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Isometric exercise and pain in patellar tendinopathy: A randomized crossover trial.

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ABSTRACT

Objectives: The aim of this study was to compare the acute effects of isometric versus dynamic resistance exercise on pain during a pain-provoking activity, and exercise-induced hypoalgesia in participants with patellar tendinopathy.

Design: This study was a pre-registered randomised crossover study. Participants were blinded to the study hypothesis.

Methods: Participants (N=21) performed a single session of high load isometric resistance exercise or dynamic resistance exercise, in a randomised order separated by a 7-day washout period. Outcomes were assessed before, immediately after, and 45 min post-exercise. The primary outcome was pain intensity scored on a numeric pain rating scale (NRS; 0-10) during a pain-provoking single leg decline squat (SLDS). Secondary outcomes were pressure pain thresholds (PPTs) locally, distally and remotely, as well as tendon thickness.

Results: There was a significant decrease in pain NRS scores (mean reduction 0.9, NRS 95%CI 0.1 to 1.7; p=0.028), and increase in PPTs at the tibialis anterior muscle (mean increase 34 kPa 95%CI 9.5 to 58.5; p=0.009) immediately post-exercise. These were not sustained 45 min post-exercise for pain (NRS) or PPTs (p>0.05). There were no differences between exercise on any outcome.

Conclusions: While patients with patellar tendinopathy decreased pain during SLDS in response to resistance training, but the magnitude was small. Contraction mode may not be the most important factor in determining the magnitude of pain relieving effects. Similarly, there were only small increases in PPTs at the tibialis anterior which were not superior for isometric exercise.

Keywords: pain measurement, pain threshold, psychophysiology, exercise induced hypoalgesia, resistance exercise, pain relief, tendon, athletes

Practical implications

- Isometric exercises for patellar tendinopathy were advised to be implemented for acute pain relief despite lack of evidence supporting their efficacy
- In the current study, small and varying decreases in pain were observed following isometric and dynamic exercises, which was not sustained for 45 minutes
- When discussing acute pain management options, patients should not be told to expect complete pain reduction from resistance exercises
- Due to the lack of superiority of the acute effect of either isometric or dynamic exercise, patient preferences can be used to guide exercise selection for acute pain management.

INTRODUCTION

Patellar tendinopathy is one of the most common musculoskeletal pain problems associated with sport, particularly those that includes jumping activities [1]. One of the most commonly used strategies for managing patellar tendinopathy are loading programs i.e. resistance training. Resistance training (i.e. a training programme) is effective in reducing pain for a range of musculoskeletal pain conditions, including tendon pain (tendinopathies) [2, 3]. For long-term rehabilitation of tendinopathies, high load resistance training is frequently used from several weeks to months [2], with level one evidence supporting its effect compared to other treatments such as stretching for long-term management [3]. Eccentric and high load dynamic exercises are often used during rehabilitation, although the choice of optimal modality for improving patient outcomes is heavily debated [4, 5]. There are multiple proposed mechanisms behind the positive effects exercise rehabilitation including local effects on the tendon structure[4], the muscle[6] and central effects[7].

In addition to resistance training, an acute bout of exercise can also acutely reduce pain sensitivity (hypoalgesia) and pain intensity to normally painful stimuli (analgesia). This is also termed exercise-induced hypoalgesia (EIH) in healthy individuals and is a short time-limited effect as a result of neurophysiological mechanisms involved in processing noxious stimuli [8]. This acute effect is likely independent of structural adaptations, and depend on neurophysiological modulation, such as opioid analgesic systems [9-11], or potentially due to the observed decreases in tendon thickness following exercise [12]. It therefore cannot be assumed that the exercise paradigms which work cumulatively over time are the best for acute pain reduction. The effect of exercise on pain and hypoalgesia has typically been evaluated using short-term aerobic exercise, or isometric resistance exercise, and investigated as the effects on pain sensitivity, measured by changes in pain thresholds [8, 13, 14]. However, the optimal mode and dosages for reducing pain is unknown.

Rio and colleagues [15] found that a single bout of isometric exercise induced greater immediate subjective pain relief during the single leg decline squat, an aggravating task for patellar tendinopathy (with an effect size of 1.1 compared to dynamic exercise), indicating the potential for isometric exercise as an acute pain management tool. However, contradictory results have been found, with another study finding a much lower pain relieving effect of isometric contractions [16], and attempts to replicate the analgesic effect in other tendinopathies have been unsuccessful [17]. Despite this, isometric exercise is advocated as providing a greater pain inhibition compared to dynamic exercises for tendinopathies, and specifically patellar tendinopathy [18]. Consequently, there is currently conflicting evidence for the acute effect of isometric exercises in patients with patellar tendinopathy. A larger and adequately designed study is needed to improve knowledge within this field.

As most research to date has focused on the long-term effects of maintained resistance training in this population (and associated structural adaptations), there is a lack of research on the short-term effects including exercise induced hypoalgesia which can be quantified using quantitative sensory testing (QST), and on the change in hypoalgesia response over time.

The primary aim of this study was to compare the acute effects of isometric versus dynamic exercise during a pain-provoking activity, in participants with patellar tendinopathy. The primary hypothesis is that isometric exercise will induce greater pain reduction during a pain aggravating activity in comparison to dynamic exercises. The secondary objective was to compare the effect of isometric and dynamic exercise on pressure pain sensitivity locally at the patellar tendon, as well as distally and on a remote site. A tertiary aim was to evaluate changes of patellar tendon thickness following the exercises.

