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Effects of 8 weeks of eccentric exercise and extracorporeal shockwave therapy on tendon tissue, perceived pain, and muscle power and strength in athletes diagnosed with patellar tendinopathy: A longitudinal study

Efectos de 8 semanas de ejercicio excéntrico y terapia de ondas de choque extracorpóreas sobre el tejido tendinoso, dolor percibido, potencia y fuerza muscular en atletas diagnosticados con tendinopatía rotuliana: un estudio longitudinal

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Abstract. Background: Patellar tendinopathy (PT) is an injury with a high prevalence in athletes that causes pain, loss of strength and sport performance levels. Purpose: to analyse the effects of 8 weeks of a conservative physical rehabilitation program that combine eccentric exercise (EE), stretching, extracorporeal shockwave therapy (ESWT), and manual therapy on tendon tissue, perceived pain, and muscle power and strength in athletes diagnosed with PT. Material and methods: Eight athletes diagnosed with PT, performed 8 weeks of EE, stretching, and ESWT. At the beginning (PRE), at 4-weeks (INT), and at the end of the 8-week intervention (POST), participants performed a countermovement jump test (CMJ), and a gradual back squat (BS) test to determine peak power (PP), mean velocity in PP (PP_{MV}), and load lifted (PP_{KG}). Furthermore, a maximum test of 5-repetition (5-RM) was evaluated in leg extension exercise, perceived pain using the Victorian Institute of Sport Assessment-Patella scale (VISA-P), and thickness in the injured and uninjured knee. Results: It was reported a lower tendon thickness POST vs. PRE in the injured knee (p=0.045), and lower values compared to the uninjured knee at PRE (p=0.004), and INT (p=0.025), but not POST (p=0.123). The CMJ and 5-RM tests showed statistical differences POST vs. PRE, and INT ($p<0.05$). Regarding BS, differences were reported in PP_{KG} POST vs PRE (p=0.033), and INT (p = 0.007), while in PP differences were found in POST vs PRE (p=0.037). Conclusions: 8 weeks of EE, stretching, ESWT, and manual therapy induce positive effects on tendon tissue healing, lower limbs muscle power and strength performance in athletes with PT.

Keywords: Injury, Physiotherapy, Rehabilitation, Recovery, Return to play, Tendinopathy.

Resumen. Antecedentes: La tendinopatía rotuliana (TR) es una lesión con una alta prevalencia en deportistas que causa dolor, pérdida de fuerza y rendimiento deportivo. Objetivo: analizar el efecto de 8 semanas de tratamiento un programa de rehabilitación conservador que incluye entrenamiento excéntrico (EE), estiramientos y ondas de choque extracorpóreas (OCE) y terapia manual sobre la rigidez tendinosa, dolor percibido, potencia y fuerza muscular en atletas diagnosticados de TR. Material y método: ocho deportistas diagnosticados con TR realizaron 8 semanas de EE, estiramientos y OCE. Al inicio (PRE), 4 semanas (INT) y al finalizar las 8 semanas de intervención (POST), los participantes realizaron un test de salto con contramovimiento (CMJ), un test incremental en sentadilla para determinar la potencia pico (PP), velocidad media a PP (PP_{MV}) y carga levantada (PP_{KG}). También, se midió un test de 5 repeticiones máximas (5-RM) en el ejercicio de extensión de rodillas, así como el dolor percibido usando la escala para TR del Victorian Institute of Sport Assessment (VISA-P) y el grosor del tendón rotuliano de la pierna lesionada y no lesionada. Resultados: se reportó una menor rigidez del tendón en la pierna lesionada en el PRE vs. POST (p=0,045), también se encontraron diferencias con respecto a la pierna no lesionada en el PRE (p=0,004) y INT (p=0,025), pero no en el POST (p=0,123). En el test de 5-RM y el CMJ se registraron diferencias en el POST vs. PRE e INT ($p<0,05$). En cuanto a la sentadilla, se reportaron diferencias en PP_{KG} POST vs. PRE (p=0,0333) e INT (p=0,007) mientras que en el PP se encontraron diferencias estadísticamente significativas únicamente en POST vs. PRE (p=0,037). Conclusiones: 8 semanas de EE, estiramientos, OCE y terapia manual induce a efectos positivos sobre la rigidez del tendón, la potencia y fuerza muscular de las extremidades inferiores en atletas con TR.

