

## Case study

## Efficacy of an inertial resistance training paradigm in the treatment of patellar tendinopathy in athletes: A case-series study

D. Romero-Rodriguez<sup>a,\*</sup>, G. Gual<sup>a,b</sup>, P.A. Tesch<sup>c</sup><sup>a</sup>Blanquerna Faculty of Health Sciences, Universitat Ramon Llull, Barcelona, Spain<sup>b</sup>Faculty of Medicine and Health Sciences, Universitat Internacional de Catalunya, Spain<sup>c</sup>Department of Health Sciences, Mid Sweden University, Östersund, Sweden

## ARTICLE INFO

## Article history:

Received 25 May 2010

Received in revised form

11 October 2010

Accepted 19 October 2010

## Keywords:

Patellar tendinopathy

Eccentric

Resistance training

Inertial resistance

## ABSTRACT

*Study design:* Case-series study with pre- vs. post-test measurements design.*Background:* Strength training programs emphasizing eccentric muscle actions have received much attention in the treatment of tendinopathies. The current study reports on the efficacy of a novel strength training paradigm using inertial eccentric-concentric resistance to treat chronic patellar tendinopathy.*Case description:* Ten athletes with chronic patellar tendinopathy (15 tendons) volunteered for the study. Subjects completed a 6-week training program employing a leg press flywheel ergometer. Pre and post measurements assessed lower limb maximal strength and vertical counter-movement-jump (CMJ) height. Surface electromyography (SEMG) analysis of paraspinal, rectus femoris, biceps femoris and medial gastrocnemius muscles were collected. All measurements were performed one week before and after the training period. Clinical measures of pain and tendon function were assessed by means of a visual analogue scale (VAS) and a patellar tendinopathy questionnaire (VISA) at baseline, post-training and follow-up (12 wk). The Wilcoxon signed-rank test was employed for data comparisons.*Results:* Eccentric strength increased after training (90%,  $p < 0.05$ ). Similarly, VAS and VISA scores improved after training as well (60% and 86%, respectively,  $p < 0.01$ ). There were no changes in CMJ height.*Conclusion:* Short-term training using inertial eccentric overload, resulted in improved muscle function and reduced subjective pain in long-lasting patellar tendinopathy.

© 2010 Elsevier Ltd. All rights reserved.

## 1. Background

Patellar tendinopathy is a frequent adverse issue in elite and recreational athletes participating in sports relying on high intensity or high volume running or hopping actions (Cook, Khan, Harcourt, Grant, Young, & Bonar, 1997; Khan et al., 1996). Its aetiology is associated with overuse leading to complaints of pain localized to the lower insertion of the patellar tendon, which typically appears during and after physical activity (Fredberg & Bolvig, 1999).

While conservative treatment of patellar tendinopathy typically comprises combinations of passive techniques, e.g., rest, ultrasound, electrotherapy (Brukner & Khan, 1993; Cook & Khan, 2001;

Ferretti, Ippolito, Mariani, & Puddu, 1983; Fredberg & Bolvig, 1999), few, if any, of these methods rest on evidence-based data. Indeed, these measures have not produced any positive effects in the treatment of chronic tendinopathy (Cook & Khan, 2001).

Strength training programs, and particularly those emphasizing eccentric muscle actions (Brockett, Morgan, & Proske, 2001; Frenette & Côté, 2000; Hortobagyi, Houmard, Fraser, Dudek, Lambert, & Tracy, 1998; LaStayo, Woolf, Lewek, Snyder-Mackler, Reich, & Lindstedt, 2003; Trappe, Carrithers, White, Lambert, Evans, & Dennis, 2002), have received much attention as potential aid in the treatment of tendinopathy. Overall, the results of past studies suggest that almost any training program employing supine or decline squats or devices offering eccentric overload (Bahr, Fossan, Løken, & Engebretsen, 2006; Cannell, Taunton, Clement, Smith, & Khan, 2001; Frohm, Halvorsen, & Thorstensson, 2005; Frohm, Saartok, Halvorsen, & Renström, 2007; Jonsson & Alfredson, 2005; Kongsgaard et al., 2009; Purdam, Jonsson, Alfredson, Lorentzon, Cook, & Khan, 2004; Rabin, 2006; Stasinopoulos & Stasinopoulos, 2004; Visnes & Bahr, 2007; Young, Cook, Purdam, Kiss, & Alfredson, 2005), could

\* Corresponding author. EUSES (University School of Sport and Health), Universitat de Girona, Francesc Macia 65, 17190 Salt, Girona, Spain. Tel.: +34 972405130; fax: +34 972400781.

E-mail address: [daniel.romero@cadscrits.udg.edu](mailto:daniel.romero@cadscrits.udg.edu) (D. Romero-Rodriguez).

improve clinical status and function in patients diagnosed with chronic tendinopathy. In spite of these investigations, eccentric training has been shown to have no effect in volleyball players with patellar tendinopathy (Visnes, Hoksrud, Cook, & Bahr, 2005). Nevertheless this intervention was carried out as home program training without direct supervision of a physical therapist.

