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Comprehensive assessment of heavy slow resistance training and high-dose therapeutic ultrasound in managing patellar tendinopathy, a randomized single-blind controlled trial

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Abstract

Background Patellar tendinopathy (PT) is a common sport injury prone to recurrence. Heavy Slow Resistance Training (HSR) and High-Dose Therapeutic Ultrasound (TUS) are frequently used interventions for PT. However, the combined effectiveness of these therapies remains unclear. This study investigated the impact of combination therapy on functional outcomes in patients with PT.

Methods Fifty-one college students aged 18–25, diagnosed with PT via musculoskeletal ultrasound, were randomly assigned to one of three groups ($n=17$ per group): combined HSR and high-dose TUS, HSR training alone, or high-dose TUS alone. The eight-week intervention included assessments using the Victorian Institute of Sport Assessment-Patella (VISA-P), Visual Analogue Scale (VAS), Y-balance Test (YBT), Modified Thomas Test (MTT), Horizontal Jumping Distance, Maximum Isometric Muscle Strength Test, and musculoskeletal ultrasound for patellar tendon thickness and blood flow. Assessments were conducted at baseline and post-intervention, with a follow-up VISA-P assessment at week 16. This randomized, single-blind controlled trial was registered on ISRCTN11447397 (www.ISRCTN.com) on February 17, 2024 (retrospectively registered).

Results All groups demonstrated significant improvements in VISA-P scores at the end of the intervention compared to baseline ($p<0.01$), with the combined group showing the greatest improvement (21 points). Follow-up at week 16 revealed continued improvement in VISA-P scores for the combined and HSR groups, while the TUS group showed a slight decrease (from 74 to 70). All groups displayed significantly reduced VAS scores post-intervention ($p<0.01$) compared to baseline, indicating decreased pain. While no significant between-group differences were observed in

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pre-intervention VAS scores, post-intervention results revealed significant differences between the combined and HSR groups ($p < 0.05$), as well as between the combined and TUS groups ($p < 0.01$).

Conclusion Both exercise intervention and high-dose TUS appear effective in reducing pain and improving motor function in individuals with PT. However, the therapeutic effect of high-dose TUS alone seems limited compared to exercise intervention. The combined application of both methods yielded the most significant improvements in pain relief and motor function enhancement.

Keywords Patellar tendinopathy, Heavy slow resistance, Therapeutic ultrasound, Efficiency, Exercise

Introduction

Patellar tendinopathy (PT) is a common chronic sports injury characterized by significant pain in the proximal patellar tendon [1]. Patients with this condition often experience tenderness in the patellar tendon area, accompanied by reduced strength and mobility in the surrounding region [2]. A study published in the 2020 British Journal of Sports Medicine highlighted that individuals with PT frequently face persistent pain and functional limitations, particularly during weight-bearing activities or those involving significant impact forces [1]. PT symptoms typically worsen following activity, and PT is frequently observed in sports that demand high levels of speed, strength, and jumps, such as volleyball and basketball, which heavily engage the leg extensor muscles [3]. Research has shown that approximately 52.3% of basketball players suffer from PT, leading to a notable decline in athletic performance [4]. PT tends to persist as a long-term issue, posing challenges for effective management without intervention [5]. Current treatment approaches for PT encompass a combination of passive and active modalities [6]. Passive treatments include options such as medication, injections, extracorporeal shockwave therapy (ESWT), ultrasound therapy, and low-intensity laser therapy. Active treatments involve strategies such as tendon loading training (TLT) [7], heavy slow resistance (HSR) training [8], and eccentric exercise training(ECC) [9].

Therapeutic ultrasound (TUS) is a frequently employed therapeutic modality in the field of physical therapy [10]. Over the years, numerous studies have investigated the effectiveness of therapeutic ultrasound in treating PT, with positive outcomes reported in certain instances [11, 12]. TUS has been shown to stimulate the self-repair mechanism of the patellar tendon, increase its temperature, elevate the pain threshold, and promote collagen elongation [6]. Additionally, high-dose TUS can influence the tissue structure of the patellar tendon, facilitating improved energy absorption and dispersion, thereby enhancing knee joint function in patients with PT [13]. Research has suggested that both high-dose and low-dose TUS can alleviate PT, with high-dose TUS demonstrating greater effectiveness [13, 14].

