The immediate and short term effects of short and long duration isometric contractions in patellar tendinopathy

Abstract

Objectives: Isometric muscle contractions are used in the management of patellar tendinopathy to manage symptoms and improve function. Little is known about whether long or short duration contractions are optimal and the mechanisms. This study examined the immediate and short term effects of long and short duration (four weeks) isometric contraction on patellar tendon pain, quadriceps muscle function and tendon adaptation.

Design: Repeated measures within subjects

Methods: Sixteen participants with patellar tendinopathy were randomised to either short duration (24 sets of 10 seconds) or long duration (six sets of 40 seconds) isometric loading, performed on a leg extension machine, five times per week for four weeks. Loading was performed at estimated 85% maximal voluntary contraction (MVC). Pain on single leg decline squat and tendon adaptation (change in tendon thickness both over the weeks and within session) were assessed at baseline, two and four weeks. Prior to the 4-week study, a sub-sample of 8 participants performed both protocols in a random order 5-7 days apart to determine immediate pain response on hop and single leg decline squat tests.

Results: There was a significant reduction in pain following isometric loading on both SLDS ($p<0.01$) and hop tests ($p<0.01$). Pain improved from weeks two to four ($p<0.05$), and quadriceps strength improved from baseline to week two and week two to week four ($p<0.05$). There were no group or interaction effect for immediate change in pain, or change in pain and quadriceps strength over four weeks. Tendon thickness did not change over the study period. There was significant transverse strain at each measurement occasion ($P<0.01$), although there were no group or interaction effects. Percentage transverse change did not change across the three measurement occasions ($p=0.08$).

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 equalised. Improvements in pain over the first four weeks of isometric loading parallel improved strength, but there was no evidence of tendon adaptation over the short 4 week study period. 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.

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

Introduction

Patellar tendinopathy is characterised by localised pain and pathology at the inferior pole of the patella that is common among jumping athletes and often impairs performance. Isometric loading has recently become more popular in managing patellar tendon pain (Rio et al., 2015, Cook and Purdam, 2014). Longer duration isometric contractions (45 seconds) of high intensity (70% maximal voluntary contraction (MVC)) are commonly used as preliminary evidence suggests they offer a greater immediate reduction in pain than isotonic loading in patellar tendinopathy (Rio et al., 2015). Isometric exercises are therefore recommended in managing patellar tendinopathy pain among competing or ‘in-season’ athletes. Isometric loading is also recommended at the commencement of rehabilitation for patellar tendinopathy if isotonic exercises are too painful (Malliaras 2015).

To date, no studies have compared the clinical effects of short and long duration isometric loading. Relatively long duration contractions of 45 seconds are recommended and have been shown to have immediate effects on pain in patellar tendinopathy (Rio et al. 2015). Isometric loading has been shown to lead to immediate reversal of motor cortex inhibition and increased motor output (MVC) and this may be secondary to immediate pain reduction following this exercise intervention in patellar tendinopathy (Rio et al., 2015).

Shorter duration contractions have been shown to have an effect on tendon adaptation (Arampatzis 2010) but their efficacy in regards to managing pain in patellar tendinopathy is not known. Therefore, investigating the relative efficacy of short and long duration contractions in managing patellar tendinopathy is warranted.. It is generally agreed that there is altered tendon morphology in tendinopathy, characterised by an increase in glycosaminoglycan (GAG) content in tendinopathic tendons (Maffulli et al., 2006). These characteristic changes in tendon structure can result in reductions in fluid exchange via reduced tissue fluid permeability, and possibly reduced free water content (Henninger et al., 2010; Dubinskaya et al., 2007). 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 following loading, but the response is blunted in tendinopathic tendons (Grigg et al., 2012; Wearing et al., 2013). No studies have investigated how the transverse strain response (change in thickness) changes over the course of loading rehabilitation for patellar tendinopathy. This tendon adaptation outcome may help to improve understanding of loading associated mechanisms in tendinopathy and is favoured to subjective measures of tendon structure on ultrasound and MRI that demonstrate poor repeatability.

