Immediate and Short-Term Effects of Short- and Long-Duration Isometric Contractions in Patellar Tendinopathy

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Abstract

Objectives: Isometric muscle contractions are used in the management of patellar tendinopathy to manage pain and improve function. Little is known about whether long- or short-duration contractions are optimal to improve pain. This study examined the immediate and short-term (4 weeks) effects of long- and short-duration isometric contraction on patellar tendon pain, and tendon adaptation. **Design:** Repeated measures within groups. **Setting:** Clinical primary care. **Patients:** Participants (n = 16, males) with patellar tendinopathy. **Intervention:** Short-duration (24 sets of 10 seconds) or long-duration (6 sets of 40 seconds) isometric knee extension loading (85% maximal voluntary contraction), for 4 weeks. **Main Outcome Measure:** Immediate change in pain with single-leg decline squat (SLDS) and hop, as well as change in pain and tendon adaptation [within-session anterior–posterior (AP) strain] were assessed over 4 weeks. **Results:** Pain was significantly reduced after isometric loading on both SLDS ($P < 0.01$) and hop tests ($P < 0.01$). Pain and quadriceps function improved over the 4 weeks ($P < 0.05$). There was significant AP strain at each measurement occasion ($P < 0.01$). Although transverse strain increased across the training period from ~14% to 22%, this was not significant ($P = 0.08$). **Conclusions:** This is the first study to show that short-duration isometric contractions are as effective as longer duration contractions for relieving patellar tendon pain when total time under tension is equalized. This finding provides clinicians with greater options in prescription of isometric loading and may be particularly useful among patients who do not tolerate longer duration contractions. The trend for tendon adaptation over the short 4-week study period warrants further investigation.

Key Words: patellar tendinopathy, isometric loading, rehabilitation, ultrasound, biomechanics, transverse strain

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INTRODUCTION

Patellar tendinopathy is characterized by localized pain and pathology at the inferior pole of the patella that is common among jumping athletes, often impairing performance. Isometric exercises may be recommended in the management of patellar tendinopathy pain among athletes,[1] especially when isotonic exercises are too painful.[2] Longer duration isometric contractions (45 seconds) of high intensity (70% maximal voluntary contraction [MVC]) are commonly used as preliminary evidence suggests that they offer a greater immediate pain reduction in patellar tendinopathy than isotonic loading.[3]

Characteristic pathology changes including an increase in glycosaminoglycan content, can result in reductions in fluid exchange through reduced tissue fluid permeability, and possibly reduced free water content.[4,5] In support of this, reduced tendon thickness immediately following a loading protocol ("transverse strain" related to fluid exchange) has been shown to occur in healthy tendons after loading, but the response is blunted in tendinopathic tendons.[6,7]

No previous study has compared the effects of long- and short-duration isometric loading on clinical outcomes (pain) and tendon adaptation (transverse strain) during the initial phase of rehabilitation for patellar tendinopathy. The aims of this study were; (1) to investigate the immediate effects of long- and short-duration isometric loading on pain and tendon adaptation (transverse strain) in patellar tendinopathy; and (2) to investigate the effects of long- and short-duration isometric loading on tendon adaptation in the initial phase (first 4 weeks) of rehabilitation for patellar tendinopathy.

METHODS

Participants

Sixteen males with unilateral or bilateral patellar tendinopathy participated in the study (Table 1 for details). Participants were recruited from State level Volleyball and Basketball leagues, as well as through local advertising and word-of-mouth. Participants were included if they had pain localized to the inferior patella pole that was aggravated by jumping, and

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TABLE 1. Characteristics of the 2 Groups at Baseline

