a change in the tendon's mechanical properties, which is a risk factor for developing symptoms.^{17,61} Energy-storage load is defined in this article as high tendon load, because it is associated with tendon injury.

Although the relationship between pain and tendon pathology is unclear, the presence of pathology appears to be a risk factor for an individual becoming symptomatic.^{17,61} Thus, it is important for clinicians to have an appreciation of tendon pathology. Briefly, tendon pathology includes increases in tenocyte numbers and rounding, and in ground substance expression, causing swelling, matrix degradation, and neovascular ingrowth.^{53,58} These changes have been extensively reviewed elsewhere.^{1,19}

● **SYNOPSIS:** The hallmark features of patellar tendinopathy are (1) pain localized to the inferior pole of the patella and (2) load-related pain that increases with the demand on the knee extensors, notably in activities that store and release energy in the patellar tendon. While imaging may assist in differential diagnosis, the diagnosis of patellar tendinopathy remains clinical, as asymptomatic tendon pathology may exist in people who have pain from other anterior knee sources. A thorough examination is required to diagnose patellar tendinopathy and contributing factors. Management of patellar tendinopathy should focus on progressively developing load tolerance of the tendon, the musculoskeletal unit, and the kinetic

chain, as well as addressing key biomechanical and other risk factors. Rehabilitation can be slow and sometimes frustrating. This review aims to assist clinicians with key concepts related to examination, diagnosis, and management of patellar tendinopathy. Difficult clinical presentations (eg, highly irritable tendon, systemic comorbidities) as well as common pitfalls, such as unrealistic rehabilitation time frames and overreliance on passive treatments, are also discussed. *J Orthop Sports Phys Ther* 2015;45(11):887-898. Epub 21 Sep 2015. doi:10.2519/jospt.2015.5987

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¹Musculoskeletal Research Centre, La Trobe University, Bundoora, Australia. ²Centre for Sport and Exercise Medicine, Queen Mary, University of London, UK. ³Australian Centre for Research into Injury in Sport and Its Prevention, Federation University, Ballarat, Australia. ⁴Department of Physical Therapies, Australian Institute of Sport, Canberra, Australia. ⁵Department of Physiotherapy, Faculty of Health, University of Canberra, Canberra, Australia. Dr Cook is supported by the Australian Centre for Research into Injury in Sport and Its Prevention, which is one of the International Research Centres for Prevention of Injury and Protection of Athlete Health supported by the International Olympic Committee. Dr Cook is a National Health and Medical Research Council practitioner fellow (ID 1058493). Mr Purdam and Dr Rio are adjunct researchers at the Australian Centre for Research into Injury in Sport and Its Prevention. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Peter Malliaras, Musculoskeletal Research Centre, La Trobe University, 249 Auburn Road, Hawthorn 3122 Australia. E-mail: peter@completesportscare.com.au ● Copyright ©2015 *Journal of Orthopaedic & Sports Physical Therapy*®

The purpose of this commentary was to combine available evidence and expert opinion to guide clinicians in key elements of examination, diagnosis, and management of patellar tendinopathy, including advice for difficult presentations.

Examination of Patellar Tendinopathy

The first clinical challenge is to establish whether the tendon is the source of the patient's symptoms. Patellar tendinopathy, as one of many potential diagnoses producing anterior knee pain, has specific and defining hallmark clinical features^{32,55} that consist of (1) pain localized to the inferior pole of the patella¹¹ and (2) load-related pain that increases with the demand on the knee extensors, notably in activities that store and release energy in the patellar tendon.^{57,77} Other signs and symptoms, such as pain with prolonged sitting, squatting, and stairs, may be present but are also features of patellofemoral pain (PFP) and potentially other pathologies. Tendon pain occurs instantly with loading and usually ceases almost immediately when the load is removed.⁷⁵ Pain is rarely experienced in a resting state.⁷⁵ Pain may improve with repeated loading (the "warm-up" phenomenon),^{55,75} but there is often increased pain the day after energy-storage activities.⁷⁵ Clinically, it is noted that dose-dependent pain is a key feature, and assessment should demonstrate that the pain increases as the magnitude or rate of application of the load on the tendon increases.⁵⁵ For example, pain should increase when progressing from a shallow to a deeper squat, and from a smaller to a greater hop height.

Assessing pain irritability is a fundamental part of managing patellar tendinopathy and consists of determining the duration of symptom aggravation (during loading) following energy-storage activities like a training session. Studies have suggested that up to 24 hours of pain provocation after energy-storage activities may be acceptable during rehabilitation,^{54,83} so here we will define "irritable" tendon pain as pain provocation of greater than 24 hours, and "stable"

tendon pain as settling within 24 hours after energy-storage activities. Usually, the aggravation of symptoms manifests as pain during loading activities, such as walking down stairs or when performing a decline squat. Pain level can be rated on an 11-point numeric rating scale, where 0 is no pain and 10 is the worst pain imaginable. The Victorian Institute of Sport Assessment-patella (VISA-P) questionnaire is a validated pain and function outcome measure that can also be used to assess severity of symptoms as well as to monitor outcomes.⁹¹ The VISA-P is a 100-point scale, with higher scores representing better function and less pain. The minimum clinically important difference is a change of 13 points.⁴⁷ In the authors' experience, as progress with patellar tendinopathy is slow and the VISA-P is not sensitive to very small changes in the condition, the VISA-P should be used at intervals of 4 weeks or more.