The aim of the current study was to explore the effects of a novel strength training paradigm in treating athletes with chronic patellar tendinopathy. A leg press flywheel ergometer (Berg & Tesch, 1994), allowing for coupled eccentric-concentric muscle actions with eccentric overload through inertial resistance, was used for training. The efficacy of this particular exercise modality has been validated in studies employing healthy subjects (Askling, Karlsson, & Thorstensson, 2003; Tous-Fajardo, Maldonado, Quintana, Pozzo, & Tesch, 2006), old populations (Onambélé et al., 2008) and patients recovering from knee injuries (Greenwood, Morrissey, Rutherford, & Narici, 2007) but not in highly trained athletes suffering from chronic tendinopathy. We hypothesized that a short-term, low-frequency, yet highly intense resistance exercise program, using brief episodes of eccentric overload, would improve the clinical status and muscle function in these subjects.

**2. Case description**

*2.1. Study design*

This prospective case-series study employed an intervention group of subjects to compare a battery of performance features and clinical assessments before (baseline) and after completing a six week resistance training program (pre- vs. post-test design). The sport training activities were not restricted through the intervention, although we recommended stopping them if symptoms increased. Clinical assessment measures were also obtained 6 weeks after completing the intervention (follow-up at week 12; Fig. 1). All trials, tests and training sessions were carried out at the Blanquerna Biomechanics Laboratory (Ramon Llull University), were supervised by two of the investigators (DR and/or GG). The study protocol was approved by the Ramon Llull University Ethic and Research's Committee.

*2.2. Subjects*

Ten male athletes diagnosed with either unilateral or bilateral chronic patellar tendinopathy and recruited from the greater Barcelona region, complied with the study inclusion and exclusion criteria listed in Table 1. Patellar tendinopathy was diagnosed in every case by a medical doctor, echographic study was conducted in the subjects they considered after a detailed physical examination. The volunteers were fully informed about the purpose, commitments and potential risks associated with the study before

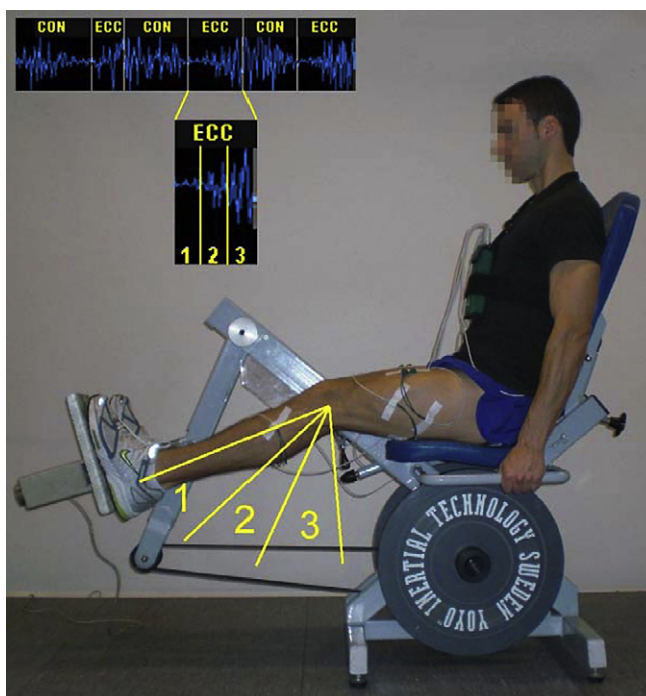
**Table 1**  
Inclusion and exclusion criterions.

Inclusion criteria	<ul style="list-style-type: none"> <li>■ Male</li> <li>■ 18–35 years old.</li> <li>■ Physically active (training/competition &gt;3 d/w).</li> <li>■ Chronic patellar tendinopathy diagnosis (lasting for a minimum period of 6 wk, uni- or bilateral).</li> </ul>
Exclusion criteria	<ul style="list-style-type: none"> <li>■ Other knee injuries (e.g., ligament rupture, meniscus or cartilage damage).</li> <li>■ Any knee surgery.</li> <li>■ Subjects undergoing invasive treatment or using orthotics.</li> <li>■ Other exclusion factors, e.g., systemic, cardiac and/or respiratory diseases and neuromuscular disorders (e.g., Parkinson's disease, multiple sclerosis, stroke or peripheral neuropathy).</li> </ul>