	Short Duration (n = 8)	Long Duration (n = 8)
Age (yrs)	26 (4.4)	30 (4.1)
Height (cm)	184.5 (5.6)	186.8 (7.3)
Weight (kg)	84.5 (9.5)	87.1 (9.4)
Duration of symptoms (yrs)	2.3 (2.0)	3.4 (1.9)
VISA-P	53 (14.5)	58 (12.8)
AP thickness (mm)	5.6 (1.7)	6.1 (1.0)
85% MVC (kg)	38.4 (6.3)	41.0 (5.6)
Bilateral pain	1 (12.5)	2 (25.0)
Right side injured/worst	6 (75.0)	5 (62.5)
Right-leg dominance	7 (87.5)	7 (87.5)
Gym weights	6 (75.0)	6 (75.0)
Manual work	0 (0.0)	1 (12.5)

NB: median (interquartile range) for parametric and frequency (proportion) for discrete data.

had ultrasound imaging confirmed patellar tendon pathology (hypoechoic regions on gray scale ± Doppler signal). Potential participants were excluded if they were not willing to stop jumping/running during the 4-week study period or had had previous patellar tendon surgery or rupture, other diagnoses that could explain their pain (eg, Hoffa's fat pad syndrome), rehabilitation or injections for patellar tendon pain within 3 months, or other lower limb injuries that would prevent them completing rehabilitation tasks. The study was approved by the local Human Ethics Committee, and participants provided informed consent. The study conformed to the principles of the World Medical Associations Declaration of Helsinki.

Isometric Loading Interventions

Participants were randomly allocated in blocks of 6 to 1 of 2 groups: (1) short-duration isometrics (24 sets of 10-second isometric contractions, 20-second rest between repetitions); or (2) long-duration isometrics (6 sets of 40-second isometric contractions, 80-second rest between repetitions). Time under tension (4 minutes) and work to rest ratio (1:2) were equal between groups. Isometric leg extension machine loading was performed with 30° knee flexion (knee extension = 0°). This is usually a tolerable position in patellar tendinopathy. Participants were provided with custom-made plywood cut at 30° to replicate the knee angle for home exercise.

Participants performed the loading program 5 times per week over the 4-week study period. During the rest time for one side, participants were instructed to load the opposite side using an identical protocol. Participants were asked to abstain from activities involving running, hopping, jumping, squatting, or any lower-body weights/strength exercises. They were also asked not to perform an isometric exercise session within 24 hours of their follow-up appointments.

Eighty-Five Percent Maximal Voluntary Contraction

At baseline, week 2, and 4, isometric loading was performed to estimate 85% MVC because tendon adaptation appears to occur with loads >70% MVC.[8] This was estimated on a leg extension machine (Impulse Fitness, Newbridge, Scotland) during an isometric hold at an angle of 30° knee flexion. A laser pointer was attached to the moving arm of the leg extension machine so that when the knee was in 30° (measured with a goniometer), the laser pointer was aimed at a mark on a wall in front of the machine. The affected side or worse side (among bilateral participants) was tested. Participants were required to perform an isometric leg extension hold for 40 seconds at this angle. Immediately after the task, perceived exertion was rated on a Borg scale from 0 to 20.[9] A rating of 17 to 18 was estimated to correspond to 85% MVC. If the rating was lower, the task was repeated with a 5 kg additional load. If the rating was higher or 40 seconds was not reached, the task was repeated with 5 kg less load until 85% MVC for a 40-second isometric contraction was estimated. Participants rested for 2 minutes between trials. For home exercise, participants were asked to exercise with a rating of perceived exertion around 17 to 18/20 or otherwise adjust the load.

Tendon Thickness and Transverse Strain

Transverse strain was defined as the percentage reduction in anterior–posterior (AP) patellar tendon thickness following an isometric loading protocol. Pilot testing revealed that a very short duration protocol (10 repetitions of 4 seconds with 4-second rest between contractions, repeating 6 sets with a 1-minute rest between sets) produced greater immediate transverse strain than the loading interventions described above (ie, repeated 10- or 40-second contractions). This protocol was not used in the intervention because it is a large excursion from current long-duration protocols and may not be clinically practical. This short isometric protocol was used to assess (1) immediate postloading transverse strain; and (2) short-term (comparing baseline with 4 weeks) transverse strain for each loading intervention. The training load used during transverse strain assessment was the 85% MVC estimated load described above. Isometric loading was performed on a leg extension machine in 30° of knee flexion. As described, a laser pointer was used to ensure correct knee angle.