A thorough examination of the entire lower extremity is necessary to identify relevant deficits at the hip, knee, and ankle/foot region. Atrophy or reduced strength in antigravity muscles, including the gluteus maximus,⁵⁵ quadriceps,²² and calf,⁵⁵ is often observed by the authors, and can be objectively assessed with clinical tests: repeated bridging or single-leg squat, resisted knee extension, and repeated calf raises.^{46,55} Foot posture/alignment,^{22,24} quadriceps and hamstring flexibility,⁹⁵ as well as weight-bearing ankle dorsiflexion range of motion^{4,62} have been associated with patellar tendinopathy and should also be assessed.

Deficits in energy-storage activities can be assessed clinically by observing jumping and hopping. There is evidence that a stiff-knee vertical jump-landing strategy (reduced knee flexion at peak vertical ground reaction force) may be used by individuals with a past history of patellar tendinopathy.⁹ A stiff-knee strategy and then going into hip extension rather than flexion during a horizontal jump landing have also been observed among participants with asymptomatic patellar tendon

pathology.²⁹ A systematic review examining landing strategies in 3 groups (controls, those with asymptomatic pathology, and those with symptomatic patellar tendinopathy) reported no differences between the controls and those with symptomatic patellar tendinopathy.⁸⁹ However, the data from the meta-analysis only included 6 symptomatic athletes. The clinical experience of the present authors suggests that athletes with patellar tendon pain tend to reduce the amount of knee flexion and appear stiff in their landing. Regardless of the individual strategy, it is optimal to try to distribute load through the entire kinetic chain, and the purpose of evaluating function (including hopping and landing) is to identify deficits that need to be addressed as part of rehabilitation.

Patellar tendon imaging does not confirm patellar tendon pain, as pathology observed via ultrasound imaging may be present in asymptomatic individuals.⁶¹ Accordingly, serial imaging is not recommended, as symptoms often improve without corresponding changes in pathology on ultrasound imaging or magnetic resonance imaging (MRI).^{27,60} However, imaging can be helpful to include or exclude potential alternate diagnoses of anterior knee pain when the clinical picture is unclear.¹⁴

Differential Diagnosis

Aside from the inferior pole of the patella, tendinopathy of the extensor mechanism of the knee can occur at the quadriceps tendon or distal insertion of the patellar tendon at the tibial tuberosity. These less common clinical presentations also have unique features. Quadriceps tendinopathy is characterized by pain localized to the quadriceps tendon³² and, in the authors' experience, is often associated with movements requiring deep knee flexion, such as those performed by volleyballers and weight lifters.⁷² Distal patellar tendon pain, often seen in distance runners, is localized near the tibial tuberosity.^{32,78} The infrapatellar bursa is an intimate part of the distal patellar tendon at-

tachment,⁸ and irritation of the bursa often coexists with distal patellar tendinopathy. Mid- or whole-tendon patellar tendinopathy is generally the result of a direct blow⁴²; however, careful differential diagnosis is required, as other structures, such as the bursae, fat pad, and patellofemoral joint, can also be injured with this mechanism. Although these less common clinical presentations have different features and management subtleties, the progressive-loading principles described below equally apply (though the exercises may require modification).

Pain is typically more variable in nature and location when structures close to the patellar tendon, as opposed to the tendon itself, are the source of pain. The contribution of Hoffa's fat pad to anterior knee pain is poorly understood. But the fat pad is known to be active in cytokine production,⁸⁷ to have vascular connections to the patellar tendon,⁶⁷ and to have fascial connections with the patellofemoral and tibiofemoral ligaments and patellar tendon.¹⁵ Fat-pad injury may be associated with a tibiofemoral hyperextension incident,²⁶ but insidious onset of fat pad-related pain is also common, often associated with repetitive end-range knee extension,²⁶ as commonly performed in some populations (eg, young gymnasts). Infrapatellar fat-pad hypertrophy has been described in association with patellar tendinopathy.²³ The main differentiator from patellar tendinopathy is the site of pain: fat-pad pain is not localized to the inferior pole but is a more diffuse pain located in the anterior inferior knee region. The pain is especially felt during end-range extension or with digital pressure applied directly to the fat pad (Hoffa test).^{26,64}

The patellofemoral joint may also be the cause of anterior knee pain among jumping athletes. Patellofemoral-related pain is generally located diffusely around the patella on pain mapping,⁶⁸ compared with the typically localized inferior pole of the patella in patellar tendinopathy. Patellofemoral pain has been suggested to be primarily a diagnosis of exclusion,

as there are no clear sensitive and specific clinical tests to help in the diagnosis.^{66,96} Athletes with PFP often report aggravation of symptoms with activities that create low tendon load, such as walking, running, or cycling,¹³ which should result in a high index of suspicion for a diagnosis other than patellar tendinopathy. Reduction of pain, when using patellofemoral taping, with provocative maneuvers, such as performing a lunge or a squat, may assist in confirmation of PFP.⁶⁶ Patellofemoral joint mobility examination may also be helpful in the differential diagnosis. In our clinical experience, patellar tendinopathy and PFP rarely coexist, and the clinical assessment (not tendon imaging) should guide management.

Plica injuries⁷⁹ and chondral surface pathology may also produce anterior knee pain. Palpation of the plica, a history of snapping sensation, and MRI often assist in the diagnosis of a plica as being the source of pain. Pathology of the superior plica may be confused with quadriceps tendinopathy both clinically and radiologically. Clinically, plica may be painful with activities requiring only shallow knee flexion (eg, walking), whereas pain from quadriceps tendinopathy is provoked with activities requiring deep knee flexion. On MRI, whereas quadriceps tendinopathy may appear as diffuse thickening and increased signal of the distal quadriceps tendon at its insertion,⁸⁶ a clearly delineated lesion deep to the quadriceps tendon raises a high index of suspicion for the superior plica involvement.^{43,79} The clinical presentation of localized osteochondral lesions of the inferior region of the patella or of the trochlea may sometimes closely mimic patellar tendinopathy. Clinically, joint effusion is generally an indicator of intra-articular injury and does not occur with either patellar or quadriceps tendinopathy.