No previous study has compared the effects of long and short duration isometric loading on clinical (pain) and tendon adaptation (transverse strain, tendon thickness) outcomes during the initial phase of rehabilitation for patellar tendinopathy. Therefore the aims of this study are; (i) to investigate the immediate effects of long and short duration isometric loading on pain and tendon adaptation (tendon thickness, transverse strain) in patellar tendinopathy; (ii) to investigate the effects of long and short duration isometric loading on pain and tendon adaptation outcome in the initial phase (time course of 4 weeks) of rehabilitation for patellar tendinopathy.

Methods

Participants

Sixteen males with unilateral or bilateral patellar tendinopathy participated in the study. 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 had ultrasound imaging confirmed patellar tendon pathology (hypoechoic regions on gray scale +/- Doppler signal). Participants had to be willing to attend a gym to perform isometric loading exercise five times per week for four weeks, and stop jumping and running activities during the four-week study period. Potential participants were excluded if they had had previous patellar tendon surgery or rupture, other diagnoses that could explain their pain (e.g. Hoffa's fat pad syndrome, patellofemoral joint pain), rehabilitation or injections for their patellar tendon pain in the previous three months, or any other lower limb injury that would prevent them completing the rehabilitation loading. The study was approved by the local Human Ethics Committee.

Participants signed an informed consent form prior to inclusion into the study. The study conformed to the principles of the World Medical Associations Declaration of Helsinki.

Pre-testing

All testing was performed at a private physiotherapy clinic in Melbourne, Australia. At the initial visit participants completed a questionnaire that included demographic data (age, height, weight, sport played, leg dominance, whether they performed lower body weight training) and basic clinical information (side of patellar tendon pain, duration of pain - see table 1). Pain and function were assessed with the Victorian Institute of Sport Assessment for Patellar Tendinopathy (VISA-P), a reliable and valid questionnaire for patellar tendinopathy (Visentini et al., 1998). A score of 0 represents the worst possible symptoms and function and a score of 100 represents no symptoms and full function. The VISA was performed so that baseline self-reported pain/dysfunction could be compared between the groups. This measure was not assessed over time because a large component (40%) relates to sporting function and in this study participants were asked to stop playing sport.

Isometric loading interventions

Participants were randomly allocated in blocks of six (selected a group number from an opaque envelope) to one of two groups: (i) short duration isometrics; or (ii) long duration isometrics. The short duration group performed 24 sets of 10 second isometric contractions with a 20 second rest between each repetition. The long duration group performed six sets of 40 second isometric contractions with an 80 second rest between each contraction. The total time under tension (240 seconds or four minutes) and work to rest ratio (1:2) were the same for both groups. Isometric loading was performed on a leg extension machine at a knee flexion angle of 30 degrees (knee extension = 0^0). This is usually a tolerable position to hold heavy load for someone with patellar tendinopathy. Participants were provided with custom made plywood cut at 30 degrees and they used this to ensure the appropriate knee angle during the home loading session.

Participants were required to perform the loading program five times per week over the four-week study period, this was performed at the participants' gym (if they had a gym membership) or the physiotherapy clinic. During the rest time for one side participants were instructed to load the opposite side using an identical protocol, so they performed the leg extension loading unilaterally, but on both sides. Participants were asked to abstain from any form of weight-bearing exercise that loads the knee extensors, including 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.

85% MVC testing

At baseline, week2 and week 4, isometric loading was performed in order to estimate 85% MVC since tendon adaptation appears to occur with loads >70% MVC (Bohm et al. 2015). This was estimated during on a leg extension machine (Impulse Fitness, Newbridge, Scotland) during an isometric hold at an angle of 30 degrees knee flexion. A laser pointer was attached to the moving arm of the leg extension machine so that when the knee was in 30 degrees (measured with a goniometer) the laser pointer was aimed at a mark that was placed on a whiteboard in front of the machine. The affected side or worse side (among bilateral participants) was tested. None of the participants reported pain that was more than minimal (defined as 3/10) during the leg extension loading sessions. 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 (Borg 1982). A rating of 17-18 was estimated to correspond to 85% MVC. If the rating was lower, the task was repeated with 5kg additional load. If the rating was higher or 40 seconds was not reached, the task was repeated with 5kg less load. This was repeated until 85% MVC for a 40 second isometric contraction was estimated, generally within two to three trials. This represents a pragmatic, clinic-based method of assessing appropriate load intensity. Participants rested for two minutes between trials. Participants were instructed to monitor their rating of perceived exertion and increase the load if their perceived exertion was lower than 17/20 on the Borg scale during any home loading session.