Ultrasound imaging measurements were performed at baseline and after each of the 6 sets of loading, producing 7 measurement occasions in total. Participants were lying supine on a treatment plinth with the knee that was being imaged flexed at 90°. Patellar tendon thickness was measured using an ultrasound machine with a 12 MHz linear array transducer (Mindray M7; Mindray, Shenzhen, China) set at a depth of 3 cm. The proximal thickness of the tendon (10 mm distal to the inferior patellar pole) was measured with the ultrasound probe placed in the sagittal plane. Care was taken to ensure some of the patella (bone) appeared in the recorded image, and the probe was aligned perpendicular to the tendon. Three ultrasound images were recorded at each measurement occasion, and the mean thickness was used in analysis.

Tendon thickness assessment was performed by one of the researchers (S.S.) who was trained by an experienced ultrasonographer and had over 30 hours of training and practice. Intrarater reliability of tendon thickness measures were assessed among a subset of 8 participants. Tendon thickness was measured on 4 occasions for each participant, without any previous tendon loading. There was a 2-minute break between testing during which participants stood up and were then repositioned again on the treatment plinth. Intrarater reliability was estimated using [interclass correlation coefficients (1, 2) = 0.95, 95% CI, 0.87-0.99]. The minimal detectable change was 0.17 mm.

Immediate Pain Response After Isometric Loading

A subsample of 8 participants was included in a randomized cross-over study. Participants performed either the short-duration (24 × 10-second isometric contractions with a 20-second rest between contractions) or long-duration (6 × 40-second isometric contractions with an 80-second rest between contractions) protocol. They performed the second protocol on a separate occasion within 5 to 7 days. Five repetitions of 2 functional tests were performed before and after the isometric loading. These included a single-leg squat to 60° knee flexion[10] and a single-leg submaximal hop (participants were instructed to hop continuously with hands on hips). Pain intensity during the functional tests was rated using a 100-mm visual analogue scale (VAS).

Data Processing

All images were exported into jpeg format for determination of tendon thickness (Image j; Wayne Rasband National Institute of Health, Bethesda, MD). The images were calibrated to enable a pixel to millimeter ratio to be determined. Measures of patellar tendon thickness (anterior to posterior) were then made at a distance of 10 mm distal to the inferior patellar pole (this site was chosen, as patellar tendon pathology typically occurs at the proximal tendon).

Sample Size Calculation

We considered a minimal clinically important difference (MCID) in thickness change to be 0.8 mm (control group baseline SD = 0.4) based on previous studies.[6,7] Given this MCID, we required 12 participants (6 per group) with power set at 0.8 and an alpha value of 0.05. Sample size for the study investigating immediate changes in pain (single-leg decline squat [SLDS]) was based on Rio et al (2015), where they identified a 4.29-point difference (control group baseline SD = 2.8) in pain VAS score between 2 loading interventions. We required 16 participants (8 per group) to identify a similar between-group difference in immediate change in pain with power set at 0.8 and an alpha value of 0.05.

Data Analysis

Statistical analysis was performed using SPSS (version 22, SPSS, Inc, Chicago, IL). Baseline group characteristics were compared using independent *t* tests [age, height, weight, duration of symptoms, VISA, patellar tendon AP thickness, and leg extension 85% MVC]. Change in pain during the SLDS task and leg extension 85% MVC were assessed between baseline and 4 weeks (the *t* test). Change in transverse strain (acute change in tendon thickness from rest) was assessed within each test session and between each group [2-way (group × session) mixed-model analysis of variance (ANOVA)]. Transverse strain at each test occasion was also compared (repeated-measures ANOVA). For the cross-over repeated-measures study, immediate change in pain during the SLDS and hop tasks were assessed following each loading protocol and compared between the groups [2-way (group × session) mixed-model ANOVA].