METHODS

This study was designed as a randomised crossover superiority trial, where participants were blinded to the study hypothesis. The protocol was approved by the local ethics committee (N-20160084), and all participants provided written informed consent prior to participation. The trial was pre-registered on clinicaltrials.gov before inclusion of the first participant (NCT03528746). The reporting of this study follows the CONSORT guidelines, the Pain-specific CONSORT supplement checklist and TIDieR guidelines for intervention reporting. All procedures were pilot tested in participants who were healthy (N=8) and with patellar tendinopathy (N=2) prior to inclusion of the first participant.

Based on the pilot study, it was decided not to include pain during exercise due to the cognitive process of evaluating pain which may influence subsequent pain recording and impede replication of the previous trial. As a result, pain during exercise was not collected as a secondary outcome, which was a protocol deviation.

Participants with patellar tendinopathy were recruited through Aalborg University and University College of Norther Denmark, local sports clubs, local clinics and social media. Interested participants who had patellar tendon related pain were invited for a clinical examination to establish the diagnosis, rule out other common causes of anterior knee pain (e.g. Patellofemoral Pain) and assess eligibility for inclusion into the study. The inclusion and exclusion criteria were as follows: (1) Participants were required to have patellar tendinopathy and be aged 18-40 years. (2) Diagnosis of patellar tendinopathy was made by a physiotherapist supervised by an experienced rheumatologist (JLO), which was based on the criteria in Rio et al.[15] as follows; pain localised to the inferior pole of the patella at palpation and during jumping and landing activities, and pain during testing on the single-leg decline squat (SLDS). The patellar tendinopathy diagnosis was confirmed by the presence of characteristic features on ultrasound imaging (i.e., hypoechoic area, Doppler and focal enlarged tendon were considered characteristic features, but not all had to present in each patient). Ultrasound (BK Flex Focus 500, BK Medical, Denmark) was done with the knee flexed to approximately 60 degrees with a transducer head of 48X13mm (High Frequency Linear 18L5, BK Medical, Denmark). Finally, participants were required to have a minimum pain (worst pain in the last week) of 3 / 10 on an 11-point numeric rating scale (NRS). Participants were excluded if they had any concurrent knee pathologies (e.g. the presence of a diffuse knee pain presentation indicative of PFP with or without tendinopathy), or previous knee surgery or had received a corticosteroid injection within the previous six months.

Participants attended two sessions, one week apart, at approximately the same time of day. On the first day, the diagnosis and eligibility was determined, in line with criteria outlined above. If participants were eligible, demographic data, including sex, age, height, weight, and sports participation (type and hours per week) were recorded, whether participants had unilateral or bilateral pain, and if bilateral, which was the most painful limb. In addition, participants completed the Victorian Institute of Sport Assessment-Patella

(VISA-P questionnaire) , duration of pain condition, as well as average and worst pain intensity in the past week (measured on an 11-point NRS, ranging from 0 to 10 from no pain to worst possible pain).

After the baseline assessment, participants performed either isometric or dynamic exercise, according to the randomisation sequence (see below). The second exercise of the allocation sequence was completed one week later, at the same time of day (within two hours of the initial assessment).

The sequence exercise type was randomised by an independent researcher (not involved in any other aspects of the study) using a computer generated allocation sequence on random.org. The generated sequences were then sealed in opaque envelopes. The researcher instructing and supervising the exercise protocols was blinded to sequence allocation, until after subjects were enrolled and completed baseline testing, at which point the participant randomly selected an envelope which determined their allocation. Outcome parameters were recorded immediately pre-exercise, immediately post exercise and 45 min post exercise.

Both the isometric and dynamic exercise protocols were based off previously published protocol by Rio and colleagues [15].

The isometric exercise session was conducted at 70% maximal voluntary isometric contraction (MVIC). Prior to completing the isometric exercise, the MVIC was assessed using isokinetic dynamometry (Biodex System 4 Pro) [15]. Participants were seated in a stable position in the dynamometer, fixated with trunk and lower limb straps with the knee at 60° of knee flexion. Participants were familiarised with the procedure and issued standardised instructions to perform a maximal effort knee extension against the dynamometer for 30 seconds. After a short break, the test was repeated three times. The peak torque recorded during these three efforts was the MVIC.

For the isometric exercise session, participants completed static isometric quadriceps contractions in the Biodex. Participants were required to isometrically exert a force equivalent to 70% of the MVIC, and to sustain this for 45s while seated with their knee in 60° flexion. The torque was verified by the Biodex system. One 45s repetition constituted a set, and this was repeated five times with two minutes break in-between. Participants received standardised and neutral vocal encouragement and feedback. "Push more, Push less, Great, Come-on".

The dynamic exercise was leg extension, completed in a leg extension machine (Body Solid Inc, GLCE365). First, the maximum load that can be lifted for eight repetitions (8RM) at 6 sec per repetition through 90 degrees range of motion (ROM) was determined. This was assessed according to the National Strength and Conditioning Association (NSCA) guidelines for RM testing. The 8RM load was used for the dynamic leg extension exercise with a pace (guided by a metronome) of three seconds per concentric contraction, 0s isometric and three seconds eccentric contraction through 90 degrees ROM. This was repeated for three sets of eight repetitions, with two minutes break between each set. Similar to the isometric exercise, participants received standardised neutral vocal encouragement.