HSR training, which includes barbell squats and deadlifts, has been shown to induce localized hypertrophy and enhance the mechanical properties of the patellar tendon region [15, 16]. It focuses on stabilizing both the centrifugal and centripetal phases of the loading movement, which enhances the subject's neurological adaptations and leads to greater strength variability. This approach has been found to be effective in improving tendon swelling and vascularization [17, 18]. HSR training can be utilized as a therapeutic strategy for individuals with patellar tendon pain and to improve knee extensor strength [8, 19].

Current studies on physical therapy and exercise interventions in subjects with PT have shown inconsistent evaluations, and there is a lack of consensus regarding the optimal treatment regimen for physical therapy [20]. Therefore, exploring combination therapies presents new research directions for PT treatment. The objective of this study was to assess the effects of HSR training on individuals with PT. We conducted a comparative study of HSR training and therapeutic ultrasound interventions among young athletes with PT to evaluate the effectiveness of these different physiotherapy approaches. We aimed to identify which therapy provides the most beneficial outcomes, thereby establishing a theoretical foundation for optimizing PT treatments.

Methods

DESIGN: This study was designed as a single-blind, randomized controlled trial. Subjects, imaging physicians, and experimental data collectors were blinded. The participants were randomly assigned to groups using the envelope method. The objective was to assess the effectiveness of HSR therapy in combination with high-dose therapeutic ultrasound and combined therapy for patellar tendinopathy by comparing pre- and post-intervention data. We implemented rigorous experimental protocols, limiting the study to the Sports Intervention Center of Wuhan Sports University, employing a consistent experimental site, and enlisting a highly trained therapist. Accordingly, the confidence level in the experiment's validity was significantly elevated.

Subjects

From October 2022 to May 2023, 53 college students with chronic patellar tendinopathy, aged 18 to 24 years old, were recruited at Wuhan Sports University. All participants underwent a centrally coordinated intervention for 8 weeks. The participants were diagnosed with chronic patellar tendinopathy by an orthopedic deputy chief physician with 15 years of clinical experience. Subjects were included only if the duration of pain was greater than three months [21]. Provocation tests based on the patellofemoral pain consensus statement were conducted to rule out patellofemoral pain in subjects [22]. Table 1 presents the baseline characteristics of the participants. If a participant experienced bilateral symptoms, the more symptomatic side was selected for data collection.

The criteria for subject inclusion in the experiment were as follows:

1. subjects with a Victorian Institute of Sport Assessment-Patella (VISA-P) questionnaire score of < 80 out of 100 [23, 24],
2. history of patellar tendon pain related to training or competition,
3. structural changes in the patellar tendon on gray-scale ultrasound and/or increased tendon vascular distribution on energy Doppler [25],
4. significant tenderness observed upon palpation near the distal end of the patellar tendon, with pain localized to the lower portion of the patella [26],
5. pain exacerbated by activities such as squatting or jumping.

Table 1 The features of the subjects

	Combined group (*N* = 17)	HSR group (*N* = 17)	TUS group (*N* = 17)	*P*-Value
Age (yrs)	21.4 ± 1.5(19–24)	22.1 ± 1.6(19–25)	21 ± 1.5(19–24)	>0.05
Height (m)	1.8 ± 0.08(1.6–1.9)	1.8 ± 0.05(1.7–1.9)	1.8 ± 0.08(1.7–1.9)	>0.05
Weight(kg)	71.7 ± 11.2(55–95)	76.4 ± 8.0(63–90)	75.7 ± 14.0(55–102)	>0.05
BMI (kg/m^2)	22.4 ± 2.2(19.0-26.9)	23.2 ± 1.6(19.4–25.8)	23.2 ± 3.0(17.4–28.4)	>0.05
Symptom duration (months)	7.2 ± 5.2 (3–24)	16.8 ± 18.7(3–70)	9.2 ± 7.0(3–24)	>0.05
Gender (male/female)	14/3	17/0	15/2	>0.05
Primary sport	4 Soccer 6 Running 2 Basketball 3 Table Tennis 1 Unknown 1 Fitness	3 Gymnastics 4 Tennis 4 Badminton 5 Basketball 2 Unknown	3 Fitness 3 Golf 4 Basketball 1 Badminton 3 Fitness 2 Running 1 Unknown	

Ultrasonographic examination, performed by a sonographer with 15 years of experience, revealed structural alterations within the patellar tendon, characterized by hypoechoic regions, tendon thickening (anterior-posterior diameter exceeding 6 mm), and/or elevated intratendinous Doppler flow [27].