RESULTS

Sixteen men with patellar tendinopathy were randomized into short-duration (n = 8) and long-duration (n = 8) groups (Figure 1). There were no significant baseline group differences for demographic characteristics (age, height, and weight), duration of symptoms, VISA-P score, patellar tendon AP thickness, or 85% MVC (independent *t* tests, $P > 0.05$) (Table 1). Other characteristics including weight training performed, leg dominance, and bilateral pain were similar between the groups (Table 1). All participants were active in sports involving impact loading of the knee. All participants had previously undertaken load-based rehabilitation for their patellar tendon pain for a minimum of 3 months. Almost all participants reported that they completed all the prescribed 5 sessions per week (96% in the short-duration and 100% in the long-duration group).

Acute Change in Pain

There was a significant reduction in pain after isometric loading on both SLDS (mean difference = 1.66, 95% CI, 0.13-3.19, $P < 0.01$) and hop tests (mean difference = 0.84, 95% CI, 0.39-1.29, $P = 0.02$) (Figure 2). There was no significant difference between long- or short-duration isometric loading for either SLDS (mean difference = −0.61 favoring short duration, 95% CI, −1.89-0.59, $P = 0.32$) or hop (mean difference = −0.25 favoring short duration 95% CI, −1.16-0.66, $P = 0.60$) and no significant interaction effects (SLDS, $P = 0.60$; hop, $P = 0.33$). There was no difference in pain changes scores among participants grouped as having high versus low baseline pain scores (SLDS, $P = 0.60$; hop, $P = 0.33$).

Within-Session Change in Anteroposterior Thickness

There was a significant reduction in AP thickness (ie, transverse strain) in session 1 (mean difference = 0.86 mm, 95% CI, 0.54-1.18, $P < 0.001$), session 2 (mean difference = 1.04 mm, 95% CI, 0.72-1.36, $P < 0.001$), and session 3 (mean difference = 1.29, 95% CI, 0.81-1.77, $P < 0.001$) (Figure 3). There were no group ($P > 0.90$) or interaction effects ($P = 0.81$). Percentage tendon transverse strain was 14% or greater at each session (session 1 = 14%, session 2 = 17%, and session 3 = 22%). Although transverse strain increased across the training period from ∼14% to 22%, this was not significant ($P = 0.08$).