The primary outcome was pain intensity assessed during a single leg decline squat (SLDS), a reliable test for provoking pain in patients with patellar tendinopathy [15, 19]. Participants were asked to stand on one limb, on a decline board, so they were in approximately 25 degrees of plantar flexion of the ankle joint. They were then asked to perform a squat, to 60 degrees of knee flexion. This was repeated three times. Participants provided a NRS score, anchored at left with '0, no pain' and at right with '10, worst possible pain'. If participants had bilateral patellar tendinopathy, data from the 'most painful' limb (indicated by participants) was used. The average NRS score across the three SLDS was used for further analysis.

The pressure pain thresholds (PPTs) were recorded using a hand-held algometer (Somedic, Hörby, Sweden) with a 1-cm^2 probe (covered by a disposable latex sheath). The tester placed the probe perpendicular to the skin at the test site, and increased the pressure 30 kPa/s. Participants were equipped with a hand-held button, which they were instructed to press at the first instance the sensation changed from pressure, to pain. The pressure at this point defined the PPT. PPTs were assessed locally at the most painful site point on the tendon, with the knee flexed to 90° as per previous methods in patellar tendinopathy, which have demonstrated excellent reliability [20]. PPTs were further assessed bilaterally at the patellar tendon. For participants with unilateral pain, the PPT on the contralateral limb was taken directly distal of the patellar apex, as previously used in asymptomatic individuals [20]. In addition to this, PPTs were assessed at the tibialis anterior muscle at the muscle belly on the test leg and on the contralateral extensor carpi radialis brevis muscle belly. PPTs were recorded in triplicates and the average value were used for further analysis. At each session, the location of PPTs was marked on the participant during the baseline assessment to ensure reproducibility in the post-exercise assessments.

Ultrasound (BK Flex Focus 500, BK Medical, Denmark), was used to quantify patellar tendon thickness. The ultrasound measurements were carried out with the participants in a supine position with the knee flexed to approximately 60 degrees with a transducer head of 48X13mm (High Frequency Linear 18L5, BK Medical, Denmark). To determine thickness, a transversal scan taken 1cm from the apex of the patella (marked by marker to ensure it was repeated at the same point post-exercise). The thickest portion of the tendon was used for measurement by manually selecting two points and measuring the vertical distance directly in the ultrasound software. The average of three measurements was used for analysis.

The sample size was based on the results from Rio et al. where they found a mean reduction of 6 NRS points in response to isometric exercise [15] in volleyball players. We aimed to account for a potentially smaller effect size due to a more heterogeneous group (wider sports participation and including females). Therefore, our samples size was based on detecting a 2±3 point difference between exercises ($p < 0.05$) in NRS with a within groups design and a power of 0.9 which would require 21 participants.

Statistical analysis

Statistics were undertaken according to a pre-established statistical analysis plan (protocol). All outcomes were approximately normally distributed, determined by visual inspection of Q-Q plots. Data are reported as mean and 95% confidence interval unless otherwise stated. Significance was accepted at $P<0.05$.

To determine if there was an effect of exercise order on the primary outcome, an independent samples t-test was run (independent grouping variable of allocation sequence; isometric *versus* dynamic) was used to examine the within subject mean differences for each assessment of the primary outcome (pain during the single leg squat) [21]. Similarly, to check the assumption of negligible carryover effects, an independent t test was calculated on the within subjects sum of effects for the primary outcomes (pain during SLDS) from both periods[21].

Separate two-way repeated measures (two within subject factors) analysis of variations (ANOVAs) were undertaken for the dependent variables of interest (primary and secondary outcomes). The within subject's factors were exercise type (isometric *versus* dynamic), and time (pre- *versus* post exercise *versus* 45 min post- exercise). In addition to this, for both isometric and dynamic interventions, effect sizes was be calculated and plotted for the change in NRS scores of the SLDS evoked pain. In cases where the assumption of sphericity was violated according to the results of Mauchly's sphericity test, Greenhouse-Geisser adjustment was used.

The primary outcome was also analysed as a categorical variable, defined as the number of responders to each intervention, quantified by the number of participants with a change equal to, or above the minimally clinically important difference (MCID) in NRS i.e. 2 points change [22]. McNemars test was used to test for differences in the proportion of participants categorised as responders to each of the interventions.

RESULTS

Participants were recruited and assessed for eligibility between July 2018 and September 2018 (Figure 1). Recruitment was ceased when 21 eligible participants were enrolled as per the a priori protocol and sample size calculation. Of these 21, one participant loss to follow-up (due to family reasons), and did not complete the dynamic exercise intervention (Figure 1). Therefore, twenty participants were included in the analysis (Figure 1). The severity of the participant's tendon pain was expressed with the VISA-P score (mean score: 47.8/100, Table 1) and the majority had contacted at least one health care practitioner (12 contacts to general practitioner, 12 to physiotherapist, one to and orthopaedic surgeon and one to a rheumatologist). All participants were actively engaged in at least one sport/activity (Table 1), with a large proportion conducting strength training (including Cross-Fit) (n=12 other sports), and other sports included handball (n=3), gymnastics (n=3) volleyball (n=1), athletics (n=1), triathlon (n=1) and running (n=1).