Palabras clave: Lesión, Fisioterapia, Rehabilitación, Recuperación, Vuelta a la competición, Tendinopatía.

Introduction

In sport modalities that require sprint and jumps, performance is influenced by the ability to generate a large amount of force in short periods of time (rate of force development, RFD) that is closely related to maximal power (Pérez-Castilla & Amador-Ramos, 2021). Muscle power reflects the relationship between load and velocity, and maximal power. Muscle power is one of the major determinants of sport performance in numerous sport modalities (Baker, Nance & Moore, 2001; Cronin & Sleivert, 2005). In resistance training has been established a relationship between mean velocity and a relative loading magnitude in resistance

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exercises (e.g., percentage of the 1 repetition maximum) (González-Badillo & Sánchez-Medina, 2010). Therefore, velocity- and power-load relationship in half squat has been studied, including the optimal load for reaching maximal power (Martínez-Cava et al., 2019). Further, vertical jumps as countermovement jump (CMJ) require brief contraction times and high RFD (Lago-Rodríguez et al., 2021), and are associated with sprint performance (Stanton, Wintour & Kean, 2017), and success in other sport modalities. In fact, height reached in a CMJ is used as an indicator of lower limb muscular power (Markovic et al., 2004).

Patellar tendinopathy (PT) was called "jumper's knee" in its original description of the pathology (Blazina et al., 1973). Nowadays, we know that it is an overuse common injury in sports characterized by repeated accelerations and decelerations, changes of directions or jumps (e.g., basketball, volleyball, racket sports) (Andarawis-Puri, Flatow & Soslowsky, 2015; Larsson, Käll & Nilsson-Helander, 2012). These actions produce repeated forces and may develop an overload on the patellar tendon (Larsson et al., 2012). PT symptomatology is characterized by pain in the anterior part of the knee, the distal pole (inferior) of the patella, and the tendon (Cook et al., 2001; Peers & Lysens, 2005). Its development can diminish functional capacity and even activities of daily living for athletes (Childress & Beutler, 2013). At the beginning, this pathology was categorized as an inflammatory injury and was called as "tendonitis" (Dan et al., 2019). However, about 20 years ago, the histologic analysis discovered that it was a degenerative process (e.g., tissue degradation, cell death, micro-tears, creation of new blood vessels) rather than inflammatory and it is actually called "tendinopathy" (Alfredson & Lorentzon, 2002; Cook et al., 2000; Dan et al., 2019).

Conservative treatments are commonly used as a strategy to treat patellar tendinopathy (e.g., non-steroidal anti-inflammatory drugs administration (NSAID), eccentric exercise (EE), stretching), with different therapeutic results. The effectiveness of NSAID in PT is not clear yet (Schwartz, Watson & Hutchinson, 2015), and long-term studies have reported adverse effects (Magra & Maffulli, 2006). On the other side, EE (Larsson et al., 2012; Gaida & Cook, 2011; Malliaras et al., 2013), stretching (Medeiros et al., 2016), and other invasive therapeutic strategies such as platelet-rich plasma (Anitua, Sánchez & Orive, 2010), intratissue percutaneous electrolysis (EPI) and EE (Abat et al., 2014), ultrasound-guided galvanic electrolysis technique (USGET) (Abat et al., 2016), high-volume infiltrations (Maffulli et al., 2016), ultrasound (Cook et al., 2001) and extracorporeal shockwave therapy (ESWT) (Han et al., 2009) have shown to improve PT. Among them, EE seems to be a powerful and non-invasive therapeutic tool in PT. Repeated bouts of EE have been shown to promote protective adaption in the muscles involved, and they could respond better to delayed-onset muscle soreness (DOMS) and its side effects (Chen et al., 2019; Langberg & Kongsgaard, 2008; McHugh et al., 1999). Furthermore, EE could cause a temporary interruption of the blow flow in the pathologic tendon (Alfredson, 2005) enhancing the remodeling of the capillaries and nerves and facilitates a decrease in the perceived pain caused (Öhberg & Alfredson, 2004).