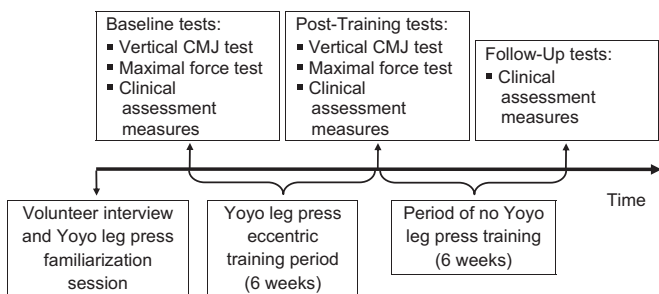
informed written consent was obtained. Age, height and body mass averaged ( $\pm$ SD)  $25 \pm 6$  yr,  $178 \pm 8$  cm and  $77.5 \pm 11$  kg. The treatment group comprised seven football (soccer) and two basketball players, and one distance runner, all competing at national level. While five of these athletes were diagnosed with unilateral tendinopathy, the remaining five displayed bilateral tendinopathy. Hence, there were 15 patellar tendons examined in the current study. When entering the study, the pain associated with the diagnosis had persisted for 31.7 (range 6–96) weeks. Knowing sport activities were not restricted, 5 out of the 10 athletes decided to continue training in their sport clubs while following the intervention process.

*2.3. Instrumentation and procedure*

Muscle strength was measured with use of a force-platform device using strain-gauge technique, attached onto the lever arm of the leg press device (Fig. 2), provided by the manufacturer (YoYo Technology AB, Stockholm, Sweden). This force gauge device summed the force from both feet acting on the platform (Berg &



**Fig. 2.** Leg press machine with a schematic representation of the 3 kinematic windows and recording of SEMG activity during the maximal force test.



**Fig. 1.** Study protocol.

Tesch, 1994). The measuring system is compatible with the MuscleLab 3010 system used for force data acquisition and analysis (Ergotest, Langesund, Norway).

Surface electromyography (SEMG) activity was measured by the Noraxon TeleMyo 900 system (Noraxon, Scottsdale, Arizona, USA) at a sample frequency of 1000 Hz. The signal was rectified, filtered (high pass: 10 Hz; low pass: 500 Hz) and smoothed (100 ms) with use of Noraxon MyoResearch 2.10 software (Noraxon, Scottsdale, Arizona, USA), following the recommendations by SENIAM (Hermens et al., 1999). The root-mean-square (RMS) of the EMG amplitude was obtained from both sides of lumbar paraspinal muscles at L3 level (ES-R and ES-L), rectus femoris (RF-R and RF-L), biceps femoris (BF-R and BF-L) and medial gastrocnemius (MG-R and MG-L), according to the Cram and Kasman location (Cram & Kasman, 1998). The skin area of muscles to be examined was lightly abraded to reduce skin impedance. Anthropometric landmarks ensured identical electrode position across tests. Bipolar surface electrodes (Ambu® Blue Sensor N-00-S, Ambu A/S, Ballerup, Denmark) were placed longitudinally over the muscle belly in the fiber direction. A reference electrode was positioned over the right tibial bone.

SEMG sampling was synchronised with kinematic data collection using the ELITE Motion Analyser System (BTS Bioengineering, Milan, Italy), allowing for three-dimensional motion assessment at a frequency of 100 Hz. This kinematic analysis was performed in the Vertical counter-movement-jump (CMJ) and the Maximal force tests to differentiate the movement phases of these actions. Markers were placed either at the spinal process of L3 and the toe tip and heel of both feet (CMJ), or on the lateral malleolus (Maximal force test).

Patellar tendon pain and function were assessed by means of a visual analogue scale (VAS) (Paul-Dauphin, Guillemin, Virion, & Briancon, 1999; Price, McGrath, Rafii, & Buckingham, 1983), and the Victorian Institute of Sports Assessment (VISA) questionnaire (Visentini, Khan, Cook, Kiss, Harcourt, & Wark, 1998). Given our particular subject sample, we employed a Spanish translated version of the VISA questionnaire (Taunton, Lloyd-Smith, & Johnston, 2004). Related to VAS, the formulated question was “How much pain do you have right now?”

#### 2.4. Strength training protocol

Subjects trained two times per week with at least two days of rest between sessions (Table 2). All sessions were supervised by one of the investigators (DR or GG). Following a standardized warm-up, the subjects performed four sets of 10 maximal bilateral coupled concentric and eccentric actions on the leg press device. The first two actions of each set were aimed at accelerating the flywheel (one single flywheel with moment inertia of 0.1452 kg m<sup>2</sup>). The subsequent eight actions were performed with maximal effort,

accelerating the wheel in the concentric action and upon completion, decelerating the wheel by means of an eccentric action. The concentric phase was executed from about 90° knee angle to almost full extension about the knee joint. The flywheel strap then rewinded by virtue of the inertial force thus initiating a reversed eccentric action. Subjects were instructed to resist gently during the first two thirds of the eccentric action and then apply maximal force to bring the wheel to a stop at approximately 90°. Thus eccentric overload was achieved in the last third of any eccentric action (window 3; Fig. 2). Following completion of a full cycle, a concentric action was instantly initiated. There was a 2 min rest between sets.

#### 2.5. Evaluation tests

All test acquisitions were carried out using an identical protocol and sequence one week before (baseline) and after the 6 week training program (Fig. 1). An orientation and familiarization session, which included performance of 3 sets of 10 repetitions at moderate intensity on the leg press device, preceded baseline testing.