Subjects were excluded based on the following criteria:

1. duration of pain less than three months,
2. history of knee surgery in the past year,
3. history of inflammatory arthropathy and the use of medications in the past year that could potentially affect the patellar tendon (e.g., quinolones),
4. use of corticosteroids for intra-articular injections in the past month,
5. history of patellar tendon rupture,
6. failure to perform a training program or participate in other treatment programs,
7. participation in an exercise program or another treatment regimen,
8. physical examination or ultrasound/MRI findings indicating the presence of additional knee pathologies,
9. inability to undergo high-energy dose ultrasound therapy or conditions for which ultrasound may be contraindicated, such as (active tuberculosis, bleeding tendency, severe cardiac disease, malignant tumors, venous thrombosis, and pregnant women).

Each subject provided informed consent after being thoroughly informed about the experimental procedures. All data collection was conducted with appropriate authorization. Figure 1 presents the flow chart outlining the experimental procedures and the status of participants in accordance with the Consolidated Standards of Reporting Trials (CONSORT) [28]. We confirm that our research adhered to these CONSORT standards.

Blinding and randomization

Before initiating the study, all participants familiarized themselves with the research procedures following a baseline assessment. After including subjects who met the required criteria, baseline data were collected to minimize potential data interference. Importantly, non-research team members collected the baseline data. Randomization was conducted by an experimenter (L.Z.Y.), who was not involved in follow-up data collection to ensure allocation concealment. L.Z.Y. recorded the group assignments on paper, sealed them in opaque envelopes, and handed them to the subjects. After the baseline data collection, subjects returned the sealed envelopes to the interventionist, who implemented the assigned interventions. Subjects remained unaware of their group assignments and were instructed not to discuss exercise