Tendon thickness and transverse strain testing

Transverse strain was defined as the percentage reduction in patellar tendon thickness following an isometric loading protocol. Pilot testing revealed that a very short duration isometric protocol (10 repetitions of four second contraction with a four second rest between contractions, and repeating six sets with a one-minute rest between sets) produced greater immediate transverse strain than the loading interventions described above (i.e. repeated 10 or 40 second contractions), and was less fatiguing, less likely to interfere with the training protocols and more clinically practical. Therefore, we used this isometric protocol to assess (i) immediate post loading transverse strain; and (ii) short term (comparing baseline to four 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 degrees of knee flexion. As described for the home loading protocols, a laser point was used to ensure the knee angle was maintained.

Ultrasound imaging measurements were performed at baseline and after each of the six sets which consisted of 10 repetitions of 4 second isometric contractions, producing seven measurement occasions in total. Participants were lying supine on a treatment plinth with the knee that was being imaged flexed at 90 degrees. 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 three cm. Minimal pressure was applied to the skin to avoid compressing the tendon with the probe. The proximal thickness of the tendon (10mm distal to the inferior patellar pole) was measured with the ultrasound probe placed in the sagittal plane. The centre point of the patellar tendon insertion into the inferior pole of the patella was measured with ultrasound and marked on the skin with a pen. Sagittal plane images were recorded, with the centre of the probe aligned with the pen mark. Care was taken to ensure some of the patella (bone) appeared in the recorded image (Figure 1) 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. Overall, there were two outcomes used in analyses: 1) Resting tendon thickness (this was taken as the baseline measure for that particular session prior to any loading); 2) transverse strain (percentage change in thickness from resting to post loading protocol).

Figure 1. Typical sagittal image showing the inferior patellar pole and patellar tendon.

Tendon thickness assessment was performed by one of the researchers (SS) who was trained by an experienced ultrasonographer and had over 30 hours of practice prior to commencing testing. The ultrasonographer was not blind to group allocation but measurement of tendon thickness from the still images was performed by a blinded assessor. Intra-rater reliability of tendon thickness measures were assessed among a subset of eight participants. Tendon thickness was measured on four occasions for each participant, prior to which no loading of the tendon was carried out. There was a two-minute break between testing during which participants stood up and were then repositioned again on the treatment plinth. Intra-rater reliability was estimated using interclass correlation coefficients (ICC (1, 2) = 0.95, 95% CI = 0.87-0.99). The minimal detectable change (95% confidence) was 0.17 mm.

Follow up assessment

Participants were followed up at two and four weeks. On both occasions, 85% MVC during the 40 second isometric hold was reassessed and tendon thickness, transverse strain were measured using identical procedures already outlined. Participants were also asked how many of the five weekly sessions they completed in order for exercise adherence to be calculated (percentage of sessions completed = (completed sessions/scheduled sessions)x100). Abstinence from activity involving impact loading for the knee, such as running and jumping, was also assessed. Pain during a single leg squat was used to monitor changes in pain during the four-week intervention. Participants performed a standard test used to elicit patellar tendon pain, involving a single leg squat to 60 degrees knee flexion whilst standing on a decline board (Zwerver et al., 2007). Pain intensity during the test was rated using a 100 mm visual analogue scale.

Immediate pain response following isometric loading

Prior to commencement of the study, a subsample of eight participants were included in a randomised cross-over study investigating the immediate effects of the isometric protocols on pain in patellar tendinopathy. Participants were randomised to perform either the short duration (24 x 10 second isometric contractions with a 20 second rest between contractions) or long duration (6 x 40 second isometric contractions with an 80 second rest between contractions) protocol. They performed the second protocol on a separate occasion within 5-7 days. Five repetitions of two functional tests were performed before and after the isometric loading. These included a single leg squat to 60 degrees knee flexion (Zwerver et al., 2007) 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.

Data processing and reliability

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

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, leg extension 85% MVC). Change in pain during the single leg decline squat task, leg extension 85% MVC and patellar tendon thickness were assessed over the four weeks, and compared between the two groups (Two way (Gp x wks) mixed model analysis of variance ANOVA). Change in transverse strain (acute change in tendon thickness from rest) was assessed within each test session and between each group (Two way (Gp x sess) mixed model ANOVA). Transverse strain at each test occasion was also compared between the three test occasions (repeated measures ANOVA). For the cross-over repeated measures study, immediate change in pain during the single leg decline squat and hop tasks were assessed following each loading protocol and compared between the groups (Two way (Gp x sess) mixed model ANOVA).