##### 2.5.1. Maximal voluntary contraction (MVC) test

Prior to any test, MVC was determined based on three 5 s maximal isometric actions. EMG activity was measured concurrently and the highest mean RMS EMG value recorded for each muscle in any 3 s window was considered maximal EMG activity. This approach allowed us to compare any EMG data obtained in the battery of tests performed (i.e., normalized data).

##### 2.5.2. Vertical counter-movement-jump (CMJ) test

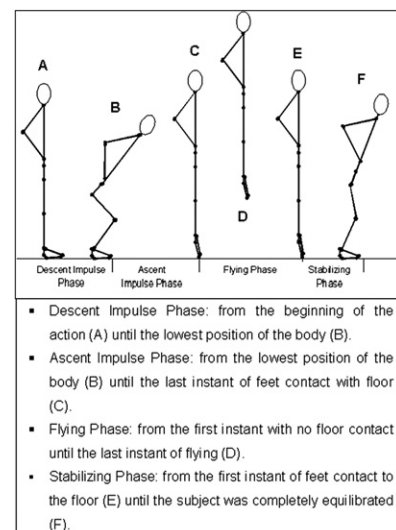
While standing on the floor with hands resting on the iliac crests, subjects were instructed to perform a maximal vertical CMJ three times. The vertical displacement of the L3 mark was used to determine jump height. All markers were used to kinematically determine RMS EMG activity in the different phases of the jump (Fig. 3). The maximal jump height and RMS EMG activity in each jump phase were data processed from the three trials.

##### 2.5.3. Maximal force test

While seated in the leg press device, subjects were instructed to execute one set of 5 bilateral actions, i.e., two submaximal actions preceded three actions with maximal effort. The malleolus

**Table 2**  
Training session.

Warm-up	<ul style="list-style-type: none"> <li>Passive stretching exercises with progressive tension for 10 s of: paraspinals, major gluteus, medial gluteus, piriformis, iliopsoas, quadriceps, adductors, hamstrings and gastrocnemius muscles.</li> <li>Aerobic exercise at 75% of the estimated Max HR: 4 min of intensity progression; 5 min at 75% and 1 min cool-down.</li> <li>Active stretching exercises with eccentric tension for 6 s of the quadriceps and hamstrings muscle groups.</li> </ul>
Training	<ul style="list-style-type: none"> <li>Resistance exercise using Yoyo® Leg Press: 4 sets of 10 repetitions (reps 3–10 with maximal effort) with 2 min rest between sets.</li> </ul>
Cool-down	<ul style="list-style-type: none"> <li>Aerobic exercise at 60% of the estimated Max HR for 6 min.</li> <li>Passive stretching exercises with progressive tension for 20 s (see Warm-up).</li> </ul>



**Fig. 3.** Kinematic phases of vertical CMJ.

landmark was used to define the start and stop of each action. Thus, each action was divided in three periods with identical displacement of the malleolus marker, obtaining three concentric and three eccentric periods. Subjects were instructed to apply maximal effort during the whole concentric action in order to accelerate the wheel and only in the last third of the eccentric action in order to break down the wheel (period number 3, Fig. 2). The RMS EMG activity of both limbs rectus femoris muscles and the concentric and eccentric mean force were analyzed in the first third of the concentric action and in the last third of the eccentric action. This procedure was carried out for the three maximal repetitions, obtaining a mean value for concentric and another for eccentric actions.

2.5.4. Clinical assessment measures

VAS and VISA scores were collected in three different time points: the week before (baseline) and after (post-training 6 weeks) the training program, and six weeks after finishing the intervention (follow-up 12 weeks).

2.6. Statistical analysis

Data were analyzed with SPSS 11.0 (SPSS Inc., Chicago, IL, USA). Normalized tests (Kolmogorov–Smirnov and Shapiro–Wilk) were applied to all examined variables. Given the small subject sample size and lack of normal data distribution, Wilcoxon signed-rank test was used for pre-post test comparisons (baseline vs. post-training). With regard to VAS and VISA assessments, Wilcoxon test was also applied for the post-training vs. follow-up comparisons. The level of significance was set at  $p < 0.05$ .

3. Results

3.1. Vertical counter-movement-jump (CMJ)

Maximal CMJ height did not show change in response to training; however 7 out of the 10 subjects showed increased CMJ height. RMS EMG activity of rectus femoris and erector spinae of the injured knees during the descent phase decreased after training (80%,  $p = 0.01$  and 66%  $p = 0.02$ , respectively). There were no pre-post differences in EMG activity of other studied muscles in any of the CMJ phases.

3.2. Maximal force

Maximal eccentric force increased (90%,  $p = 0.03$ ) following training. There was a trend for increased maximal concentric force (70%). For details see Table 3 and Figs. 4 and 5. Concentric RMS EMG activity of rectus femoris of the injured limb decreased (73%,  $p = 0.03$ ) after training, and there was a trend for increased eccentric RMS EMG activity of this muscle (66%).