The age of the patient must also be considered in the differential diagnosis process. Both patellar tendinopathy and isolated fat-pad irritation are common in adolescents.¹³ Adding to the challenge of diagnosis in this age group, excessive



FIGURE 1. Single-leg decline squat performed with an upright torso, to 90° of knee flexion or maximum angle allowed by pain.

stresses applied to developing growth plates may result in Osgood-Schlatter syndrome at the tibial tuberosity (common) or Sinding-Larsen-Johansson syndrome at the inferior pole of the patella (rare),⁴⁴ both potential causes of anterior knee pain. People of any age are also vulnerable to systemic and sinister causes of knee pain and other symptoms (eg, tumor, infection), and these instances of nonmechanical pain presentations should be referred appropriately.¹³

Management of Patellar Tendinopathy

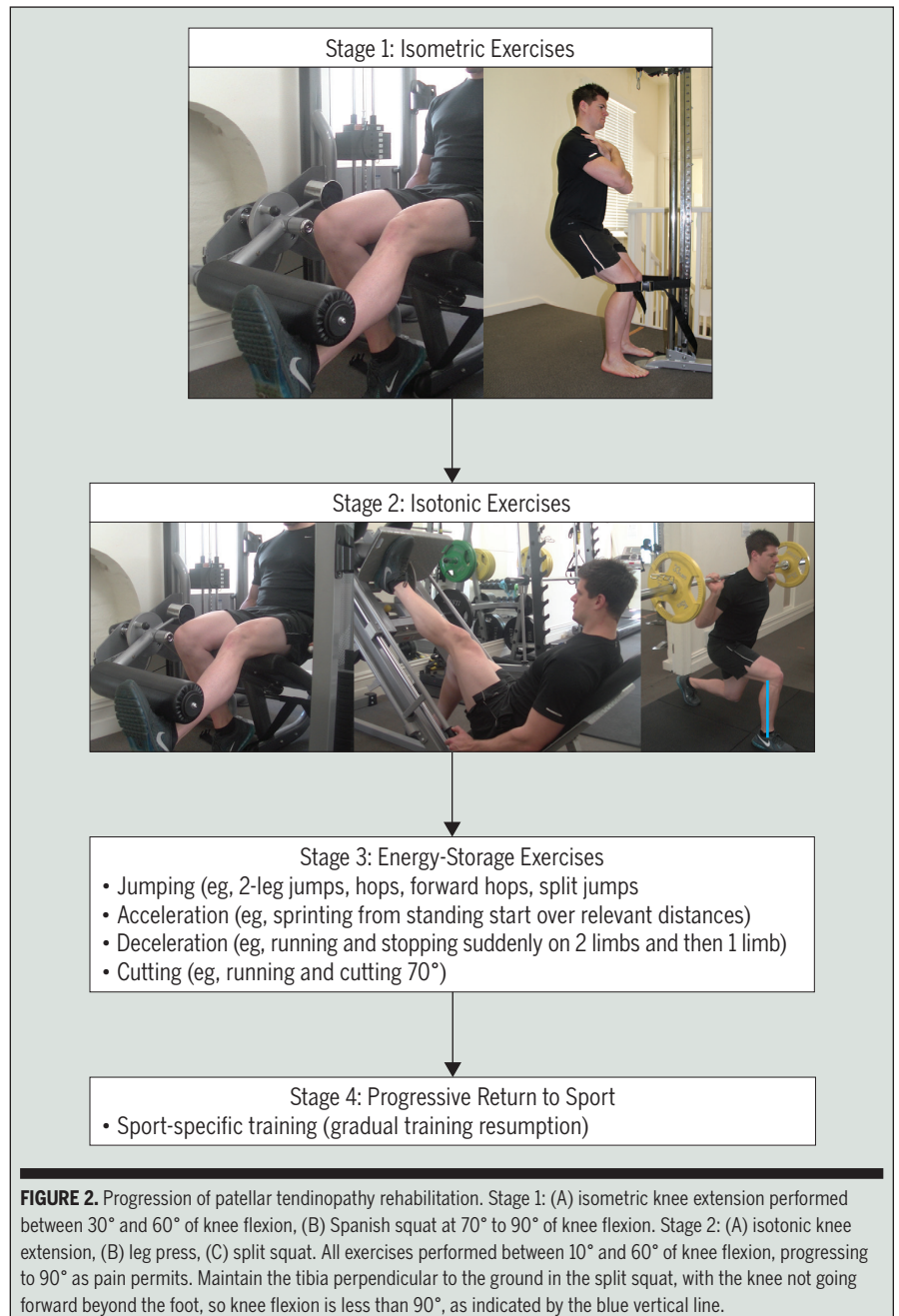
The most investigated intervention for patellar tendinopathy is exercise, especially eccentric exercise.⁶⁰ For example, the decline squat program involves performing 3 sets of 15 repetitions, twice daily, of single-leg eccentric squats, with an upright torso, while standing on a decline board (FIGURE 1).^{50,71,97} The concentric phase of the squat is performed either using both lower extremities or the unaffected side only. This program was developed to concentrate load on the patellar tendon.^{71,98} However, eccentric

[CLINICAL COMMENTARY]

exercise for the treatment of patellar tendinopathy may be too aggressive for patients with a high level of irritability, particularly during the sports season.^{34,93} Eccentric exercise, if used in isolation, as is often described in the literature, also fails to address specific impairments that may exist throughout the kinetic chain, such as calf weakness.