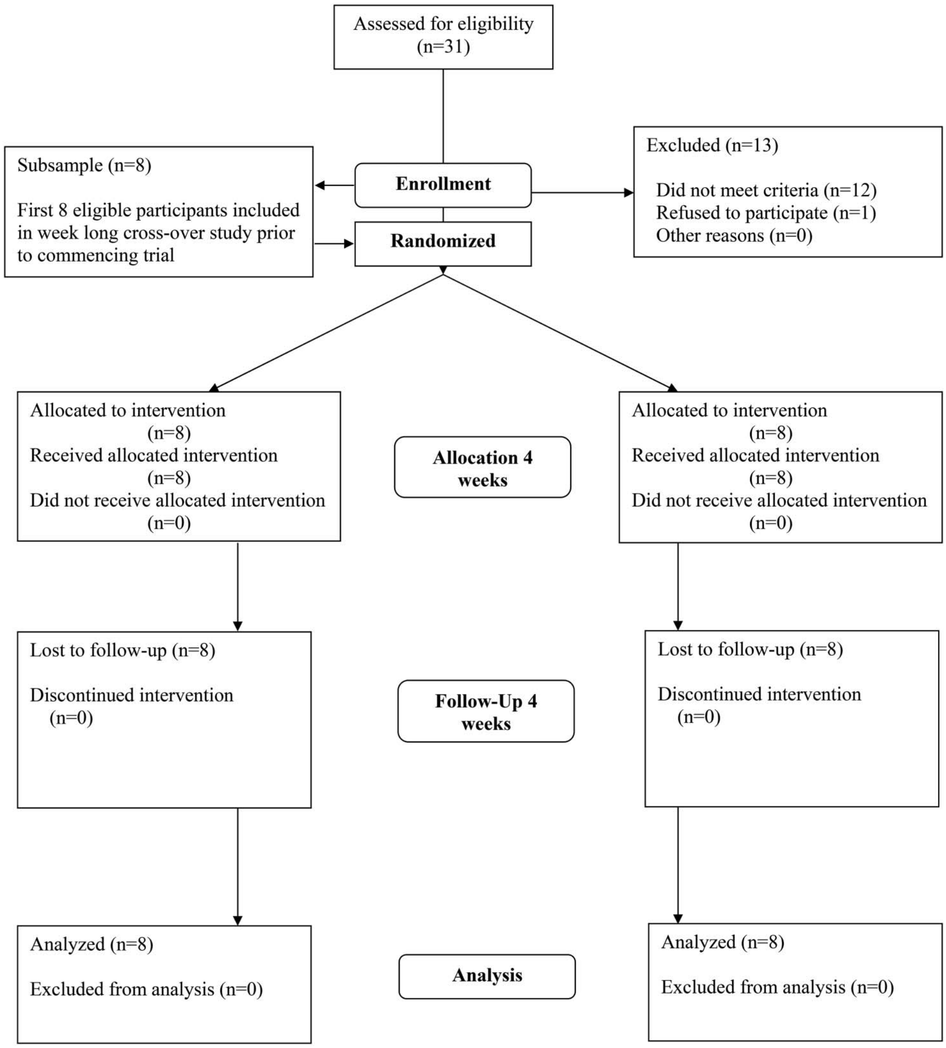

Figure 1. Flow of participants through the trial.

Over the 4-week intervention, there was a significant increase in 85% MVC (mean difference = 9.92 kg, 95% CI, 6.85-12.99, $P < 0.001$) and decrease in SLDS pain (mean difference = −1.8, 95% CI, −3.28 to −0.31, $P < 0.001$) across the cohort. Our study was not powered to detect between-group differences in these variables, so they were not investigated.

DISCUSSION

Our findings indicate that long- and short-duration isometrics have a similar effect on immediate pain among people with patellar tendinopathy, when total time under tension is equalized. This finding is unlikely to be explained by inadequate power, given our study was powered to identify a meaningful effect, and the between-group effect size was very small. Shorter duration isometric loading may be better tolerated, so our findings provide more options for clinicians prescribing isometric exercise intervention for people with patellar tendinopathy.

Recommendations of long-duration isometric contractions are based on a single study among 6 athletes' patellar tendinopathy.[3] Rio et al[3] reported a pain reduction from a mean of 7 to 0.17 (numeric rating scale from zero to 10) on SLDS testing after 5 repetitions of 45 seconds of isometric loading at 70% MVC. It can be argued that our load intensity of 85% MVC of a 40-second hold is comparable with the Rio et al's short-duration 70% MVC.[3] Our comparatively modest reduction in pain (eg, pain with SLDS only reduced by 1.66 on the VAS) may be explained by training at 30 rather than 60 (smaller tendon moment arm and load), or higher SLDS baseline pain in the Rio et al's study (mean 7 vs 3 in our study), although baseline pain was not associated with isometric pain response in our study (post hoc analyses reported in results).

We have shown significant and relatively large acute reductions in tendon thickness (14%) with cyclic isometric loading, and a trend for greater changes in tendon thickness across the sessions (22%). This may be explained by the increased load (85% MVC) under which the transverse strain test was performed at weeks 2 and 4. We chose this design because it represents what occurs in clinical practice when exercise loading is increased progressively. Even if the trend toward an increased fluid flow response is related to increasing loading, it does suggest that the tendon matrix is