3.3. Clinical assessment measures

Patellar tendon pain, as assessed by VAS, decreased after training (60%,  $p < 0.01$ ). Likewise, VISA questionnaire showed improved functional capacity and performance after training (86%,  $p < 0.01$ ).

Table 3  
Maximal force results.

	Post-Pre	
	Increase: Number/Total (%)	95% CI
Concentric mean force	7/10 (70)	42–98
Eccentric mean force	9/10 (90)*	71–100*

% = percentage showing increase; CI = confidence interval; \*significant change.

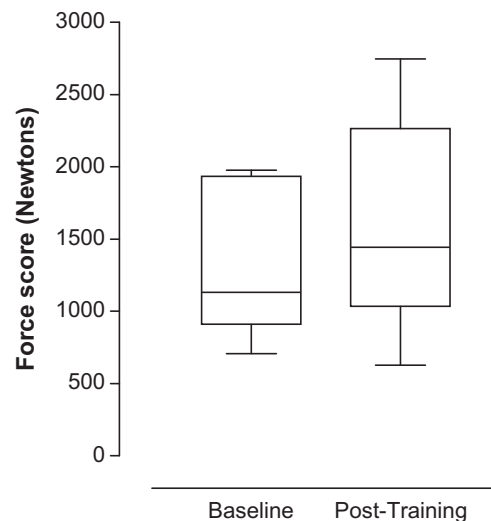


Fig. 4. Leg press concentric force (box-plot graph).

There were no further changes in VAS or VISA at the 12 week follow-up compared to post-training (Table 4; Figs. 6 and 7).

4. Discussion

The current investigation reports marked clinical improvement accompanied by increased strength and neuromuscular activation in response to eccentric overload resistance training in athletes suffering from chronic patellar tendinopathy. Albeit our findings at large support earlier reports (Bahr et al., 2006; Cannell et al., 2001; Frohm et al., 2007; Jonsson & Alfredson, 2005; Kongsgaard et al., 2009; Purdam et al., 2004; Rabin, 2006; Stasinopoulos & Stasinopoulos, 2004; Visnes & Bahr, 2007; Young et al., 2005), they are novel in that these positive results were prompted by a short-term, low-frequency intervention (6 weeks; 12 exercise sessions; <24 min contractile activity), characterized by maximal effort and eccentric overload in each repetition, and employed in highly trained athletes.

While eccentric mean force increased in response to training, concentric mean force showed no significant increase. Yet, there

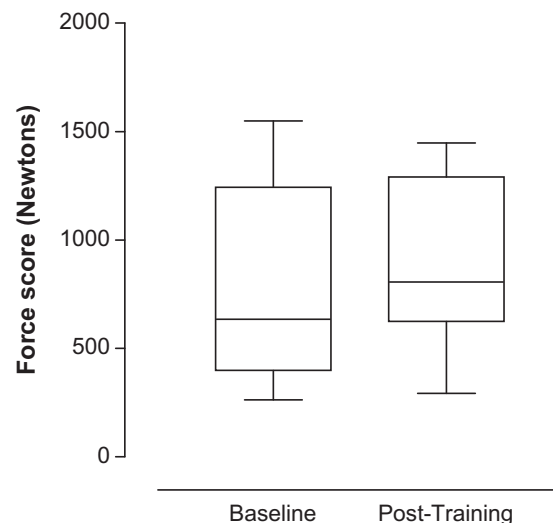


Fig. 5. Leg press eccentric force (box-plot graph).

**Table 4**  
Clinical assessment results.

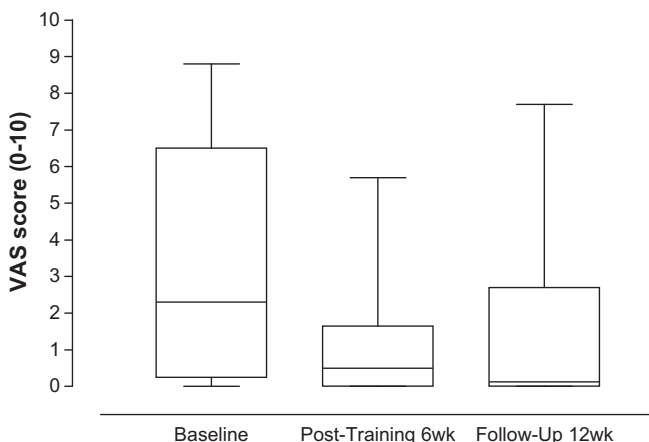
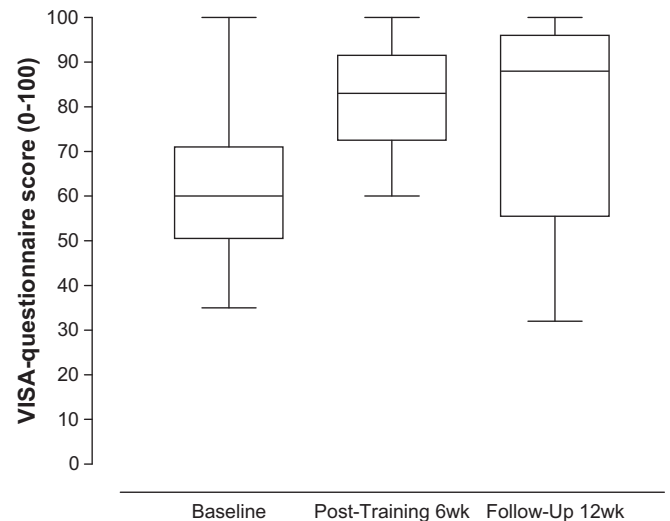
	Post–Pre		Control–Post	
	Improvement: Number/Total (%)	95% CI	Improvement: Number/Total (%)	95% CI
VAS	9/15 (60)*	35–85	6/14 (43)	11–67
VISA	13/15 (87)*	64–98*	6/10 (60)	27–87