There were no significant differences on the primary outcome between the two sequence groups (isometric-dynamic and dynamic-isometric) for the mean differences, or the sum of effects, indicating no influence of exercise order and negligible carryover effects respectively.

In the ANOVA there was no significant interaction between mode of exercise and time on NRS scores of pain during SLDS ($F(2,38)=0.6$, $p=0.561$, partial $\eta^2 = 0.03$; Figure 2; Table 2). There was a main effect of time ($F(1.4,38)= 4.7$, $p=0.028$), partial $\eta^2 = 0.19$). The pain NRS score was lower immediately post exercise (mean difference 0.9 NRS points 95%CI 0.1 to 1.7; Post-hoc: $p=0.028$) compared to baseline. There were no significant differences in NRS scores of pain during SLDS between 45 min post exercise and baseline (mean difference 0.4 NRS points 95%CI -0.1 to 0.8; Post-hoc: $p= 0.089$). The proportion of responders (NRS scores during SLDS reduced by 2 points compared with baseline) were not significantly different between isometric and dynamic exercise interventions immediately after the exercise (4 versus 6 respectively; $p = 0.73$) or 45 min after the exercise (0 versus 4 respectively; $p=0.16$).

For PPTs at the patellar tendon of the painful knee, there was no significant interaction between mode of exercise and time ($F(1.6,38)=0.0$, $p=0.196$, partial $\eta^2 = 0.08$) or main effect of time ($F(2,38)=1.5$, $p=0.239$, partial $\eta^2 = 0.07$) (Table 3).

There was no significant interaction effect between mode of exercise and time for PPTs at the tibialis anterior muscle ($F(2,38) =0.5$, $p=0.62$, partial $\eta^2 = 0.03$) (Table 3) but there was a main effect of time ($F(2,38)=4.0$, $p=0.027$, partial $\eta^2 = 0.17$). Pairwise comparisons revealed increased PPTs at the tibialis anterior muscle post exercise compared to baseline (mean difference 34 kPa 95%CI 9.5 to 58.5, $p=0.009$), with no differences 45 min post exercise compared with baseline (mean difference 17.2 kPa 95%CI -12.3 to 46.7, $p=0.238$) (Figure 3).

There was no significant interaction between mode of exercise and time ($F(2,38)=0.7, p=0.519$, partial $\eta^2 = 0.03$) (Table 3) or main effect for time ($F(2,38)=1.1$, $p=0.340$, partial $\eta^2 = 0.06$) for PPT at the contralateral extensor carpi radialis brevis muscle.

For PPTs at the contralateral patellar tendon, there was no significant interaction between mode of exercise and time ($F(1.5,28.8)=0.04$, $p=0.603$, partial $\eta^2 = 0.02$) (Table 3) or main effect for time ($F(1.4,26.8)=0.9$, $p=0.383$, partial $\eta^2 = 0.05$).

There was no significant change in patellar tendon thickness from pre to post exercises ($F(2,38)=0.5$, $p=0.593$, partial $\eta^2 =0.03$) (Table 3) or interaction between mode of exercise and time ($F(2,38)=0.2, p=0.821$, partial $\eta^2 =0.01$).

DISCUSSION

The current study aimed to test previous findings on the short-term analgesic effect of isometric resistance exercise for patients with patellar tendinopathy. Contrary to our pre-defined hypothesis, no significant difference was found between isometric and dynamic resistance exercise on acute pain during a pain-provoking activity, or pain sensitivity. There was an effect of time, i.e. a small decrease in self-reported pain during movement evoked pain immediately following exercises, with no differences between isometric or dynamic exercises. This finding was supported by the increased PPTs at the tibialis anterior muscle immediately post exercise, indicating EIH, but not at the patellar tendon or in other locations indicating a lack of a systemic effect. However, no significant difference was observed between the two exercises for either outcome. Changes were not sustained 45 minutes post-exercise, despite a tendency for pain to be lower than at baseline ($p=0.089$), indicating pain ratings were returning to baseline at the 45min follow-up. Only a small number of participants reported a clinically relevant decrease in pain, which was not different between the exercise conditions.

Overall, the magnitude of the exercise-induced changes in pain intensity found in the current study were discouraging, based on the previous data indicating a substantial effect of isometric exercise (over 6 points on the NRS) [15]. The current study contradicts the magnitude of these effects and challenges the generalisability of previous findings. Despite replicating the exercise protocol, the magnitude of pain reduction to dynamic exercise reported by Rio and colleagues [15] was also much larger and clinically relevant, compared to the present results where only a small proportion of participants had a clinically relevant change in pain after exercise. The populations are similar in terms of severity (VISA-P score of 47.9 in the current study compared to 52.8 [15], although the relatively long symptom duration and high proportion of bilateral cases in the current study could indicate a high severity. However, these data were not provided by Rio and colleagues which hampers a direct comparison in populations. Furthermore, the study by Rio and colleagues included only n=6 adult male volleyball players, which would make the generalisability to wider populations of patellar tendinopathy limited. We included all types/sports and both males and females, and sex may be important due to established sex differences in pain perception, although women have been demonstrated to be more responsive to EIH [23]. On the other hand Pearson et al. [16] recently compared short versus longer contraction times in patients with patellar tendinopathy and found they were equally effective on acute pain relief with pain during a SLDS reduced by 1.7 cm on a VAS scale. The magnitude of change is pain is much more similar to our results compared to the study by Rio and colleagues, which may indicate the large decrease is pain following contractions in these 6 individuals may not be generalizable. Several papers which have investigated the acute pain-relieving effects of isometric exercises on common lower limb tendinopathies. In Achilles tendinopathy,. [17] some patients reported an improvement, while others had a pain flare-up after the heavy isometric loading while Riel et al. [24] did not find a difference in the acute effects on pain between the two exercise types, in patients with plantar fasciopathy.