Results

Sixteen men with patellar tendinopathy were randomized into the groups (short duration (n=8); long duration (n=8)). There were no significant baseline differences between the groups for demographic characteristics (age, height, weight), duration of symptoms, VISA-P score, patella tendon AP thickness or 85% MVC (Independent t-tests, $p>0.05$) (Table 1). The mean VISA-P scores (56 to 62) indicated that participants' sporting activity was limited by their patellar tendon pain. Other characteristics including weight training performed, leg dominance, and bilateral pain were also similar between the groups (Table 1).

All participants were active in sports involving impact loading of the knee (Table 2). All participants had previously undertaken load-based rehabilitation for their patellar tendon pain for a minimum of three months. In both groups, seven (87.5%) participants adhered to no sport participation during the four-week study period. Almost all participants reported that they completed all of the prescribed five sessions per week (96% in the low duration and 100% in the long duration group).

Table 1: Characteristics of the two 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)	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

Table 2: Sport played by the participants

	short duration	**long duration**
Football	2 (25)	5 (63.5)
Basketball	2 (25)	1 (13.5)
Volleyball	1 (13.5)	none
Cricket	1 (13.5)	1 (13.5)
Running	1 (13.5)	none
Cheerleading	1 (13.5)	none
Rock climbing	1 (13.5)	none
Rugby	none	1 (13.5)

Immediate change in pain

There was a significant reduction in pain following isometric loading on both SLDS (p<0.01) and hop tests (p<0.01) (Figure 2). There was no significant difference between long or short duration isometric loading for either SLDS (p=0.95) or hop (p=0.75) and no significant interaction effects (SLDS, p=0.60; hop, p=0.33).

For the SLDS test, one participant experienced an increase in pain, two had no change and the remaining reported reduced pain. The mean change on the SLDS test was small (mean = 0.8, SD = 0.9, range = -0.2 to 3.0). All participants experienced reduced pain on the hop test and again the mean change was small (mean = 1.7, SD = 3, range = 0.1 to 4.3). 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).

Figure 2. Immediate effects of long and short duration isometric loading on pain on single leg decline squat and hop tests

Change in pain over 4 weeks

Pain reported during single-leg decline squat testing reduced significantly during the study period but only between week two and four (Figure 3). There was no significant difference between long or short duration isometric loading (p=0.34, power = 0.15) or interaction effect for change in pain on the SLDS test (p=0.65, power = 0.11).

Figure 3. Pooled single leg decline squat (SLDS) pain scores across the training period. (Mean ± SD). * Significantly differences between weeks (p< 0.05).

Change in strength and tendon outcomes over 4 weeks

Eighty-five percent MVC increased significantly from baseline to two weeks, and from two to four weeks (Figure 4). There was no significant difference between long or short duration isometric loading (p=0.21, power = 0.23) or interaction effect for change in 85% MVC (p=0.11, power = 0.43).

Figure 4. Pooled values for 85% isometric loading at baseline, week 2 and week4 (Mean ± SD). * Significantly differences between weeks (p< 0.05).

Resting anteroposterior thickness did not change over the three sessions (p=0.26, power = 0.23) and there were no group (long or short duration loading) (p>0.66, power = 0.10) or interaction effects (p=0.58, power = 0.66). There was a significant reduction in AP thickness (i.e. transverse strain) within each session immediately following the loading protocol (p<0.01) (see Figure 5) but 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%, session 3 = 22%). Although transverse strain increased across the training period from ~14 % to 22%, this was not significant (p=0.08).

Discussion

Isometric loading is a popular modality for treating patellar tendon pain and long duration isometric contractions are recommended (Rio et al., 2015, Cook and Purdam, 2014). Our data suggests that long and short duration isometrics (with total time under tension equalised) have a similar effect on immediate pain among people with patellar tendinopathy. Further, we found that isometric contraction was associated with reduced pain, increased quadriceps strength but did not have a significant effect on patellar tendon thickness or transverse strain in the initial period of rehabilitation for patellar tendinopathy. There were no differences in pain and strength outcomes for the long and short duration isometric contractions. Our findings provide clinicians with greater options when approaching rehabilitation of patients with patellar tendinopathy. In some instances, isometric loading may be better tolerated with a shorter 10 second contraction time (Malliaras et al. 2015). Further work is needed to determine if reducing the total time under tension, which is likely to positively influence adherence, would lead to similar pain improvement.