% = percentage of improvement; CI = confidence interval; \*significant change.

was an overall robust increase in muscle strength. In this context, the substantial inter-individual variation in muscle strength and subjective pain, both before and after the intervention, should be acknowledged. This is an inherent problem in any study involving subjects in pain and calling for cooperation while performing exercise at maximal voluntary effort. Hence, the statistical power required to show significant responses to any exercise intervention is typically rather substantial.

No previous study, exploring the efficacy of strength training emphasizing eccentric actions in the treatment of patellar tendinopathy, have reported EMG activity along with changes in muscle strength or function. The results of the maximal force test, assessed using the same device where subjects carried out the training, showed a correlation between the increase of rectus femoris activity and strength during the eccentric action. Even taking into account concentric action also showed a tendency to increase in strength, rectus femoris EMG activity decreased in this action. One possible explanation could be the task-specificity carried out, i.e., although the concentric action was not eliminated during the task, the investigators pointed out the need to apply all the effort in the last third of the eccentric action, thus achieving higher strength improvements in the lengthening phase comparing to the shortening one.

The rectus femoris and paraspinal muscles of the injured limb showed decreased EMG activity in the CMJ impulse phase and this was accompanied by a non-significant increase in CMJ height. Again, the increase in maximal strength, noted in the maximal force test, had no or minimal impact on performance in the more explosive CMJ task. Similarly, neither Bahr et al. (2006) nor Frohm et al. (2007) reported improved performance in the CMJ as a result of strength training involving eccentric actions. Collectively, while the benefits of eccentric training in reducing pain were substantial, it appears the associated improvements in muscle function were more subtle.

**Fig. 6.** Subjective pain measured by VAS (box-plot graph).**Fig. 7.** Subjective pain and tendon function measured by VISA questionnaire (box-plot graph).

Signs of clinical improvement in response to resistance training comprising eccentric actions in patients diagnosed with patellar tendinopathy, were reported more than twenty years ago (Stanish, Rubinovich, & Curwin, 1986). As reviewed by Visnes and Bahr (2007), more recent work have ascribed the reduced pain associated with patellar tendinopathy to the effects of the eccentric exercise component *per se* (Cannell et al., 2001; Frohm et al., 2007; Jonsson & Alfredson, 2005; Purdam et al., 2004; Stasinopoulos & Stasinopoulos, 2004; Young et al., 2005). However, the preferred exercise paradigm or specifics of contractile activity exercise triggering this response, remains to be defined.

Albeit our study design did not allow us to compare the efficacy across studies, we believe the reported results were caused by the intervention because pain scores were not attenuated further over a 6 week period following completion of the training program. This is noteworthy given the long-lasting clinical assessment of the patients examined here (exceeding on average 30 weeks).

To our knowledge, no previous study employed inertial resistance training to produce eccentric overload actions; an approach that has shown efficacy in healthy and trained individuals (Askling et al., 2003; Tous-Fajardo et al., 2006), older men and women (Onambélé et al., 2008), and patients recovering from knee trauma or surgery (Greenwood et al., 2007). Subjects in the current study were requested to apply maximal force in the concentric action. In the subsequent eccentric action, modest effort was applied at the beginning, and eccentric overload was produced in a narrow window in the last third of the movement. At first, this approach may appear somewhat challenging in lieu of the reported negative effects of isolated concentric resistance training (Jonsson & Alfredson, 2005), obviously producing much less force and hence tendon strain in the treatment of subjects with patellar tendinopathy. If anything, the current results are commensurate with that forceful stretch-shortening actions can be tolerated and indeed reduce pain and symptoms of patellar tendinopathy.

Following this trend, Kongsgaard et al. (2009) compared corticosteroid injection vs. isolated eccentric actions and heavy slow resistance training. The last group showed better improvements and combined eccentric and concentric muscle actions, as we have registered in our own study. One of the possible reasons to explain these results is the benefits the eccentric-concentric transitions may have in the chronically degenerated tendon, a possible research topic for further studies.