Despite the widespread clinical use of eccentric exercise for the treatment of patellar tendinopathy,^{35,92} there are limited high-quality data that demonstrate positive clinical outcomes of this approach.⁶⁰ Kongsgaard et al⁵⁴ performed a randomized clinical trial comparing heavy slow resistance (HSR) exercise and the decline squat program. The HSR program consisted of concentric/eccentric squats, hack squats, and leg presses, using both lower extremities. For each exercise, 3 to 4 sets were performed, progressing from an initial load based on 15 repetition maximum (15RM) to 6RM. Pain and functional outcomes on the VISA-P were similar at 6 months, but patient satisfaction of those using the HSR program was significantly greater (70%) than patient satisfaction of those using the decline squat program (22%). The authors of a recent systematic review determined that there was limited evidence supporting the decline squat program and moderate evidence supporting the HSR program.⁶⁰ Based on the current evidence and their own clinical experience, the authors of this commentary favor the use of an HSR-style program over the decline squat program for the management of patellar tendinopathy.

A 4-stage rehabilitation progression for patellar tendinopathy is proposed, based on the available evidence and the authors' opinion. The focus is on developing load tolerance of the tendon itself, the musculoskeletal unit, and the kinetic chain. Key rehabilitation exercises in each stage are outlined (FIGURE 2). Progression criteria are individualized, based on pain, strength, and function (TABLE).



First, loading modification is used with the goal of reducing pain. This involves initially reducing high-load energy-storage activities that may be aggravating the pain. Volume and frequency (number of days per week they are performed) of the highest-intensity activities, such as maximal jumping, may need to be reduced in consultation with both the athlete and coach. Both load

modification and eventual progressive loading are based on careful pain monitoring. Some pain is acceptable during and after exercise, but symptoms should resolve reasonably quickly after exercise and should not progressively worsen over the course of the loading program, as monitored by the 24-hour response.⁵⁴

The authors measure pain response using a pain-provocation test, such as

TABLE

REHABILITATION STAGES
AND PROGRESSION CRITERIA

Stage	Indication to Initiate	Dosage
1. Isometric loading	More than minimal pain during isotonic exercise*	5 repetitions of 45 seconds, 2 to 3 times per day; progress to 70% maximal voluntary contraction as pain allows
2. Isotonic loading	Minimal pain during isotonic exercise*	3 to 4 sets at a load of 15RM, progressing to a load of 6RM, every second day; fatiguing load
3. Energy-storage loading	A. Adequate strength [†] and consistent with other side B. Load tolerance with initial-level energy-storage exercise (ie, minimal pain during exercise and pain on load tests returning to baseline within 24 h)*	Progressively develop volume and then intensity of relevant energy-storage exercise to replicate demands of sport
4. Return to sport	Load tolerance to energy-storage exercise progression that replicates demands of training	Progressively add training drills, then competition, when tolerant to full training

Abbreviation: RM, repetition maximum.

*Minimal pain defined as 3/10 or less.

[†]For example, around 150% body weight (4 × 8) for most jumping athletes.

the single-leg decline squat⁷⁰ (FIGURE 1), which is performed with an upright torso to 90° of knee flexion or maximum angle allowed by pain, as rated on a numeric rating scale at maximum knee flexion angle. The test is administered daily, at the same time of day, throughout the entire rehabilitation process. As tendon pain is intimately linked with load, the authors describe the response to the test as “load tolerance.” If the pain score on the load test (eg, 1 repetition of the single-leg decline squat test at the same depth) has returned to baseline within 24 hours of the activity or rehabilitation session, the load has been tolerated. If the pain is worse, load tolerance has been exceeded. It is the authors’ opinion that pain assessment based on a standard load test for each individual is more important than a pain rating during exercise to determine the progression of loading through the course of the rehabilitation. Some authors have suggested that a pain level of up to 3 to 5 on a 0-to-10 numeric rating scale (0 is no pain and 10 is the worst pain imaginable) during exercise is acceptable.^{54,83} A pain rating of 3/10 or less is defined as acceptable and “minimal”

pain in this article, but this should only be used as a guide, and it is reiterated that in our opinion, greater emphasis should be placed on the 24-hour pain response to a predefined load test.

Stage 1: Isometric Loading Five repetitions of 45-second isometric mid-range quadriceps exercise at 70% of maximal voluntary contraction have been shown to reduce patellar tendon pain for 45 minutes after exercise, a response associated with a reduction in motor cortex inhibition of the quadriceps, which is associated with patellar tendinopathy.⁷⁴ Isometric exercises are indicated to reduce and manage tendon pain and initiate loading of the muscle-tendon unit when pain limits the ability to perform isotonic exercises.¹⁸ Isometrics, using a knee extension machine (FIGURE 2), are ideal for patellar tendinopathy, as they isolate the quadriceps. In our experience, performing the isometric exercises in mid-range knee flexion (around 30°-60° of flexion) is more comfortable, as people with patellar tendinopathy often have pain when performing these with the knee near full extension (possibly due to impingement of the fat pad) or with

greater knee flexion. Resistance should be increased as quickly as tolerated and the exercise should be performed on a single leg if possible. An alternative is the Spanish squat⁶ (FIGURE 2), which is a double-leg squat performed at an angle of approximately 70° to 90° of knee flexion (a deeper angle is generally tolerated for a double-leg exercise) with the assistance of a rigid strap fixating the lower legs. This option can be useful, especially when there is limited or no access to gym equipment (eg, the traveling athlete).