ESWT dispenses sonic pulses which produce strong forces in the tissue. Its therapeutic effects are attributed to an analgesic and a tissue regeneration process (Zwerver et al., 2016). It was first used for kidney stones treatment, however, nowadays is widely used for several orthopedic pathologies (e.g., calcific rotator cuff tendinosis, greater trochanteric pain syndrome, Achilles and patellar tendinopathy) (Andriolo et al., 2019; Huisstede et al., 2011; Mani-Babu et al., 2015). Specifically in tendinopathies ESWT works through the stimulation of neovascularization at the tendon-bone junction (Wang, Huang & Pai, 2002). It is recommended in lower limb tendinopathies as initial treatment and/or as long-term treatment (i.e. > 6 months) (Andriolo et al., 2019; Everhart et al., 2017; Mani-Babu et al., 2015). Combining EE and ESWT appears to produce better therapeutic effects in tendinopathies compared to EE or ESWT alone (Loppini & Maffulli, 2012), and in Achilles midportion tendinopathy (Andriolo et al., 2019). Although EE and ESWT are promising strategies to treat patellar tendinopathy, the effect of these therapeutic approaches together has not been fully investigated on muscle performance. To our knowledge, there are no studies that have analyzed the effect of EE plus ESWT on the velocity- and power-load relationship, and CMJ performance in athletes with patellar tendinopathy. Therefore, the present study aimed to determine the effects of 8 weeks of EE and ESWT on tendon tissue, perceived pain, and muscle power and strength in athletes diagnosed with PT.

Materials and Methods

Experimental design

The study involved a longitudinal study that consisted of eight athletes diagnosed with PT who underwent an 8-week conservative physical rehabilitation program that combined EE, stretching, ESWT, and manual therapy. All participants continued training and competing during the recovery program. At the beginning, at the middle (4-weeks) and at the end of the study (8-weeks), participants came to the laboratory for echographic, perceived pain, muscle power and strength assessments. The following evaluation tools were used: i) Echographic assessment to evaluate and control the status of the patellar tendon. The uninjured leg was used as a control lower limb to determine the differences produced by the recovery program on the echographic healing tissue analysis; ii) Victorian Institute of Sport Assessment-Patella (VISA-P questionnaire) to assess the perceived pain; iii) CMJ and an incremental back squat test to determinate the lower limbs muscle power; and iv) Leg extension 5-repetition maximum test (5-RM) to evaluate the lower limbs muscle strength. All athletes signed the informed consent form prior to the study. The study followed the guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of the University Isabel I (code: UI1-PI017).

Participants

The sample was formed by 8 participants (6 males and 2 females). All participants were federated athletes who participated in a sport modality with high impact on the knee (i.e., basketball, volleyball, handball and jump modalities) and competed in regional or national competition in the same recruitment season. They were diagnosed with PT, according to the criteria of Rio et al. (2015), by a medical doctor and a physical therapist. All the participants fulfilled the next inclusion criteria: i) aged between 18-49 years; ii) not having previously undergone knee surgery or analgesic or platelet-rich plasma infiltration; iii) not having consumed in the previous 3 months steroids or nutritional supplement that could affect their sport performance or hormone; iv) not being a smoker; v) not having any cardiovascular disorder.

Training program

For the EE program, it was selected single-leg decline squat exercises. The technique of the exercise involved start standing on the painful leg in a declined planed (25°) and slowly squatting down until reaching 90° of knee flexion. The rhythm of the exercise was of 2 seconds during eccentric contraction and, participants must maintain an upright trunk. This technique at 90° of flexion guarantees 60° in the patellar tendon (point of maximum tension) (Holden et al., 2020). Accordingly with Purdam et al. (2004), participants performed 3 sets of 10 repetitions with 2 minutes of recovery between sets once a day, 6 days a week (instead of twice a day as Purdam's program). Participants used the visual analogue scale (VAS) for pain assessment after every session and recorded in a training diary. When participants scored 3 points or less in VAS, the load was increased with a weight vest of 5 kg. Before and after every eccentric training session, participants performed stretching of quadriceps and hamstring during 30 seconds with a minute of recovery between sets.

Extracorporeal shock wave therapy (ESWT)

During the first 4-weeks all participants received each 10 days one session of ESWT and manual therapy in the clinic with deep manual massage of the patellar tendon and quadriceps femoris muscle discharge in both lower limbs (i.e., 3 sessions in this period). At the 6th and 8th weeks they received the last two treatment sessions (i.e., 5 treatment sessions in total). After applying the ESWT and manual therapy, we encouraged all participants to avoid exercise during the next 24 hours to enhance tissue recovery.