The positive clinical outcomes along with the improved muscle function shown here supports the implementation of high intensity, low-frequency exercise protocols emphasizing brief episodes of eccentric overload in the treatment of chronic patellar tendinopathy in athletes. It is worth noting that no more than 12 training sessions were performed over the 6 week intervention, and less than 24 min were dedicated to muscle contractile activity.

While our results are encouraging it remains to be proven whether the efficacy of this high eccentric force, low volume and frequency intervention, is superior to other exercise strategies using greater volume and/or different eccentric exercise paradigms. On the other hand, it is important to point out the limitations of the present study. The lack of control group, even taking into account it is difficult to create one in a sport population looking to improve the functionality as fast as possible, is a major issue to bear in mind. Future studies using larger sample sizes should be designed such that the decisive stimulus (e.g., amplitude or rate of stretch, force of action, bilateral or unilateral execution) of the eccentric-concentric action (emphasizing on the eccentric phase) that triggers adaptations resulting in reduced pain in patients with chronic patellar tendinopathy, could be identified. The results of the current study suggest that resistance training by means of inertial resistance, aids in the treatment of chronic patellar tendinopathy.

#### Ethical statement

The current study protocol was approved by the Ramon Llull University Ethic's and Research's Committee.

The volunteers participating in the study were fully informed about the purpose, commitments and potential risks associated with the study before an informed written consent was obtained.

#### Conflict of interest statement

The authors declare that they have no conflict of interests.

Dr Per A. Tesch is a co-owner of YoYo Technology AB. Dr Tesch has not participated in the intervention process, nor the data acquisition and analysis of this study.

#### Acknowledgements

We acknowledge Lluís Costa for valuable advice on statistical analysis, and the Blanquerna Biomechanics Laboratory's staff for advanced technical support.

This study was supported by the Professional Catalonian Board of Physiotherapy (Barcelona, Spain).