The exercise dosage depends on individual factors, but evidence and clinical experience indicate 5 repetitions of a 45-second hold, 2 to 3 times per day,^{18,74} with 2 minutes of rest between holds to allow recovery. A 70% maximal voluntary contraction load, which has been associated with reduced pain,⁷⁴ can be estimated clinically on a knee-extension machine by selecting the resistance that can be held for 45 seconds. The key is to progress the load based on tolerance and, as discussed earlier, regular reassessment of pain response with load tests. The authors have found that too little resistance (eg, isometric knee extension as when performing quad sets or the use of an elastic band to provide an isometric resistance and holding at a set deformation of the band) or progressing the load too quickly and beyond load tolerance are not effective. A good prognostic sign for isometrics is an immediate reduction in pain with loading tests (eg, a single-leg decline squat test) after isometric exercise. It is important that there be no muscle fasciculation during the isometric exercises, as this may be perceived to indicate that the load is too high. In stage 1, isometric exercises should be used in isolation (ie, without isotonic loading). This stage may last a few weeks (sometimes longer) when managing individuals with a high level of pain irritability. Other exercises, such as heel raises, to address other strength or flexibility deficits throughout the lower extremity can also be initiated during this initial phase.

The patient response to heavy isometric exercises during this stage may further assist with confirming the diagnosis. While people with patellar tendinopathy report decreased pain both during and immediately following knee extension isometric holds, individuals with other sources of anterior knee pain (eg, patellofemoral joint) may feel worse using heavy knee extension exercises (or the Spanish squat), potentially due to high patellofemoral joint reaction forces.⁸⁵

Stage 2: Isotonic Loading Loaded isotonic exercise is initiated when it can be performed with minimal pain (3/10 or less on a numeric pain-rating scale). A positive response to regular reassessment of pain with load tests continues to be important. Isotonic load is important to restore muscle bulk and strength through functional ranges of movement. Based on clinical experience, the HSR program discussed earlier can be adapted to suit the individual and maximize patient outcomes. Initially, knee flexion during both non-weight-bearing and weight-bearing exercises should be limited to between 10° and 60° of knee flexion or less, depending on pain, then progressed toward 90° of flexion or further, as pain permits and based on the sport demands. The authors have found that flexion beyond 90° and full knee extension can be provocative in the early stage of performing isotonic exercises; that is why due caution is warranted initially.

Exercises from the HSR program include leg presses, squats, and hack squats. However, a common pitfall is including only double-leg, multijoint exercises (eg, double-leg squats) that may not address quadriceps strength asymmetry if the athlete spares (protects) the affected side. The authors prefer exercises that can be progressed easily to single-leg loading, including leg press, split squat, and seated knee extension (leg extension machine) (FIGURE 2). Leg press and seated knee extension can be commenced initially and split squats added when technique and capacity under load are adequate. As in stage 1, the seated knee extension ma-

chine is useful to isolate the action of the quadriceps. The same HSR program dosage as used by Kongsgaard et al⁵⁴ in their clinical trial is recommended: 3 to 4 sets at a resistance corresponding to 15RM, progressing to 6RM, performed every second day. It is important to progress to heavier loading (ie, 6RM) as tolerated, as heavy load is associated with tendon adaptation.¹²

Stage 1 exercises should be continued on the “off” days to manage pain within the limits of muscle fatigue and soreness associated with the isotonic loading. Stage 2 exercises should be continued throughout rehabilitation and return to sport.

Stage 3: Energy-Storage Loading Reintroduction of energy-storage loads on the myotendinous unit is critical to increase load tolerance of the tendon and improve power as a progression to return to sport. Initiating this stage is based on the following strength and pain criteria: (1) good strength (eg, ability to perform 4 sets of 8 repetitions of single-leg press with around 150% body weight for most jumping athletes); and (2) good load tolerance with initial energy-storage exercises, defined as minimal pain (3/10 or less on a numeric pain-rating scale) while performing the exercises, and return to baseline pain (if there was an initial increase) during load tests, such as the single-leg decline squat, within 24 hours.

As with the other stages, individualization and clinical reasoning are necessary. In addition, progression should be developed within the context of the loads the individual patient is required to attenuate for their sport and performance level. The following examples, extrapolated from published data, may assist in providing context to tendon loading and force and rate changes with progression to energy-storage exercise. A bilateral leg press (which is not an energy-storage loading exercise) performed with a resistance equal to 3 times body weight (1.5 body weight for each lower extremity) exerts a patellar tendon force equivalent to 5.2 body weight and a loading rate estimated at around 2 body weight per sec-

ond.⁷³ In comparison, during the landing phase of a vertical jump, peak patellar tendon forces have been estimated to be 5.17 ± 0.86 body weight, with a loading rate of 38.06 ± 11.55 body weight per second.⁴⁹ Higher patellar tendon forces are reported in the horizontal landing phase of a stop land/jump sequence, with peak patellar tendon forces of 6.6 ± 1.6 body weight and loading rates up to 93 ± 23 body weight per second.²⁸ This provides an understanding that the major change through these activities is rate of loading of the tendon, which should be progressed gradually through relevant energy-storage activities for the individual athlete.

Choice of exercise will depend on the demands of the individual sport. Thus, the selection and parameters of energy-storage programs may vary greatly among individuals who participate in different sports, as well as among positions in the same sport. Planning for this stage requires close consultation with the athlete and coach to appropriately determine the training frequency, volume, and intensity of the energy-storage exercise, and the type of exercise. Energy-storage exercise options may include jumping and landing, acceleration, deceleration, and cutting/change-of-direction activities, depending on the demands of the sport (FIGURE 2).