In our study, EIH was detected distally at the tibialis anterior by increases in PPTs immediately post exercise. The observed magnitude of the EIH response detected by PPTs distally after exercise is similar to that which has previous been detected after isometric or aerobic exercise [23, 25]. Despite this, a positive EIH response was not found locally at the patellar tendon or remotely at the extensor carpi radialis brevis muscle. This is surprising, as EIH is considered a systemic/centrally mediated pain modulation [11, 26]. This could be due to dysfunctional endogenous pain inhibition, as has been demonstrated in patients with other musculoskeletal pain conditions such as shoulder myalgia [27]. It cannot be ruled out that such manifestations are present in painful- persistent tendinopathies, considering the mean pain duration of the current sample is 24 months, and patients with patellar tendinopathy have previously been demonstrated increased pain sensitivity [28]. However, this is speculative as we did not include a control group without tendon pain for comparison.

While the mechanisms of exercise on pain and EIH are not yet fully understood, there appear to be multiple analgesic systems which play a role [9, 10]. Some characteristics, such as exercise stress/severity (e.g. exercise duration and temperature) appear to influence the relative contribution of opioid versus non-opioid mechanisms in animals [29]. Further research is needed to investigate which other parameters contribute to this, and whether results are similar between patient populations and healthy controls. For example, data in healthy subjects show that both short and long duration contractions, and low and high load isometric exercise affect pain perception with hypoalgesia occurring after only one minute of low load (25%MVIC) contractions [8, 13, 14]. Whether or not these parameters have similar responses on tendon pain has yet to be determined. One possibility, was that changes in patellar thickness may explain the potential effect of one exercise over another. However, in the current study we found no changes in tendon thickness following resistance training exercises, which is in contrast to previous research showing that acute tendon overload via cross-fit training resulted in an increased tendon thickness in healthy individuals[12] which could indicate that the volume or intensity play a role. However, further research in patients with patellar tendinopathy is needed to determine if such an acute change in thickness is indeed associated with changes in symptoms.

In healthy individuals meta-analysis indicated that both isometric and dynamic exercise are effective in influencing pain perception [8]. Isometric exercise has commonly been used, many studies have also evaluated aerobic exercise [8], and there are data available regarding dynamic or concentric resistance exercise. These have found dynamic exercise effective [8, 30], and data from first investigations over 20 years ago, show large effect sizes of around 0.99-1.08 [31].

Isometric exercises for immediate pain relief was quickly highlighted as a strong tool for managing pain in patients with lower limb tendinopathies [7, 18]. Based on the current study there was no statistically significant superior effect of isometric exercise compared to dynamic exercises. It should be noted that this study included adult participants with chronic tendinopathy of a relatively long symptom duration. It is unclear if participants' with acute tendinopathy or adolescents with other patellar tendon related pain conditions (e.g. Osgood Schlatter) may produce different results. Further research is needed to further elucidate the mechanisms underpinning acute and cumulative exercise induced analgesia in order to inform how to modulate exercise intensity and dosages to optimise outcomes for patients with tendinopathy in both the short and long term.

One of the strengths of the current study is the study design, which was pre-registered with the statistical analysis plan specified a priori in the protocol. Additionally, we based our diagnosis of patellar tendinopathy on objective characteristic features examined by ultrasound, in addition to the clinical assessment. One if the limitations of the current design is the lack of a 'no-exercise' control condition, so it cannot be ruled out the SLDS NRS declines over time. However, this limitation doesn't affect the overall conclusion regarding the superiority of the contraction modes. Another limitation is that the assessor was not blinded to the different exercise conditions. Further, isometric and dynamic strength was measured on the same day as testing. However, as the EIH effect is relatively short-lived and participants were given a break prior to baseline pre-exercise assessment, and as this was the same under both conditions, we do not believe this affects the conclusion of results. The effect of the different exercises on the affective dimension of pain (i.e. pain unpleasantness) was not documented, which is also a limitation. Finally, we did not detect a functional EIH response at all sites, but without a control group cannot determine if these patients with patellar tendinopathy have a decreased response to exercise induced analgesia compare to healthy individuals without musculoskeletal pain. Further research could investigate this, as well as whether or not it has implications for treatment outcomes. Similarly, due to the large heterogeneity in the acute effects to acute pain relief, whether or not this is associated with sustained pain relief following a resistance training intervention is warranted.

The current study demonstrates that there is no statistically superior immediate effect of isometric exercise compared to dynamic exercise on pain, or on pain perception (hypoalgesia). The optimal mode and dosage for inhibiting pain in patients with patellar tendinopathy has been controversial, but this study indicates that the contraction mode may not be the most important factor.

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Figure Legends

Figure 1. Flowchart of included participants.

Figure 2. Individual participant data plot of pain during SLDS on the test limb before, immediately after and 45 min after isometric exercise (top) and dynamic exercise (bottom).