#### References

- Asklings, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian Journal of Medicine & Sciences in Sports*, 13(4), 244–250.
- Bahr, R., Fossan, B., Løken, S., & Engebretsen, L. (2006). Surgical treatment compared with eccentric training for patellar tendinopathy (Jumper's Knee). A randomized, controlled trial. *Journal of Bone and Joint Surgery, American Volume*, 88(8), 1689–1698.
- Berg, H. E., & Tesch, P. A. (1994). A gravity-independent ergometer to be used for resistance training in space. *Aviation, Space and Environmental Medicine*, 65(8), 752–756.
- Brockett, C. L., Morgan, D. L., & Proske, U. (2001). Human hamstring muscles adapt to eccentric exercise by changing optimum length. *Medicine and Science in Sports and Exercise*, 33(5), 783–790.
- Brukner, P., & Khan, K. M. (1993). *Clinical sports medicine*. Sydney, Australia: McGraw-Hill.
- Cannell, L. J., Taunton, J. E., Clement, D. B., Smith, C., & Khan, K. M. (2001). A randomized clinical trial of the efficacy of drop squats or leg extension/leg curl exercises to treat clinically diagnosed jumper's knee in athletes: pilot study. *British Journal of Sports Medicine*, 35(1), 60–64.
- Cook, J. L., & Khan, K. M. (2001). What is the most appropriate treatment for patellar tendinopathy? *British Journal of Sports Medicine*, 35(5), 291–294.
- Cook, J. L., Khan, K. M., Harcourt, P. R., Grant, M., Young, D. A., & Bonar, S. F. (1997). A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. The Victorian Institute of Sport Tendon Study Group. *British Journal of Sports Medicine*, 31(4), 332–336.
- Cram, J. R., & Kasman, G. S. (1998). *Introduction to surface electromyography*. Gaithersburg, MD, U.S.: Aspen Publishers Inc.
- Ferretti, A., Ippolito, E., Mariani, P., & Puddu, G. (1983). Jumper's knee. *American Journal of Sports Medicine*, 11(2), 58–62.
- Fredberg, U., & Bolvig, L. (1999). Jumper's knee: review of literature. *Scandinavian Journal of Medicine & Science in Sports*, 9(2), 66–73.
- Frenette, J., & Côté, C. H. (2000). Modulation of structural protein content of the myotendinous junction following eccentric contractions. *International Journal of Sports Medicine*, 21, 313–320.
- Frohm, A., Halvorsen, K., & Thorstensson, A. (2005). A new device for controlled eccentric overloading in training and rehabilitation. *European Journal of Applied Physiology*, 94, 168–174.
- Frohm, A., Saartok, T., Halvorsen, K., & Renström, P. (2007). Eccentric treatment for patellar tendinopathy: a prospective randomised short-term pilot study of two rehabilitation protocols. *British Journal of Sports Medicine*, 41, e7.
- Greenwood, J., Morrissey, M. C., Rutherford, O. M., & Narici, M. V. (2007). Comparison of conventional resistance training and the fly-wheel ergometer for training the quadriceps muscle group in patients with unilateral knee injury. *European Journal of Applied Physiology*, 101, 697–703.
- Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., et al. (1999). *European recommendations for surface ElectroMyoGraphy: Results of the SENIAM Project*. Enschede, The Netherlands: Roessing Research and Development.
- Hortobagyi, T., Houmar, J., Fraser, D., Dudek, R., Lambert, J., & Tracy, J. (1998). Normal forces and myofibrillar disruption after repeated eccentric exercise. *Journal of Applied Physiology*, 84(2), 492–498.
- Jonsson, P., & Alfredson, H. (2005). Superior results with eccentric compared to concentric quadriceps training in patients with jumper's knee: a prospective randomised study. *British Journal of Sports Medicine*, 39, 847–850.
- Khan, K. M., Bonar, F., Desmond, P. M., Cook, J. L., Young, D. A., Visentini, P. J., et al. (1996). Patellar tendinosis (jumper's knee): findings at histopathologic examination, US, and MR imaging. Victorian Institute of Sport Tendon Study Group. *Radiology*, 200, 821–827.
- Kongsgaard, M., Kovanen, V., Aagaard, P., Doessing, S., Hansen, P., Laursen, A. H., et al. (2009). Corticosteroid injections, eccentric decline squat training and heavy slow resistance training in patellar tendinopathy. *Scandinavian Journal of Medicine & Science in Sports*, 19, 790–802.
- LaStayo, P. C., Woolf, J. M., Lewek, M. D., Snyder-Mackler, L., Reich, T., & Lindstedt, S. L. (2003). Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation and sport. *Journal of Orthopaedic and Sports Physical Therapy*, 33, 557–571.
- Onambélé, G. L., Maganaris, C. N., Mian, O. S., Tam, E., Rejc, E., McEwan, I. M., et al. (2008). Neuromuscular and balance responses to flywheel inertial versus weight training in older persons. *Journal of Biomechanics*, 41, 3133–3138.
- Paul-Dauphin, A., Guillemin, F., Virion, J.-M., & Briançon, S. (1999). Bias and precision in visual analogue scales: a randomized controlled trial. *American Journal of Epidemiology*, 150(10), 1117–1127.
- Price, D. D., McGrath, P. A., Rafii, A., & Buckingham, B. (1983). The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain*, 17, 45–56.
- Purdam, C. R., Jonsson, P., Alfredson, H., Lorentzon, R., Cook, J. L., & Khan, K. M. (2004). A pilot study of the eccentric decline squat in the management of painful chronic patellar tendinopathy. *British Journal of Sports Medicine*, 38, 395–397.
- Rabin, A. (2006). Is there evidence to support the use of eccentric strengthening exercises to decrease pain and increase function in patients with patellar tendinopathy? *Physical Therapy*, 86(3), 450–456.
- Stanish, W. D., Rubinovich, R. M., & Curwin, S. (1986). Eccentric exercise in chronic tendinitis. *Clinical Orthopaedics & Related Research*, 208, 65–68.
- Stasinopoulos, D., & Stasinopoulos, I. (2004). Comparison of effects of exercise programme, pulsed ultrasound and transverse friction in the treatment of chronic patellar tendinopathy. *Clinical Rehabilitation*, 18(4), 347–352.
- Taunton, J., Lloyd-Smith, R., & Johnston, C. (2004). Pierna. In G. S. Kolt, & L. Snyder-Mackler (Eds.), *Fisioterapia del deporte y el ejercicio* (pp. 442). Madrid, Spain: Elsevier.
- Tous-Fajardo, J., Maldonado, R. A., Quintana, J. M., Pozzo, M., & Tesch, P. A. (2006). The flywheel leg-curl machine: offering eccentric overload for hamstring development. *International Journal of Sports Physiology and Performance*, 1, 293–298.
- Trappe, T. A., Carrithers, J. A., White, F., Lambert, C. P., Evans, W. J., & Dennis, R. A. (2002). Titin and nebulin content in human skeletal muscle following eccentric resistance exercise. *Muscle & Nerve*, 25, 289–292.
- Visentini, P. J., Khan, K. M., Cook, J. L., Kiss, Z. S., Harcourt, P. R., & Wark, J. D. (1998). The VISA score: an index of severity of symptoms in patients with jumper's knee (patellar tendinosis). Victorian Institute of Sport Tendon Study Group. *Journal of Science and Medicine in Sport*, 1(1), 22–28.
- Visnes, H., & Bahr, R. (2007). The evolution of eccentric training as treatment for patellar tendinopathy (jumper's knee): a critical review of exercise programmes. *British Journal of Sports Medicine*, 41, 217–223.
- Visnes, H., Hoksrud, A., Cook, J., & Bahr, R. (2005). No effect of eccentric training on jumper's knee in volleyball players during the competitive season: a randomized clinical trial. *Clinical Journal of Sports Medicine*, 15(4), 227–234.
- Young, M. A., Cook, J. L., Purdam, C. R., Kiss, Z. S., & Alfredson, H. (2005). Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. *British Journal of Sports Medicine*, 39(2), 102–105.