The start point of the energy-storage rehabilitation protocol depends on load tolerance and function during the initial energy-storage exercises. For example, a jumping athlete may initially be able to tolerate performing only 3 sets of 8 to 10 low-intensity jumps and landings (eg, jumps with limited jump height and/or landing depth). The volume and intensity (depth and speed of the low-intensity jumps and the split squat jumps) can then be progressed as tolerance increases and depending on individual goals. Eventually, higher-intensity loads/exercises can be added in an attempt to simulate sport-specific training volume and intensity (eg, single-leg hops, forward hops, deeper split squat jumps,

and sport-specific jumps such as volleyball block and spike jumps). This process can take several weeks to months for some athletes (eg, for volleyball players to build up to the 300 landings typically performed in a single training session).⁵ For athletes who do not require significant volumes of jumping and landing in their sport (sprinters, rugby players), a similar progression targeting acceleration, deceleration, and/or cutting/change-of-direction maneuvers may be emphasized (FIGURE 2). Clearly, many athletes (basketball players, for example) may require a combination of jumping/landing and acceleration, deceleration, and cutting abilities.

Accurate quantification of load is important at this stage. In jumping sports, the number and intensity of jumps and all other energy-storage activities should be considered to ensure that loads are progressively applied to meet the ultimate demands of the sport. For example, a high jumper may progress through double- to single-limb small vertical jumps and hops, to horizontal bounding (eg, 4-6 times, 8-12 contacts), 2-legged hurdle jumps up to 1 m high (eg, 3 times, 8 contacts), scissor jumps over the bar from 5-step run-up (8-10 contacts), then flop jump from 5-step run-up (8-10 contacts), and finally to a full run-up flop jump (8-10 contacts). In essence, the volume (ie, number of contacts or jumps) is progressed before the intensity (jump height and speed) for each exercise to approach the optimal training intensity and energy-storage exercise demands of the sport.

The introduction of energy-storage exercises is often the most provocative stage, so loading is performed every third day initially, based on a 72-hour collagen response to high tendon loading, as described by Langberg et al.⁵⁶ Progressions are guided by pain experienced in the decline squat 24 hours after exercise, as described earlier. Stage 1 isometric loads can be used in combination to manage stable pain following energy-storage exercise; however, increased pain in the

load response test the day after a stage 3 training session indicates that load tolerance has been exceeded (irritable pain) and loading should be adjusted accordingly (eg, regress to the previous level of training, or further, to restore load tolerance on load tests again). In some instances, pain may increase for days after an energy-storage progression that was not gradual enough. Therefore, it may be necessary to regress to solely isometrics for several days until pain is settled. Stage 3 exercises can then be reintroduced with modification of the progression that was considered to be provocative. The authors have found that performing isometric loading (stage 1, low tendon load) and then isotonic loading (stage 2, medium tendon load) on subsequent days provides a 3-day, high-low-medium load cycle (with 1 rest day per week) that is generally well tolerated. Some athletes feel worse the day after a rest day, requiring a program that loads the tendon every day, most likely with isometric exercises.

Stage 4: Return to Sport Progression back to sport-specific training can be commenced when the individual has completed energy-storage progressions that replicate the demands of his or her sport in regard to the volume and intensity of relevant energy-storage functions. At that time, stage 3 exercises are replaced by a graded return to training and eventually competition. In the early phases, training should match the volume and intensity of final progression of stage 3 energy-storage exercises, gradually replacing stage 3 activities with a volume and intensity similar to those of training drills to replicate the participation and fitness demands of the sport. Return to sport is recommenced when full training is tolerated without symptom provocation (24-hour response on load test, such as the single-leg decline squat) and any existing power deficits have been resolved. The authors often use the triple hop test for distance⁴⁵ or maximal vertical hop height for that purpose.

Ideally, sports loads (competition and training) should be performed every 3

days, as with the stage 3 exercises, but this can vary depending on symptom response and demands of individual sports/teams. Our recommendation would be no more than 3 high-intensity training or competition sessions that involve energy-storage exercises within a week in the recovering tendon, which in elite sport is maintained as a principle for the first year of return.

Maintenance Exercise

As a maintenance program once athletes have returned to sport, stage 2 strengthening exercises are performed at least twice per week, preferably using loaded and single-leg exercises (eg, split squats, seated knee extension, leg press). Stage 1 isometric exercises can be continued and performed intermittently (eg, prior to or after training) for their immediate effect on pain. Athletes should also continue addressing other relevant flexibility and strength deficits identified throughout the lower extremity, such as gluteal or calf-strengthening exercises.

Common Management Pitfalls

Rehabilitation of patellar tendinopathy can be a slow and frustrating process, both for the athlete and clinician. There are multiple potential management pitfalls in the rehabilitation stages outlined, including failure to gain control of pain, normalize muscle capacity, effectively progress energy-storage exercises, and effectively progress return-to-sport training volume and intensity. More specific pitfalls will be outlined in this section, including unrealistic rehabilitation time frames, inaccurate beliefs and expectations about pain, failure to identify central sensitization, overreliance on passive treatments, not addressing isolated muscle deficits, failure to address kinetic-chain deficits, and not adequately addressing biomechanics.

Unrealistic Rehabilitation Time Frames The temptation or pressure to shorten rehabilitation time is understandable given athletes' eagerness to return to sport and the demands of

competing in elite sport. In the authors' experience, progression of rehabilitation is related to symptom response to load (load tolerance) and neuromuscular function, both of which also determine capacity to return to play. Progression can be slow, sometimes taking 6 months or longer. Bahr and Bahr⁵ investigated long-term outcome after eccentric training to manage patellar tendinopathy and determined that only 46% (6/13) of athletes had returned to full training and were pain free at 12 months. In the authors' experience, poor baseline neuromuscular function, muscle atrophy, pain irritability, as well as multiple prior intratendinous interventions (eg, platelet-rich plasma or other injections) appear to be associated with longer rehabilitation times. It is important to educate patients and other stakeholders (parents, coaches) about realistic time frames. All stakeholders should be involved in setting short- and long-term goals, based on strength and functional targets (eg, a leg-press strength of 8RM on the affected side and equal performance on the triple hop for distance are commonly used in elite athletes by the present authors), as these serve to motivate athletes, monitor progress, and provide objective measures for progression.