Recommendations of long duration isometric contractions is based on a single study among a comparable population (VISA-P mean 53 versus approximately 58 in our study) of active athletes with patellar tendinopathy (Rio et al. 2015). Rio et al. (2015) reported a pain reduction from a mean of seven to 0.17 (numeric rating scale from zero to ten) on single leg decline squat testing following 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 to the Rio et al. short duration 70% (Brzycky 1993). Despite similar protocols, we found a more modest reduction in pain (3.4 to 2.6 on a visual analogue scale) during single leg decline squat testing. There are key study differences that may explain the discrepancy. First, Rio et al. performed loading at 60 degrees versus our protocol performed at 30 degrees of knee flexion, so the load may have been higher in their study. Second, even though VISA-P scores were comparable between the groups, the Rio et al. (2015) cohort had greater pain on single leg decline squat testing at baseline (mean of 7 versus mean of 3 in the current study). Third, using the numerical rating scale may have biased participants towards larger and more definite changes in pain following the intervention.

As expected, given the loading program undertaken and cessation of aggravating activities such as jumping, pain with loading (single leg decline squat test) improved during the study between weeks two and four. As with immediate changes in pain, participants in both the long and short duration isometric groups experienced similar improvement in pain during the final two weeks of the intervention. Given we did not include a control group that rested from sporting activity but did not perform isometric loading, we do not know how much pain improvement relates to stopping sporting activity. It is likely that reducing sports activity had some effect. However, our pragmatic study was designed to replicate the initial few weeks of rehabilitation, when people are often advised to moderate sporting activity, and to specifically compare the two isometric protocols.

Participants in this study experienced significant improvement in leg extension strength following the heavy isometric loading, as would be expected following loaded exercise interventions, and there were no group differences in strength adaptation. Lack of group differences in this outcome is consistent with reports that the time under tension integral is the most important determinant of muscle size and strength adaptation (Riog 2009). In our study time under tension and load intensity (tension) was equalised between the groups.

In contrast to muscle strength adaptation, there was no change in tendon thickness or immediate transverse strain response to load across the four-week intervention. This supports the view that tendon adaptation most likely will take several months and lags behind neuromuscular adaptation (Bohm et al. 2015). Tendon is generally less responsive than muscle in the short term but it is important to note that we only considered two tendon adaptation outcomes and did not consider microstructural change (eg change in fibril morphology) that have been shown to change in patellar tendinopathy following an exercise intervention (Kongsgaard 2010). So although our data suggest no tendon adaptation following our isometric loading protocols, and no differences between groups, more data on other outcomes and longer follow-up times are needed.

The trend for increased transverse strain across the four weeks is worth mentioning. Here we show relatively large immediate reductions in tendon thickness (14%) with cyclic isometric loading, and although not significant, a large effect size indicating greater changes in tendon thickness reductions chronically across the sessions (22%). This may be explained by the increased load (85% MVC) under which the transverse strain test was performed at week two and four. However, we chose this design as it represents what occurs in clinical practice when exercise loading is increased progressively. Even if the trend towards an increased fluid flow response is related to increasing loading, it does suggest that the tendon matrix is responsive in the short term to heavier loading. Regardless, we did not see a decrease in thickness of the tendon over the four weeks suggesting that a transient tendon response to load does not translate to tendon adaptation, but this may be explained by our short follow up time.