Figure 3. Mean change (95% CI) in pressure pain thresholds from baseline. (*indicated significant difference from baseline; test indicates test limb; contra indicates contra-lateral limb).

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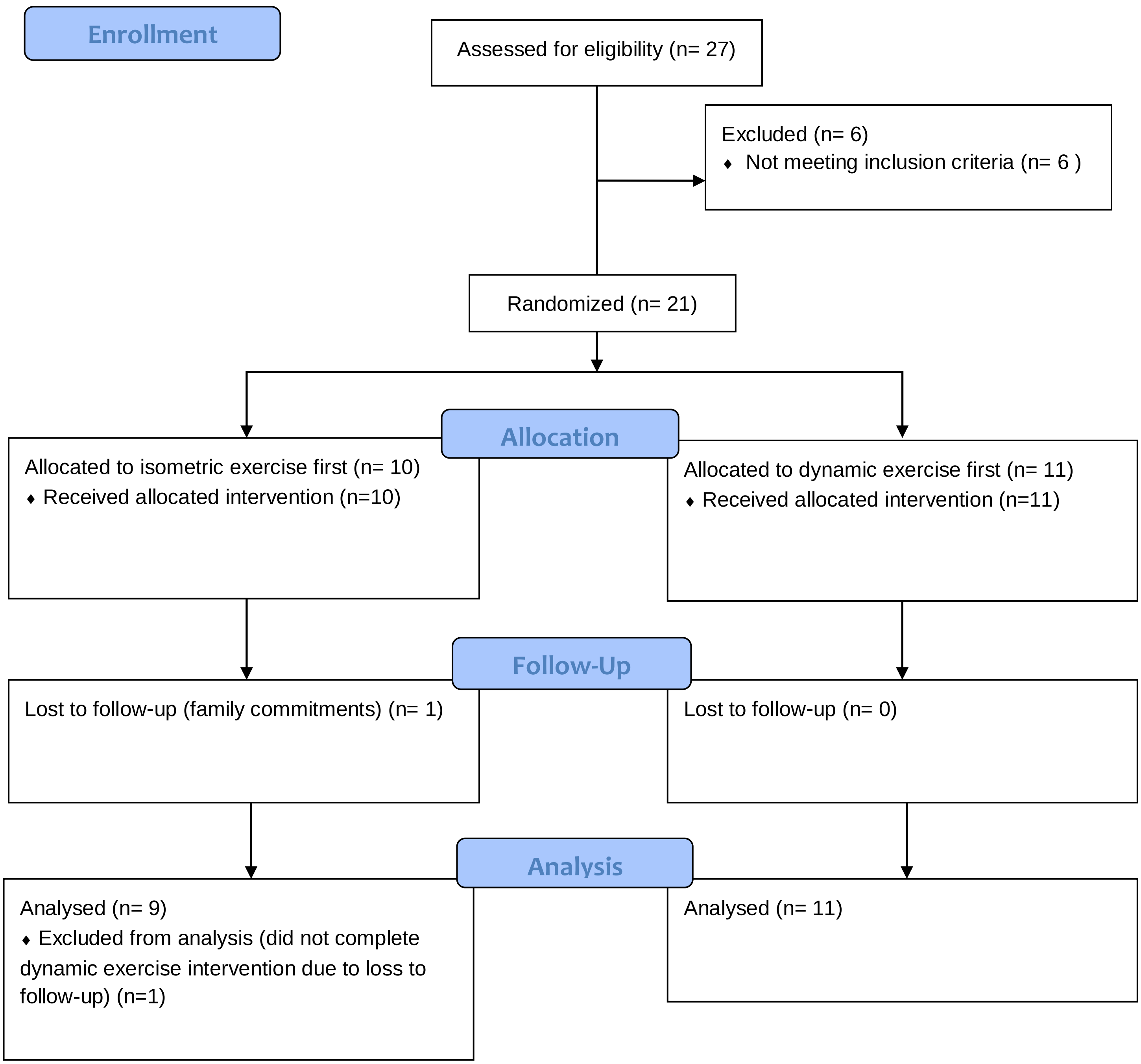
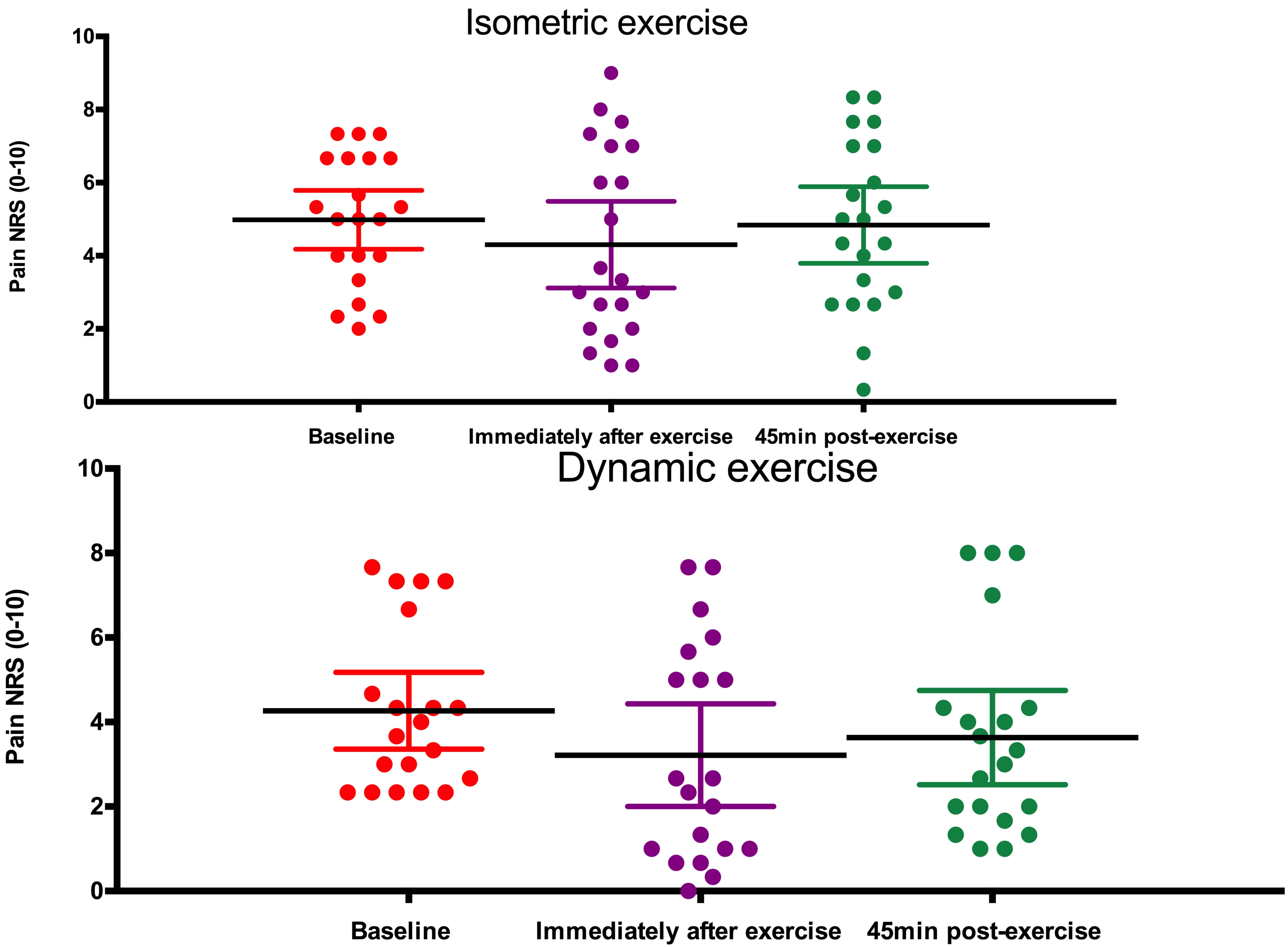
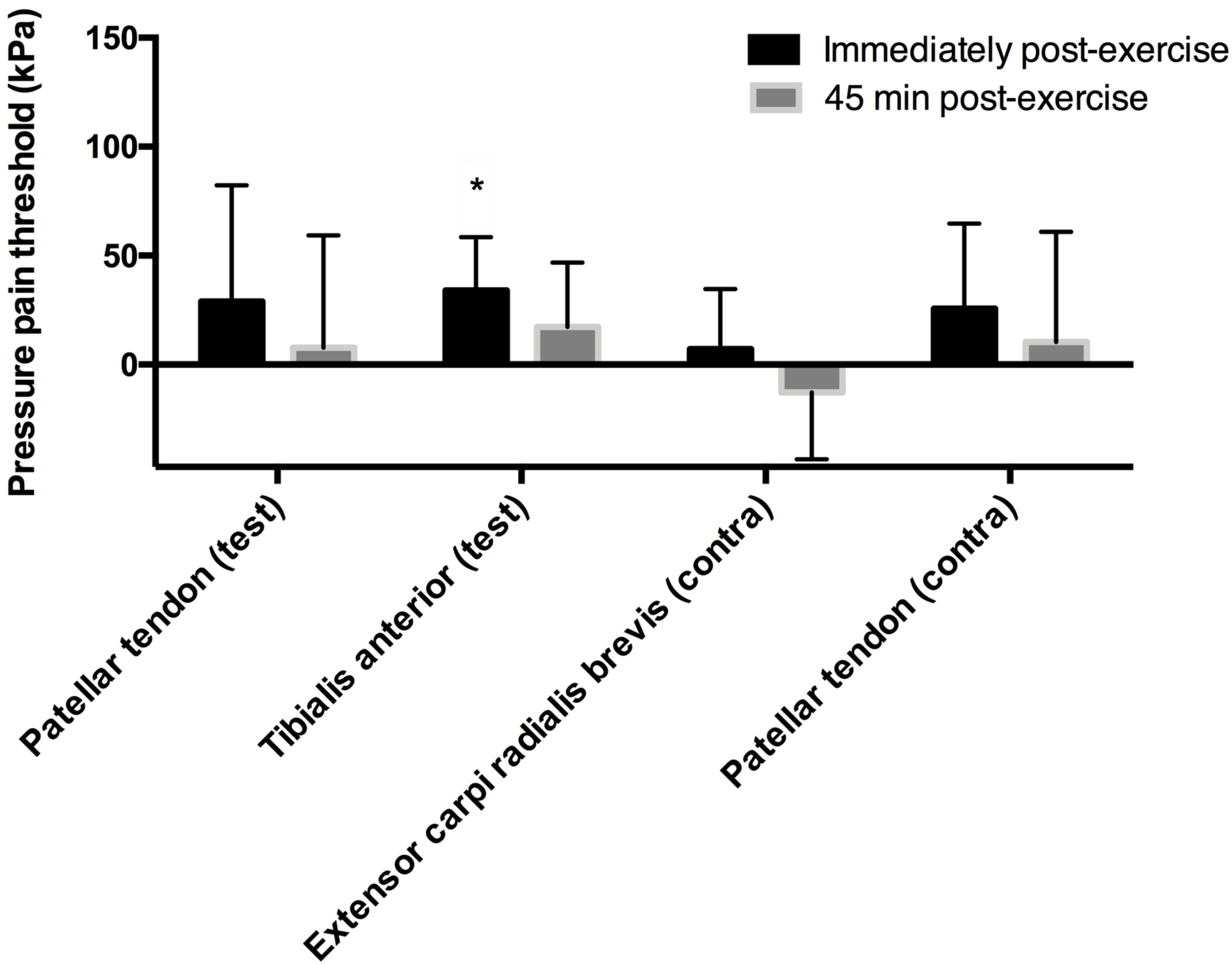