Inaccurate Beliefs and Expectations About Pain Beliefs about pain and pathology may influence the development and management of unresponsive symptoms.^{7,65} Some athletes may have been told that "tears" and "degeneration" have caused permanent tendon "weakening," increasing the risk of rupture. Patellar tendon rupture (in the absence of systemic disease) in sport is rare.⁵⁹ Some athletes may develop fear-avoidance behavior, which has been associated with poorer functional outcomes in individuals with lower-limb tendinopathy.⁸² Education about pain and realistic time frames for rehabilitation are important. This includes education regarding the potential link between psychosocial factors and pain. Athletes need to be aware that pain is not

necessarily equal to harm, and some pain during rehabilitation is acceptable. It is important to educate patients regarding the concept of load tolerance as defined in this article, so that they are eventually able to self-manage based on symptom response to load.

Failure to Identify Central Sensitization There is evidence of sensory and motor changes in lateral elbow tendinopathy that suggests central sensitization, including secondary hyperalgesia and reduced reaction times.^{10,20,31} There is a paucity of literature on this issue, with only 1 study demonstrating reduced mechanical pain threshold in individuals with patellar tendinopathy.⁹⁰ Despite the lack of supporting literature, the authors have occasionally encountered typical central sensitization features in patients with patellar tendinopathy, often associated with multiple failed injections and/or surgery. Careful pain mapping may identify diffuse sensitivity to manual palpation and more diffuse rather than localized pain on tendon loading. These individuals often have a long history of pain that is not aggravated by the typical jumping, change-of-direction, and other energy-storage loads that are a clear feature of patellar tendinopathy, suggesting that their pain is no longer related to a tendinopathic process. Our experience is that these patients are less likely to respond to an isolated tendon rehabilitation approach.

Overreliance on Passive Treatments Common passive or adjunct interventions include manual therapy, such as transverse frictions, electrotherapy (eg, ultrasound), shockwave therapy, and injections (sclerosing, steroid, platelet-rich plasma). Given that exercise is the most evidence-based intervention,³⁹ the authors recommend against using only passive interventions in the management of patellar tendinopathy.³⁵ While there may be useful adjuncts for pain management to enable rehabilitation progression, using passive interventions as a substitute for exercise is less than op-

timal, given that passive strategies have not been shown to normalize tendon matrix or muscle tissue or to address other deficits throughout the lower extremity.³⁹ The use of passive interventions may lead to reliance on the therapist to deliver a cure, which is misleading. Friction massage has been shown to be less effective than exercise as a stand-alone intervention.⁸⁴ While there is limited evidence that shockwave may offer a benefit equivalent to that of exercise,^{36,94} the exercise programs utilized in these comparative studies were either poorly described or not best practice. There is no high-quality evidence (from randomized trials) to support the stand-alone use of other passive interventions to effectively manage patellar tendinopathy.³⁹

In the authors' experience, multiple tendon injections can lead to poorer long-term outcomes, perhaps secondary to protracted unloading of the tendon and lower extremity. Kongsgaard et al⁵⁴ reported that steroid injection used in isolation was associated with a poorer outcome at 6 months compared with exercise. It must be emphasized that there are few high-quality studies on injection therapies to date,⁸⁸ and injections are often offered when rehabilitation has been inadequate.⁸⁰ The key strategy for avoiding multiple passive interventions is setting realistic goals based on a sound understanding of the condition and its rehabilitation. Despite potential pitfalls and limited evidence, judicious use of passive interventions may still be occasionally indicated, but only as an adjunct to exercise, especially in difficult presentations that will be discussed below.

Not Addressing Isolated Muscle Deficits Rio et al⁷⁴ found that patellar tendinopathy was associated with substantial motor cortex inhibition of the quadriceps, which may explain persistent muscle atrophy with longstanding patellar tendinopathy. Altered neuromuscular output is likely to be a response to pain, but may persist even after symptoms have resolved.⁴⁸

Compound (bilateral and involving other muscle groups) rehabilitation exercises, such as double-leg squatting, lunging, and gym-based exercise such as the leg press, may not adequately address quadriceps atrophy if compensatory strategies spare the very muscle group targeted. A clinical indicator of compensatory strategy is fatigue in the gluteals rather than quadriceps during compound exercises such as the leg press. Seated knee extension, using moderate resistance, is an ideal exercise option because it can specifically load the quadriceps³ and, when performed isometrically, has demonstrated reversibility of quadriceps inhibition immediately following the exercise bout.⁷⁴

Failure to Address Kinetic-Chain Deficits In rehabilitation, there is a temptation to focus on the injured site, in this case the patellar tendon. Addressing other potentially contributing factors present throughout the lower extremity is essential for successful resumption of sporting activity. As discussed in the assessment section, lack of hamstring and quadriceps flexibility,⁹⁵ as well as restricted ankle dorsiflexion^{4,62} range of motion and decreased calf and hip extensor function, may be associated with patellar tendinopathy, and addressing these deficits should be part of its comprehensive rehabilitation.⁵⁵ A truly comprehensive approach should also consider deficits of the trunk musculature as well as the contralateral lower extremity.