The ESWT was realized with a Storz Medical MP100 (Storz Medical AG, Tägerwilen, Switzerland). The physiotherapist applied three different treatment steps, the two first steps on the patellar tendon, and the third-one over the distal part of the quadriceps femoris muscle (Al-Abbad & Simon, 2013). This third step was administered with the V-ACTOR tool to eliminate the tension at the muscle belly (R-SW 1,5 bar, 1,500 pulses, frequency 10 Hz; R-SW 2 bar, 2,000 pulses, frequency 15 Hz; V-ACTOR 2 bar, 2,500 pulses, frequency 25 Hz).

Result variables

Echographic assessment was used to assess and control the healing status of the PT (ESAOTE My Lab 60). According to López-Royo et al. (2020), athletes were lying supine with a roller under the knees with around 20° of flexion. To determine the clinical region these factors were considered: i) Palpation of the zones with higher sensitivity and which reproduce patient's symptoms; ii) Tendon regions with degenerative changes and augmented thickness of the tendon. Tendon thickness was measured on longitudinal scans to take the bone junction as a reference and to allow the examiner to take measurements at the same point (Fredberg et al., 2008; Giacchino, 2018). Ultrasound (US) was applied with a gel as a driving agent over the patellar tendon with full contact between the US head and the treatment region. Circular slow movements of the US head were done (i.e. ≈ 4 cm / s) (de Jesus, et al., 2019).

VISA-P questionnaire was used to analyze pain. This questionnaire presents a maximum score of 100 points implying the absence of pain symptoms or functional disorders, and then the subjects could participate in any sport without limitations. However, a score of 0 points implies maximal pain and functional limitations. This questionnaire is considered effective for detecting patellar tendon abnormalities (Visentini et al., 1998), and it is a reliable tool (Frohm et al., 2004).

The lower limbs muscle power was assessed with a CMJ and a gradual incremental BS test. CMJ test was performed for assessing explosive force of lower limbs. Before the CMJ test, participants performed a standardized warm-up (Carlos-Vivas et al., 2018). Therefore, after 2 minutes of recovery, participants performed 5 CMJ at increased intensity with 3 minutes rest at the end, and then, the tests started. Athletes performed 3 CMJs at maximal intensity interspersed by a period of 45 seconds. During the execution of the jump, an evaluator at 1.5 m in the frontal plane recorded the jump with a cell phone (iPhone 7; Apple, Cupertino, CA, USA), using My Jump app. My jump app present validity with a gold standard for assessing height jump with a gold standard (force platform) (ICC=0.996). The maximum height of the 3 jumps was recorded. To execute the CMJ, participants started with the arms on the hips and the leg extended and continue with a bending of the knees to 90° and immediately and synchronously extend the knees (concentric action) in an explosive movement to attain the maximum height possible. In the flight phase, the knees should be extended, and the hands kept on the hips (Garnacho-Castaño et al., 2015).

BS is a commonly exercise used for assessing maximal strength and power of the lower limbs (López-Trujillo et al., 2022). Therefore, a gradual incremental BS test was used to assess muscular power. Based on previous studies (Maté-Muñoz et al., 2018), 2 repetitions interspersed with a period of 2 seconds between repetitions at a maximum velocity of displacement was initiated with a load corresponding to 20 kg. During all tests, movement velocity and power were measured with a linear position transducer (v.4.1, Speed4Lift, Madrid, Spain) that has been validated (Pérez-Castilla et al., 2019). When participants displaced the bar with a mean velocity above 0.8 m/s the load was increased 10 kg and the recovery between sets was of 3 minutes. When the bar was displaced below 0.8 m/s, the load increased by 5 kg. The test was completed when the peak power (PP) was determined. Other variables analyzed were the mean velocity at PP (m/s) (PP_{MV}), and load lifted at PP (kg) (PP_{KG}), reached in the repetition where PP was registered. BS was performed in a multipower, bar-guiding system Smith machine (Matrix, Chácara Alvorada, Brazil). During the BS execution, participants stand with feet shoulder-width apart and the barbell placed on top of the shoulder blades with hands clutching the barbell. The movement initiated until a flexion of the knees to 120° that was followed by an extension to the original standing position at the maximum velocity (Maté-Muñoz et al., 2018).