Enrollment
Assessed for eligibility (n= 27)
Excluded (n= 6)
♦ Not meeting inclusion criteria (n= 6)
Randomized (n= 21)
Allocation
Allocated to isometric exercise first (n= 10)
♦ Received allocated intervention (n=10)
Allocated to dynamic exercise first (n= 11)
♦ Received allocated intervention (n=11)
Follow-Up
Lost to follow-up (family commitments) (n= 1)
Lost to follow-up (n= 0)
Analysis
Analysed (n= 9)
♦ Excluded from analysis (did not complete dynamic exercise intervention due to loss to follow-up) (n=1)
Analysed (n= 11)



Isometric exercise
Pain NRS (0-10)
0
2
4
6
8
10
Baseline
Immediately after exercise
45min post-exercise
Dynamic exercise
Pain NRS (0-10)
0
2
4
6
8
10
Baseline
Immediately after exercise
45min post-exercise



Pressure pain threshold (kPa)
150
100
50
0
Immediately post-exercise
45 min post-exercise
*
Patellar tendon (test)
Tibialis anterior (test)
Extensor carpi radialis brevis (contra)
Patellar tendon (contra)

Age (years)	26.5 (6.4)
Sex (% female)	41
BMI* (kg/m^2)	25.6 (23.2 – 29.1)
VISA-P Score (0-100, 100 being best)	47.9 (11.6)
Symptom duration* (months)	24 (10 -84)
Bilateral pain (%)	52
Contact with health care practitioner due to knee pain (%Yes)	82
Worst pain past week (NRS points)	7.9 (1.6)
Mean pain past week (NRS points)	4.3 (1.6)
Weekly sports participation (h)	8.8 (4.2)

Table 1. Participant demographics and characteristics at baseline reported as mean (standard deviation) unless otherwise indicated (*: indicates median and inter-quartile range). VISA-P: Victorian Institute of Sport Assessment-Patella.

Time	Mean	95% CI
	Isometric	
Baseline	5	4.1 to 5.8
Immediately post- exercise	4.2	3.0 to 5.5
45 min post-exercise	4.8	3.7 to 5.9
	Isotonic	
Baseline	4.3	3.4 to 5.2
Immediately post- exercise	3.2	2.0 to 4.4
45 min post-exercise	3.6	2.5 to 4.7
	Difference (isometric – isotonic)	
Change from baseline to immediately post- exercise	-0.3	-1.3 to 0.7

	Time	Isometric		Dynamic		Mean difference Isometric *vs* Dynamic	
		Mean	**95% CI**	**Mean**	**95% CI**	**Change from baseline to post-exercise**	**95% CI**
PPT Patellar tendon (kPa)	***Baseline***	489	399 to 579	454	348 to 560		
	post-exercise	492	371 to 613	509	383 to 634	-53	-128 to 23
	45 min post-exercise	458	363 to 552	470	356 to 583		
PPT Tibialis Anterior (kPa)	***Baseline***	442	349 to 536	407	321 to 493		
	post-exercise	485	377 to 593	432	343 to 522	18	-38 to 73
	45 min post-exercise	456	349 to 546	427	337 to 518		
PPT contra-lateral extensor carpi radialis brevis (kPa)	***Baseline***	271	225 to 318	287	225 to 350		
	post-exercise	293	225 to 361	280	210 to 350	29	-14 to 72
	45 min post-exercise	263	15 to 332	270	214 to 326		
PPT contralateral patellar tendon (kPa)	***Baseline***	553	435 to 670	526	413 to 640		
	post-exercise	590	465 to 715	540	421 to 660	23	-63 to 110
	45 min post-exercise	559	432 to 687	541	417 to 664		
Patellar tendon	***Baseline***	0.5	0.45 to 0.55	0.51	0.47 to 0.55		

thickness (cm)	***post-exercise***	0.49	0.44 to 0.53	0.5	0.46 to 0.55	0.01	-0.04 to 0.03
	45 min post-exercise	0.5	0.45 to 0.55	0.51	0.46 to 0.55		

Table 2. Mean (95% CI) pressure pain threshold (PPT) and patellar tendon thickness at baseline, immediately post-exercise and 45min post-exercise.