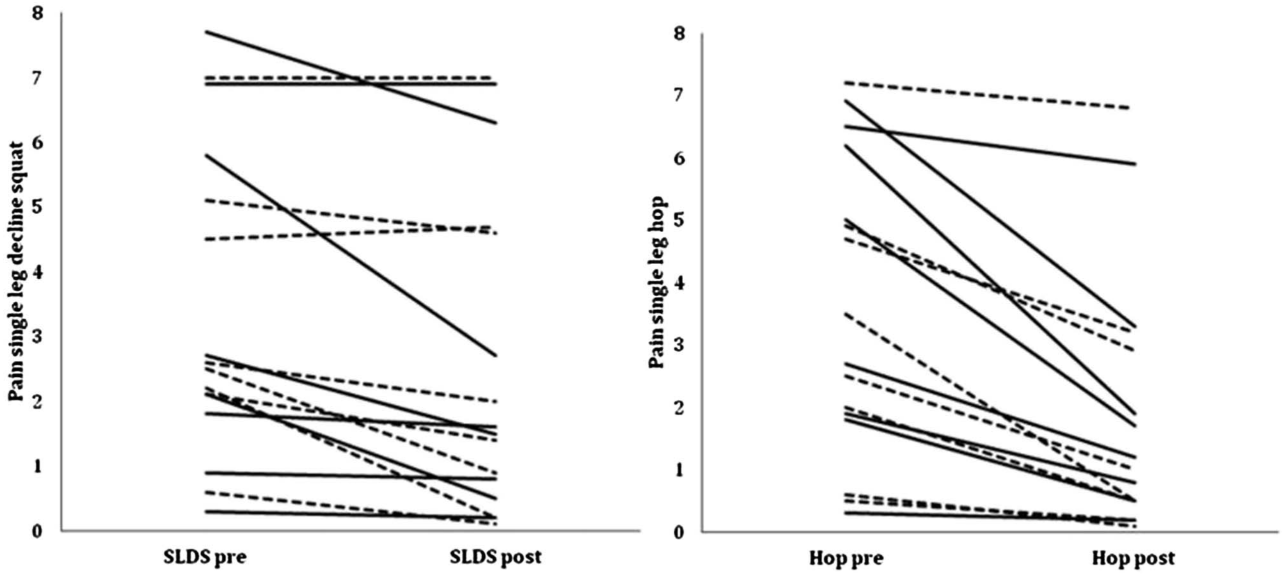

Figure 2. Immediate effects of long- and short-duration isometric loading on pain on SLDS and hop tests.

responsive in the short term to heavier loading. Wearing et al[12] reported that transverse strain changes in tendinopathic tendons were minimal (0.2%) and significantly less than that of healthy tendons (~6%). In another study, it was reported that transverse strain values for healthy subjects in the patellar tendon were ~22.5% with 90 repetitions of double-legged squats, at a loading of 175% body weight.[7] Transverse strains in our study approximate this finding in normal tendons, but this may be explained by differential stimuli using our isometric protocol. Greater time under tension may be the important factor, with this likely allowing time for greater fluid movement out of the tendon. Work is needed to understand whether transverse strain is relevant for clinical outcome, and if so how it can be optimized.

Across the cohort, there was improvement in pain (on SLDS) across the 4-week study period. Furthermore, leg extension strength improved significantly and this is consistent with reports that the time under tension and load determine strength adaptation.[13]

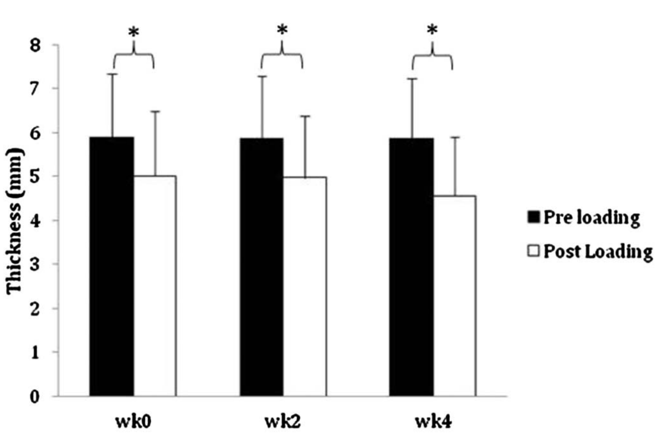

Figure 3. Mean ± *SD* values of patellar tendon thickness. *Significant within-session changes in thickness ($P < 0.05$).