The lower limbs muscle strength was assessed through a 5-RM test in the leg extension exercise (Selection Leg Extension, Technogym, Cesena, Italy). Based on previous studies (Gail & Künzell, 2014), the test included a specific warm-up consisting of 10 repetitions with a load corresponding to an estimated 10-RM (based on the individual assessment). Then, after a period of recovery of 3 minutes, and based on individual assessment, the test started with a selected a load which the participants could lift ≈5-RM. For the leg extension execution, the participants sat on the machine with their hands clasped on the handles. From this position, the participants raised their legs 30, 60, and 90 degrees of knee flexion successively. Then, the legs returned to the starting position (Escamilla et al., 2001).

Statistical analysis

Data are presented as mean (M) ± standard deviation (SD). A Shapiro-Wilk's test and a Levene's test was used for contrasting the normality distributions of the variables and the homogeneity of variances. For analyze the effect of the intervention on the different variables assessed on pain, CMJ, BS and 5-RM test, a repeated measures analysis of variance (ANOVA-RM) was applied for detecting differences in the different assessment: pre-intervention (PRE), at 4th week (INT), and at post-intervention (POST). For the analysis of the echocardiographic image of the PT, it was applied a two-way ANOVA-RM time (PRE vs. INT vs. POST) as intra-subject factor, and knee (injured vs uninjured) as inter-subject factor. In the chase of statistical differences, a Bonferroni post-hoc was performed. ANOVA-RM effect sizes (ES) were calculated using partial eta squared (Ƞ2p), considering small (<0.25), medium (0.26–0.63) and large effect (>0.63) (Ferguson, 2009). Statistical significance was set at $p<0.05$. All the statistical tests were performed using the Statistical Package for Social Sciences (version 20.0 for Mac, SPSS™ Inc., Chicago, IL, USA).

Results

The descriptive data of the participants are shown in the Table 1.

Table 1.
Descriptive data of the participants.

Variable	Total (n=8)	Male (n=6)	Female (n=2)
Age	27.14 ± 8.25	23.80 ± 7.29	35.5 ± 0.71
Height (m)	1.80 ± 0.11	1.85 ± 0.08	1.77 ± 0.73
Weight (kg)	80.63 ± 7.73	83.5 ± 7.26	73.55 ± 2.62
BMI (m/kg^2)	24.94 ± 2.11	24.34 ±1.96	26.46 ± 2.20

Abbreviations: BMI: body mass index.

In this study the accomplishment of the EE was ≈ 93% of the recommended volume. The participants completed 5.6 ± 0.9 weekly sessions during the 8-week of the intervention period.

Echographic Assessment

Regarding to the echographic image of the PT, it was observed an effect for time (*F*=3.419; *p*=0.044; η2p=0.160), and knee factor (injured: 6.60 ± 0.329 mm vs. uninjured: 4.71 ± 0.329 mm; *F*=16.549; *p*<0.001; η2p=0.315), but not for the interaction time·knee (*F*=; *p*=0.556; η2p=0.032). So, it was reported a lower tendon thickness POST vs. PRE (5.05 ± 0.402 mm vs 6.486 ± 0.402 mm; p=0.049). In this line, it is observed in the injured knee a lower thickness POST vs. PRE (5.686 ± 0.569 mm vs 7.743 ± 0.569 mm; p=0.045) (see Figure 1), whereas in the comparison of the injured vs uninjured knee it was reported differences in PRE (*p*=0.004), and INT (*p*=0.025), but not in POST (*p*=0.123).

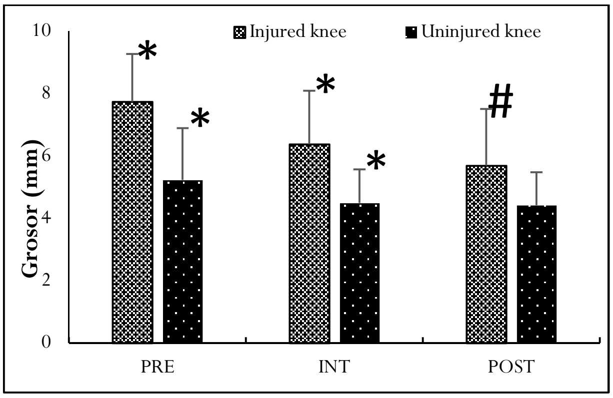

*Figure 1. Thickness on the different assessment in injured and uninjured knee. Abbreviations: PRE: Assessment pre-intervention; INT: Assessment at 4th week; POST: Assessment post-intervention. * Statistical differences between injured and uninjured knee in a same assessment; #: Statistical differences between POST vs PRE and INT in the same knee.*

Perceived pain

It was not reported any difference for the time in the VISA-P score (*F*=2.244; *p*=0.202; η2p=0.473) (see Figure 2).