Not Adequately Addressing Biomechanics Athletes with patellar tendinopathy may require progressive jump-land retraining. The strategies of landing with a stiff knee^{9,29,89} and moving into hip extension rather than hip flexion (in a horizontal jump)²⁹ have been associated with higher patellar tendon injury. Landing kinematics can be retrained, focusing on soft landings on the forefoot-midfoot region, with greater ankle, knee, and hip range of motion,⁶⁹ to reduce the magnitude of peak vertical ground reaction forces and peak loading rates.²⁵

Landing retraining can be progressed from double- to single-leg landings. Importantly, changes to jump-landing mechanics should not be attempted prior to adequate rehabilitation (ie, meeting criteria to progress to stage 3 energy-storage exercise). Pain and weakness are commonly the cause of changes in landing strategies and should be addressed first.

Difficult Patient Presentations

This section is based on the authors' experience and provides management guidance for difficult presentations, including athletes with highly irritable tendons, athletes with systemic comorbidities, in-season athletes, deconditioned athletes, and young jumping athletes.

Highly Irritable Tendons A highly irritable tendon is defined as the clinical situation in which pain is significantly and sometimes dramatically increased for several days or weeks after even subtle progressions of energy-storage load. The patellar tendon that is highly irritable may require the use of bilateral loading exercises early in the rehabilitation process; however, progression to single-leg isometric loading with resistance should remain a short-term aim, guided by load-tolerance assessment, particularly the 24-hour response to load. Selected adjunct interventions, which may include nonsteroidal anti-inflammatory drugs or corticosteroids (taken orally or with a peritendinous injection)¹⁸ in difficult cases, can be very useful in reducing symptoms to allow load progression within a controlled rehabilitation program. The authors have observed that intratendinous injections, such as platelet-rich plasma, administered to the highly irritable tendon are more likely to have a negative effect, potentially due in part to the needle passing through richly innervated peritendon.⁹²

Systemic Comorbidities The etiology of patellar tendinopathy is multifactorial, including both load-related and systemic drivers.^{37,38,40,41,63} Systemic pathological drivers associated with tendinopathy include increased central adiposity,

even in the young, active population.⁶³ Although uncommon, symptomatic patellar tendinopathy may be associated with metabolic, autoimmune, or connective tissue disease (eg, diabetes, psoriatic arthritis).¹ Symptoms are often bilateral, and a high level of irritability may be present. Clinicians should perform adequate screening to rule out systemic comorbidities as contributing factors to patellar tendinopathy, particularly when it is difficult to attribute significant load history to the onset of pain. The principles of management for tendinopathy in the presence of a systemic driver are as described for the irritable tendon, but may require a referral for proper medical management.

In-season Athletes In-season athletes with patellar tendinopathy can be difficult to manage,¹⁸ primarily because energy-storage loading may be difficult to modify sufficiently to allow symptoms to settle. A key requirement is to address underlying muscle strength deficiencies within the overall sports training environment while persistent symptoms continue to restrict training and competition. There is evidence that using the decline squat program during the season, among jumping athletes, does not improve symptoms,⁹³ and may actually increase the risk of developing pain among athletes with asymptomatic pathology of the tendon as seen on imaging.³⁴ The authors have found that isometric exercises (eg, seated knee extension, Spanish squat holds) are most effective at managing pain and can be performed several times daily, as described under stage 1 of the rehabilitation process. This should be coupled with load management by reducing or removing training drills that involve high-intensity energy storage (eg, landing or change of direction), and intrinsic unloading through better distribution of energy absorption across the joints of the lower extremity (kinetic chain). Anti-inflammatories, the tendon polypill,³⁰ corticosteroid (oral or injectable),⁵⁴ and high-volume injection²¹ may again have an adjunct role, for

example, in the short time leading up to a tournament or toward the end of the season. As discussed above, multiple interventions at the expense of carefully planned and executed rehabilitation are not recommended, and preference should be given to the least provocative and least invasive options.

Deconditioned Athletes The authors have found that athletes who return to training and playing after a period of inactivity are susceptible to developing the symptoms of patellar tendinopathy, particularly athletes with a past history of patellar tendinopathy. This may occur from both brief and longer periods of inactivity due to other minor or more severe injuries, as well as scheduled holidays and the off-season. The primary concern is the resulting deconditioning of the quadriceps muscle, the muscles of the rest of the kinetic chain, and the tendon matrix itself, which require significant training over time to restore. During prolonged absences (of greater than 2 to 3 weeks, although it may be less in some people) from training, specific quadriceps and more general lower-limb strengthening exercises should be performed, along with energy-storage exercises once or twice a week (see return-to-sport section above), particularly for athletes at high risk or with a history of patellar tendinopathy.

Young Jumping Athletes The authors have experienced particular challenges in managing patellar tendinopathy in a subset of young jumping athletes (generally 14 to 17 years of age) who develop highly irritable symptoms. Often, symptom onset coincides with a sharp increase in training volume, such as starting to play for multiple sports teams. The talented young athlete is often highly committed, both in terms of training and playing, not uncommonly across more than 1 sport and/or more than 1 team. The cornerstone of management of these young athletes includes adequate load management and progressive rehabilitation as described above, followed by sensible and progressive return-to-training loads.

CONCLUSION

PATELLAR TENDINOPATHY CAN frequently be difficult to manage. This review highlights key clinical aspects in diagnosis, examination, and management. The cornerstone of patellar tendon management and rehabilitation remains a highly specific and thorough approach to progressive loading of the lower extremity (kinetic chain), muscle-tendon unit, and tendon itself. In this commentary, we propose a 4-stage rehabilitation program based on available evidence and expert opinion that can assist the clinician in guiding athletes back to sport effectively. These stages can be modified for difficult presentations to optimize management outcomes. ●

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