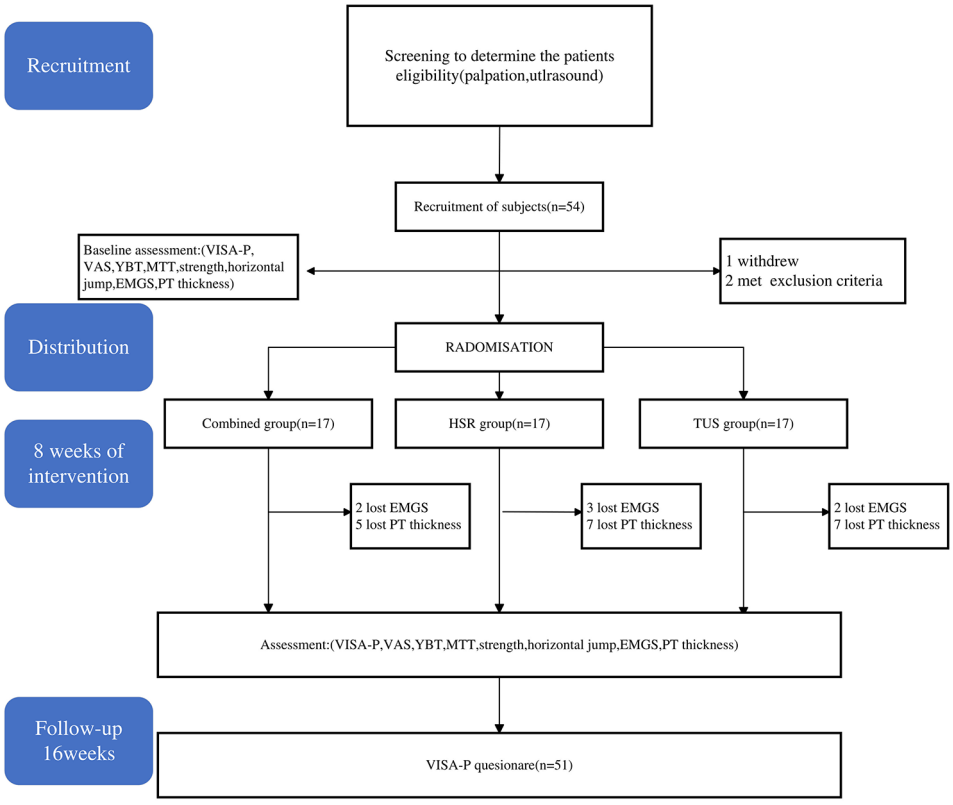

Fig. 1 Study flow chart

regimens or therapeutic measures during the study period. The intervention was supervised by two therapists (HJ, NX) who were not blinded to the group assignment. However, the imaging physician remained blinded during the outcome data collection.

Interventions

HSR training

Heavy slow resistance training methods, as demonstrated by Kongsgaard [8], involve intervention protocols with symmetrical loading on both legs. HSR primarily aims to improve tendon and muscle strength through controlled, slow movements under heavy loads, maximizing time under tension. This approach recruits a high number of motor units and promotes muscle-tendon adaptation, enhancing functional performance and aiding in injury prevention [15]. Subjects were asked to perform three weekly training sessions, each including three movements (squat, leg press, Bulgarian deep squat). These training movements (Fig. 2) adhered to NSCA-CSCS standards [29]. Load intensity and repetitions were progressively adjusted throughout the program: starting with 12 repetitions maximum (12RM) in the first two weeks, reducing to 10RM in the third and fourth, 8RM in the fifth and sixth, and finally 6RM in the seventh and eighth weeks. During each exercise, subjects followed a metronome, spending 3 s on both the eccentric and concentric phases of the movement, totaling 6 s per movement. To enhance tendon mechanical properties and facilitate adaptations, the loading protocol followed [19], with an intensity exceeding 70% of the one-repetition maximum (1RM), ensuring no more than 12 repetitions per set. Participants with partial pain (VAS<3) were allowed to continue as long as pain did not increase in subsequent sessions. A therapist supervised each session to ensure accuracy, completion of training maneuvers, and subject safety. Each session included a pre-training warm-up and post-training stretching.

High-dose TUS therapy

High-dose TUS therapy was administered to both the combined and TUS groups as part of the intervention. High-dose TUS therapy (ULTRASOUND UNIT US-700, Japan) targeted the entire patellar tendon region. Full contact was maintained between the subject's patellar tendon and the high-energy TUS conductor, with the gel used as the interface. Throughout the procedure, subjects were positioned supine with a cushion under the knee for immobilization, and the knee was slightly flexed at approximately 20 degrees [13]. The subjects underwent high-dose therapeutic ultrasound treatment three times per week for a total of eight weeks. If subjects exhibited

Fig. 2 Exercise protocol of HSR group, composed of a series of three movements: (**a**) Squat, (**b**) Leg press, and (**c**) Bulgarian deep squat

Table 2 Therapeutic ultrasound (TUS) dosimetric parameters

Parameters	Adjusts
Frequency	1MHZ
Mode	Continuous
Time	10 min
Energy	4920 J / per application
Effective radiation area	5.5cm^2
BNR	3.2–3.6%±30%
Intensity	1.5w/cm^2

bilateral symptoms, the knee with the more symptomatic side received high-dose TUS treatment. Details on the dosage settings and duration of high-dose TUS are provided in Table 2.

Combination therapy

The combined group followed the same 8-week training regimen as the training group. Participants performed four sets of each maneuver, taking a 2-minute rest between sets. Immediately following the training sessions, subjects received high-dose TUS therapy, using identical treatment parameters, duration, and materials as those used in the TUS group.

Outcome measure

The primary outcome was the VISA-P questionnaire scores [24]. Higher questionnaire scores indicated better functioning, with a minimal clinically important difference of 13 points [30]. Patients completed the questionnaires independently without assistance after a brief explanation provided by the primary researcher assistant (HJ). The questionnaire was administered at baseline, 8 weeks, and 16 weeks.