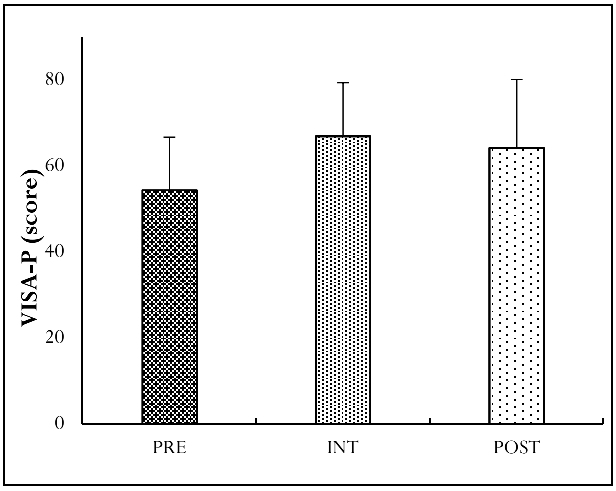

Figure 2. Subjective pain perceived by the VISA-P score at the different time assessments. Abbreviations: PRE: Assessment pre-intervention; INT: Assessment at 4th week; POST: Assessment post-intervention; VISA-P: Victorian Institute of Sport Assessment-Patella.

Muscle power and strength assessment

In the muscle power tests it was observed in CMJ test a significant effect for factor time (*F*=10.441; *p*=0.016; η2p=0.807) with a higher maximum height reached in POST vs. PRE (*p*=0.031), and INT assessments (*p*=0.007) (see Table 2). In BS test, it was reported a statistical effect for factor time in PP_{KG} (*F*=10.980; *p*=0.016; η2p=0.815), with a higher performance POST compared to PRE (*p*=0.033), and INT (*p*=0.007). However, in PP it was observed a trend to statistically differences (*F*=5.211; *p*=0.060; η2p=0.676) with higher power output POST compared to PRE (*p*=0.037), without any difference in PP_{MV} was reported (*F*=2.188; *p*=0.208; η2p=0.467).

In the muscle strength 5-RM test, it was observed a statistical effect for factor time (*F*=24.443; *p*=0.003; η2p=0.907), with differences between PRE vs. INT (*p*=0.019), and POST (*p*=0.001).

Discussion

The present study was observed after 8 weeks of a conservative physical rehabilitation program combining EE, stretching, ESWT, and manual therapy, significant positive effects on tendon tissue healing and muscle power and strength performance in athletes diagnosed with PT.

Table 2.
Performance variables in muscle power and strength tests.

Test	Variable	PRE	INT	POST	p-value
CMJ	Maximum height reached (cm)	35.3 ± 9.5	36.8 ± 11.0	39.5 ± 11.3 #	0.016*
BS	PP_{KG}	55.0 ± 14.4	63.2 ± 18.5	73.6 ± 22.4 #	0.015*
	PP (W)	416.3 ± 115.0	494.3 ± 165.4	532.3 ± 185.9 λ	0.060
	PP_{MV} (m/s)	0.74 ± 0.1	0.75 ± 0.1	0.72 ± 0.1	0.208
5-RM	Kg	60.4 ± 13.9	70.0 ± 13.0 Φ	75.4 ± 10.9 λ	0.003*

Abbreviations: 5-RM: 5-Repetition maximum; BS: Back squat; CMJ: Countermovement jump; INT: Assessment at 4th week; POST: Assessment post-intervention; PP_{MV}: Mean velocity at peak power; PP: Peak power; PP_{KG}: Load lifted at peak power; PRE: Assessment at pre-intervention.* Statistical differences for factor time; #: Statistical differences between POST vs PRE and INT; λ: Statistical differences between POST vs PRE; Φ: Statistical differences between INT vs PRE

To our knowledge, this is the first study to assess and report improvements in the load-velocity profile in athletes during the recovery period of PT.