Previous work reported that tendinopathy resulted in a blunted response of the tendon transverse strain with loading compared to healthy subjects. Using a combination of concentric and eccentric loading (double legged squats -45 reps at 145% body weight) Wearing et al. (2015) reported that transverse strain changes in tendinopathic tendons were minimal (0.2%), and significantly less than that of healthy tendons (~ 6%). In contrast to these findings, we showed that cyclic isometric loading produces a much greater transverse strain response. Wearing et al (2013) reported transverse strain values for healthy subjects in the patellar tendon of ~22.5 % with 90 repetitions of double legged squats, at a loading of 175% body weight. Thus, our finding of increased transverse strain over the four-week period being similar to that in healthy subjects is indeed interesting. However, the fact that we also show relatively large transverse strains in the initial stages suggests that there are differential stimuli using our isometric protocol to the previous dynamic protocols described. It could be that the 'time under tension' is the major influencing factor. Tendon is described as being viscoelastic and as such exhibits strain in a time dependant manner. With this in mind, it can be understood that if a stress is applied for a longer period of time, then the tendon structure will likely affect the viscous element to a larger degree and undergo more strain (creep), all things being equal. This resultant increased longitudinal strain may also be accompanied by a concomitant reduction in tendon thickness. More work is needed to understand the mechanisms underpinning change in patellar tendon transverse strain (fluid loss or other mechanism), and the relevance to clinical outcome in patellar tendinopathy.

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. The sample size may have also limited power in identifying significant differences (e.g. change in transverse strain response from baseline to four weeks). In addition, a longer training period and increased participant numbers would add to the ability of this study to discriminate potential mechanistic changes exhibited by tendinopathic tendons with chronic isometric loading.

Isometric exercises are a popular treatment for patellar tendon pain, and long duration contractions are recommended. This study found that long and short duration isometrics contractions are equally effective for immediate relief of patellar tendon pain when total time under tension is equalised. Improvements in pain over the first four weeks of isometric exercise parallel improved strength, but there was no evidence of tendon adaptation over the short 4 week study period. This finding provides clinicians with greater options when prescribing isometric exercise for patellar tendinopathy.

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Conflict of interest

None of the authors have any conflict of interest to declare in relation to this manuscript

References

Arya, S., Kulig, K., 2010. Tendinopathy alters mechanical and material properties of the Achilles tendon. J. Appl. Physiol. 108, 670–5. doi:10.1152/japplphysiol.00259.2009

Beyer, R., Kongsgaard, M., Hougs Kjær, B., Øhlenschlæger, T., Kjær, M., Magnusson, S.P., 2015. Heavy Slow Resistance Versus Eccentric Training as Treatment for Achilles Tendinopathy: A Randomized Controlled Trial. Am. J. Sports Med. 43, 1704–11. doi:10.1177/0363546515584760

Bohm, S., Mersmann, F., Arampatzis, A., 2015. Human tendon adaptation in response to mechanical loading: a systematic review and meta-analysis of exercise intervention studies on healthy adults. Sport. Med. - Open 1, 7. doi:10.1186/s40798-015-0009-9

Buckley, M., Sarver, J., Freedman, B., Soslowsky, L., 2013. The dynamics of collagen uncrimping and lateral contraction in tendon and the effect of ionic concentration. - PubMed - NCBI. J Biomech 46, 2242–9.

Chimenti, R.L., Flemister, A.S., Tome, J., McMahon, J.M., Flannery, M.A., Xue, Y., Houck, J.R., 2014. Altered tendon characteristics and mechanical properties associated with insertional achilles tendinopathy. J. Orthop. Sports Phys. Ther. 44, 680–9. doi:10.2519/jospt.2014.5369

Ciccone, W.J., Bratton, D.R., Weinstein, D.M., Elias, J.J., 2006. Viscoelasticity and temperature variations decrease tension and stiffness of hamstring tendon grafts following anterior cruciate ligament reconstruction. J. Bone Joint Surg. Am. 88, 1071–8. doi:10.2106/JBJS.E.00576

Cook, J.L., Purdam, C.R., 2014. The challenge of managing tendinopathy in competing athletes. Br. J. Sports Med. 48, 506–9. doi:10.1136/bjsports-2012-092078

Drew, B.T., Smith, T.O., Littlewood, C., Sturrock, B., 2012. Do structural changes (eg, collagen/matrix) explain the response to therapeutic exercises in tendinopathy: a systematic review. Br. J. Sports Med. 1–8. doi:10.1136/bjsports-2012-091285

Dubinskaya, V.A., Eng, L.S., Rebrow, L.B., Bykov, V.A., 2007. Comparative study of the state of water in various human tissues. Bull. Exp. Biol. Med. 144, 294–7.