This is the first study to show that there are beneficial effects on patellar tendon pain from both long- and short-duration isometric contractions, but there are study limitations that need to be highlighted. A control group of people with patellar tendinopathy that stopped sporting activity but did not perform isometric loading would have allowed us to delineate the effect of exercise versus rest from other activities on improved pain during the study. A longer training period would add to the ability of this study to discriminate potential mechanistic changes exhibited by tendinopathic tendons with chronic isometric loading, especially given tendon is generally less responsive than muscle in the short term. Furthermore, it is important to note that we did not consider microstructural change (eg, change in fibril morphology) that has been shown to change in patellar tendinopathy after an exercise intervention.[14] Therefore, more data on other outcomes and longer follow-up times are needed.

CONCLUSION

This study found that long- and short-duration isometric contractions are equally effective for immediate relief of patellar tendon pain when total time under tension is equalized. It is difficult to provide highly targeted rehabilitation therapies in tendinopathy, as the mechanisms underlying tendon adaptation in these therapies are poorly understood. This study provides insight about potential for tendon adaptation, which may generate new hypotheses surrounding the benefit gained from rehabilitation exercises.

PRACTICAL IMPLICATIONS

1. Short- and long-duration isometric contractions with equal time under tension produce similar immediate reductions in patellar tendon pain.
2. Although not significant, there was a decrease in tendon thickness across the training period ~22%. This may have important implications for tendon rehabilitation and requires further investigation with a larger cohort over a longer training period.

3. This study provides clinicians the option of applying short- or long-duration isometric contractions in managing patellar tendinopathy.

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References

1. Cook JL, Purdam CR. The challenge of managing tendinopathy in competing athletes. *Br J Sports Med*. 2014;48:506–509.
2. Malliaras P, Cook J, Purdam C, et al. Patellar tendinopathy: clinical diagnosis, load management, and advice for challenging case presentations. *J Orthop Sports Phys Ther*. 2015;45:887–898.
3. Rio E, Kidgell D, Purdam C, et al. Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. *Br J Sports Med*. 2015;49:1277–1283.
4. Henninger HB, Underwood CJ, Ateshian GA, et al. Effect of sulfated glycosaminoglycan digestion on the transverse permeability of medial collateral ligament. *J Biomech*. 2010;43:2567–2573.
5. Dubinskaya VA, Eng LS, Rebrow LB, et al. Comparative study of the state of water in various human tissues. *Bull Exp Biol Med*. 2007;144:294–297.
6. Grigg NL, Wearing SC, Smeathers JE. Achilles tendinopathy has an aberrant strain response to eccentric exercise. *Med Sci Sports Exerc*. 2012;44:12–17.
7. Wearing SC, Hooper SL, Purdam C, et al. The acute transverse strain response of the patellar tendon to quadriceps exercise. *Med Sci Sports Exerc*. 2013;45:772–777.
8. Bohm S, Mersmann F, Arampatzis A. Human tendon adaptation in response to mechanical loading: a systematic review and meta-analysis of exercise intervention studies on healthy adults. *Sport Med Open*. 2015;1:7.
9. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;4:377–381.
10. Zwerver J, Bredeweg SW, Hof AL. Biomechanical analysis of the single-leg decline squat. *Br J Sports Med*. 2007;41, 264–268; discussion 268.
11. Bryzac M. Strength testing—predicting a one rep max from reps to fatigue. *J Phys Edu Rec Dance*. 1993;64:1.
12. Wearing SC, Locke S, Smeathers JE, et al. Tendinopathy alters cumulative transverse strain in the patellar tendon after exercise. *Med Sci Sports Exerc*. 2015;47:264–271.
13. Roig M, O'Brien K, Kirk G, et al. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. *Br J Sports Med*. 2009;43: 556–568.
14. Kongsgaard M, Qvortrup K, Larsen J, et al. Fibril morphology and tendon mechanical properties in patellar tendinopathy: effects of heavy slow resistance training. *Am J Sports Med*. 2010;38:749–756.