The initial echographic assessment showed significant differences between the injured vs uninjured knee, with higher patellar tendon thickness on the pathological lower limb (+48.1%). This significant difference was maintained in the fourth week of evaluation, but the intervention started to improve tendon tissue and the differences decreased (+42.0%). Finally, the significant differences disappeared at the end of the 8 weeks (+28.8%). In this line, it was observed a significant lower tendon thickness of the injured knee at 4th week (17.7%) and after completing the multicomponent treatment intervention (i.e., EE, stretching, ESWT, and manual therapy), at the 8th week (-26.6%). These results are clinically relevant because echography techniques and magnetic resonance are the gold standard methods for clinical examination and evaluation in PT (Adler & Finzel, 2005; Campbell & Grainger, 2001; Warden & Brukner, 2003). This is in line with the literature because it has been shown that EE produce decreased muscle damage markers post-exercise (e.g., creatine kinase or protein C-reactive) (Neme et al., 2013), reduction in tendon volume and thickness (Kongsgaard et al., 2009), and increased collagen (Langberg et al., 2007). Thus, adaptation to EE exercise stimulates a remodeling process in skeletal muscle and tendon, promoting protective effects (Hori et al., 2007). Further, the single-leg decline (15°-30°) squat exercise selected for the present study (i.e. 25°), has been shown to be more effective than horizontal squat exercise in patellar tendinopathy (Zwerver, Bredeweg & Hof, 2007). The force momentum, the tension on the patella, and the electromyographic activity of the quadriceps are higher in decline compared to horizontal squat (Frohm, Halvorsen & Thorstensson, 2007; Richards et al., 2008). These effects might contribute to the recovery of the tendon tissue. In this sense, Lee et al. (2020) observed improvements after 12-week EE of single-legged decline squat in the tendon mechanical properties (i.e. Reduction in tendon stiffness and increase of tendon strain). In this study Lee et al. (2020), the combination of EE plus ESWT has not been shown to be more effective than EE alone. Furthermore, it has been estimated that 55% of PT patients return to a good or excellent recovery state using EE alone (Gaida & Cook, 2011).

The main and novelty results of the present study were the significant improvements achieved in the muscle power of the lower limbs and the stabilization of the velocity-power-load relationships during a rehabilitation program. In the BS muscle power test, we observed significant improvements and a large ES in PP_{KG} POST vs PRE and INT, with the same behavior that we have seen in the echographic and CMJ evaluation (+14.9% in the 4th week, +33.8% in the 8th week). Further, in PP the athletes shown a large ES between POST vs. PRE and INT, and a significant higher power output POST vs. PRE, also with the same recovery behavior (+18.7% at 4th week, +27.9% at 8th week). These results have practical applications because an increased power output production is related with a better sport physical performance (Cronin & Sleivert, 2005). Regarding our results, it is interesting to highlight that there are no differences in PP_{MV} during the recovery process. This seems to reflect that the maximum velocity at which it is produced the peak power is stable, even when the patient usually has higher pain values and more damage in the tissue. To our knowledge, this is the first time in the literature that the configuration of the load-velocity profile during the PT recovery has been reported. In healthy subjects it was observed (González-Badillo & Sánchez-Medina, 2010) that the mean maximal propulsive velocity at peak power is also stable and it is related to a relative loading magnitude (i.e., Percentage of the 1RM). Then, it seems that the relation between the velocity associated to the peak power remains stable even inside a rehabilitation program. These results might be clinically relevant to guide healthcare professionals to plan recovery progression because velocity movement can be used as a useful parameter to prescribe resistance exercises. However, more research is needed to corroborate our results.

Specifically in jump power, the CMJ maximum height was reached after the 8 weeks of treatment, with significant differences between PRE and INT assessments, and large ES. Similarly, as we have seen in echographic and BS data, after the 4th week of intervention the jump power of the lower extremity muscle starts to improve (+1.5cm; +4.3%), but it did not reach significance until the 8th week (4.2cm; +11.9%). Our results agree with Visnes et al. (2005) which observed significant but lower improvements in volleyball players with PT after 12 weeks of EE on CMJ (+1.2cm). However, other studies with EE interventions in PT did not show positive changes in CMJ height (Biernat et al., 2014; Frohm et al., 2007; Romero-Rodriguez, Gual & Tesch, 2011). This lower or absence of improvements in CMJ performance may be due to the lack of a stretching stimulus into the training program (Biernat et al., 2014; Frohm et al., 2007; Romero-Rodriguez, Gual & Tesch, 2011) that it was present in our study, and which may enhance the stretching-shortening cycle. In tendinopathies, the periarticular muscles which surround the injured joint show a characteristic stiffness (Dimitrios, Pantelis & Kalliopi, 2012), and a reduce capacity to produce force and use kinetic energy (Nosaka et al., 2001; 2002). Static stretching produced general beneficial effects in the range of motion of the body joints (Behm & Chaouachi, 2011; Wanderley et al., 2019), and it seems to be effective in combination with EE in elbow tendinopathy (Pienimäki et al., 1998), and PT (Dimitrios et al., 2012). It might stimulate a sarcomere distribution in series (Zöllner et al., 2012), viscoelastic adaptations (Kubo et al., 2001; Reid & McNair, 2001), and stretching tolerance (Kay, Husbands-Beasley & Blazevich, 2015).