Grigg, N.L., Wearing, S.C., Smeathers, J.E., 2012. Achilles tendinopathy has an aberrant strain response to eccentric exercise. Med. Sci. Sports Exerc. 44, 12–7.

doi:10.1249/MSS.0b013e318227fa8c

Grigg, N.L., Wearing, S.C., Smeathers, J.E., 2009. Eccentric calf muscle exercise produces a greater acute reduction in Achilles tendon thickness than concentric exercise. Br. J. Sports Med. 43, 280–283. doi:10.1136/bjsm.2008.053165

Hannafin, J.A., Arnoczky, S.P., 1994. Effect of cyclic and static tensile loading on water content and solute diffusion in canine flexor tendons: an in vitro study. J. Orthop. Res. 12, 350–6. doi:10.1002/jor.1100120307

Helland, C., Bojsen-Møller, J., Raastad, T., Seynnes, O.R., Moltubakk, M.M., Jakobsen, V., Visnes, H., Bahr, R., 2013. Mechanical properties of the patellar tendon in elite volleyball players with and without patellar tendinopathy. Br. J. Sports Med. 47, 862–8. doi:10.1136/bjsports-2013-092275

Henninger, H.B., Underwood, C.J., Ateshian, G.A., Weiss, J.A., 2010. Effect of sulfated glycosaminoglycan digestion on the transverse permeability of medial collateral ligament. J. Biomech. 43, 2567–73. doi:10.1016/j.jbiomech.2010.05.012

Kang, S., Thordarson, D.B., Charlton, T.P., 2012. Insertional Achilles tendinitis and Haglund’s deformity. Foot ankle Int. 33, 487–91. doi:10.3113/FAI.2012.0487

Kongsgaard, M., Qvortrup, K., Larsen, J., Aagaard, P., Doessing, S., Hansen, P., Kjaer, M., Magnusson, S.P., 2010. Fibril morphology and tendon mechanical properties in patellar tendinopathy: effects of heavy slow resistance training. Am. J. Sports Med. 38, 749–756. doi:10.1177/0363546509350915

Maffulli, N., Reaper, J., Ewen, S.W.B., Waterston, S.W., Barrass, V., 2006. Chondral metaplasia in calcific insertional tendinopathy of the Achilles tendon. Clin. J. Sport Med. 16, 329–34.

Malliaras, P., Cook, J., Purdam, C., Rio, E., 2015. Patellar Tendinopathy: Clinical Diagnosis, Load Management, and Advice for Challenging Case Presentations. J. Orthop. Sports Phys. Ther. 45, 887–98. doi:10.2519/jospt.2015.5987

Maquirriain, J., Kokalj, A., 2014. Acute Achilles tendinopathy: effect of pain control on leg stiffness. J. Musculoskelet. Neuronal Interact. 14, 131–6.

Rio, E., Kidgell, D., Purdam, C., Gaida, J., Moseley, G.L., Pearce, A.J., Cook, J., 2015. Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. Br. J. Sports Med. 49, 1277–83. doi:10.1136/bjsports-2014-094386

Thornton, G., Shrive, N., Frank, C., 2001. Altering ligament water content affects ligament pre-stress and creep behaviour. - PubMed - NCBI. J Orthop Res 19, 845–51.

Visentini, P.J., Khan, K.M., Cook, J.L., Kiss, Z.S., Harcourt, P.R., Wark, J.D., 1998. 0m ' ns I I I) 22–28.

Wall, M.E., Banes, A.J., 2005. Early responses to mechanical load in tendon: role for calcium signaling, gap junctions and intercellular communication. J. Musculoskelet. Neuronal Interact. 5, 70–84.

Wearing, S.C., Hooper, S.L., Purdam, C., Cook, J., Grigg, N., Locke, S., Smeathers, J.E., 2013. The acute transverse strain response of the patellar tendon to quadriceps exercise. Med. Sci. Sports Exerc. 45, 772–777. doi:10.1249/MSS.0b013e318279a81a

Wearing, S.C., Locke, S., Smeathers, J.E., Hooper, S.L., 2015. Tendinopathy alters cumulative transverse strain in the patellar tendon after exercise. Med. Sci. Sports Exerc. 47, 264–271. doi:10.1249/MSS.0000000000000417

Zwerver, J., Bredeweg, S.W., Hof, a L., 2007. Biomechanical analysis of the single-leg decline squat. Br. J. Sports Med. 41, 264–268; discussion 268. doi:10.1136/bjsm.2006.032482