The lower limbs muscle strength results also showed the efficacy of the multicomponent treatment. In the 5-RM test significant improvements and an ES large POST vs. PRE and INT were observed, with the same behavior we have seen in the echographic, CMJ, and BS assessment (+15.9% at 4th week, +24.8% at 8th week). These results agree with the literature that observed improvements in eccentric strength (+90%) after 6 weeks of an EE program with an isoinertial machine (Romero-Rodriguez et al., 2011), isokinetic concentric knee extension strength after 12 weeks of eccentric overload training (+11.4%) or one leg decline squat (+6.7) (Frohm et al., 2007), and in the moment of force in hamstring muscles after 12 weeks of drop squat (+14%) or knee extension and curls exercises (+17.7%) (Cannell et al., 2001).

In relation to patient perception of pain and function, we did not observe significant differences in the VISA-P score between the start and end of the treatment intervention. Perceived pain scales have been presented as an affordable and effective technique to monitor and diagnose patellar tendinopathy (Visnes et al., 2005; Woodley, Newsham-West & Baxter, 2007). The VISA-P has been reported, together with decline squat exercise and tendon pain history, to be an effective strategy to detect patellar tendon abnormalities in athletes (Visentini et al., 1998). However, the VISA-P results shown in the present study were not in line with the relevant improvements of the knee injured function (i.e. Enhanced muscle power and strength performance), The majority of the previous studies with EE interventions in which VISA-P questionnaire was performed, observed improvements in perceived pain of 18-46% after 4 to 8 weeks (Abat et al., 2014; 2016; Romero-Rodriguez et al., 2011), 19-35% after 12 weeks (da Cunha et al., 2012; Lee et al., 2020; Morton et al., 2014; Young et al., 2005; Warden et al., 2008), 7-114% after 24 weeks (Biernat et al., 2014; Dimitrios et al., 2012; Frohm et al., 2007; Thijs et al., 2017) and 72-128% after 52 weeks (Bahr et al., 2006; Kaux et al., 2015; Young et al., 2005). Our findings agree with Visnes et al. (2005) who did not report positive changes in VISA-P scale in elite volleyball players after 12 weeks of EE (i.e. 25° Decline squat), neither at 6 nor 30 weeks of follow-up. It is important to highlight that the participants in both studies continued training and competing during the recovery process, and this fact may influence the absence of positive results in perceived pain and function. Other factor that might influence on it was the low adherence (i.e. 59% of the recommended volume) reported in Visnes et al. (2005), but not in our study as was reported in the results section (≈ 93%).

This study is not exempt of limitations. Therefore, the main limitation of the present study was the small sample size that is explained by the difficulties in recruiting federated athletes to the study. This limitation has favored to include a high range of aging (from 18 to 36 years) that could be converted into a confusion factor because greater impacts sustained as the competition as training along years could favor the PT in athletes with age. It has been reported a relationship between age and the number of sonographic abnormalities (Benítez-Martínez et al., 2019). The explanation of this relationship could be a decreased water content with age (Danielsen & Andreassen, 1988) that causes changes in the mechanical properties of the tendon (Carroll et al., 2008). The small sample size and heterogeneity in age of the participants suggest that the results reported must be taken cautelous. Future studies must include a higher sample size, include groups of different ages and include comparations between different therapy protocols.

Conclusions

In conclusion, 8 weeks of EE, stretching, ESWT, and manual therapy may induce significant positive effects on tendon tissue healing, lower limbs muscle power and strength performance in athletes diagnosed with patellar tendinopathy. It seems that the maximum velocity at which the peak power was produced was stable during all recovery processes, and there were only changes in the exercise load which progressively increased. This is the first time that the conformation of the load-velocity profile is reported in the literature during PT recovery. The changes reported in ultrasound but not in pain suggest the idea that there is no strong relationship between tendon tissue and pain.

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