The secondary outcomes were as follows. To maintain data integrity, all data collection was conducted by the same researchers (L.Y.C, HJ, NX). If a subject experienced a physical injury or requested withdrawal from the study at any time during data collection or training, the experiment was immediately terminated.

VAS

We employed a 10-centimeter visual analog scale (VAS) to evaluate the intensity of patellar tendon pain in the subjects, with 0 indicating no pain and 10 representing the most severe pain [31]. After explaining the questionnaire's content to the subjects, patients were instructed to squat on a 25-degree inclined platform [32]. They were then asked to independently assess the degree of patellar tendon pain during squatting using the VAS scale without any guidance from the evaluator. These assessments were conducted both before the intervention and again 8 weeks post-intervention.

Lower quarter Y balance test

The Lower Quarter Y Balance Test (YBT-LQ) is an instrument used to assess dynamic postural control, a variant of the Star Excursion Balance Test (SEBT) that reflects a subject's balance ability and has demonstrated reliability and validity [33, 34]. The test methodology was similar to Plisky et al. [33], but participants were instructed to place their hands on their pelvis to eliminate upper extremity influence on balance. Participants extended the opposite leg to push the test board as far as possible in three directions: anterior-lateral, posterior-medial, and posterior-lateral (Fig. 3). After each test, they returned to the starting position without touching the ground or relying on the test block for support. The push distance was recorded. Each participant performed four practice trials with each leg in each direction before the official test. A 5-minute rest was provided before the formal start to optimize performance [35]. The best of three official tests was recorded for analysis. To account for individual leg length and height variations, nudge distance was normalized based on each participant's lower limb length [36].

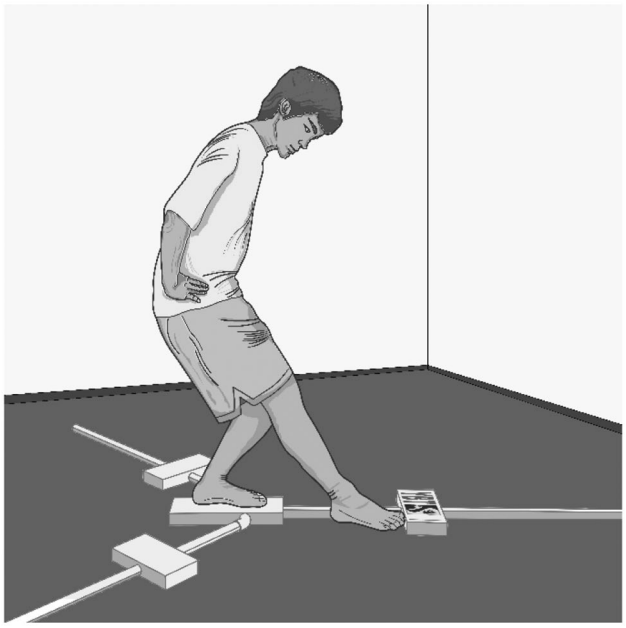

Fig. 3 Schematic diagram of YBT test

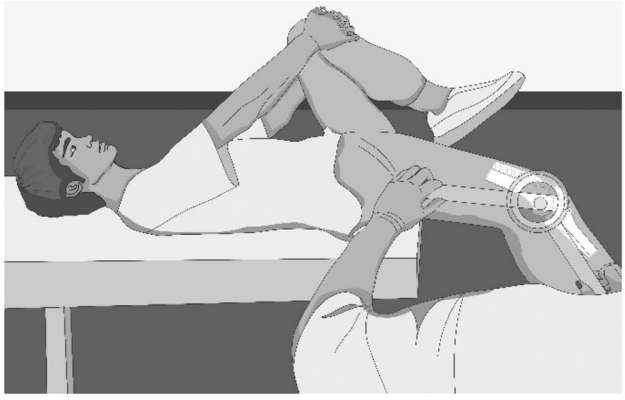

Fig. 4 The mortified tomas test

The maximum reach distance (%MAXD) was then calculated using the formula: [(6 × farthest distance) / (sum of both lower limb lengths, a and b) × 3] × 100%MAXD [36, 37]. YBT tests were measured at baseline and at the end of the intervention (leg length was recorded as the distance from the anterior superior iliac spine to the medial malleolus in the supine position) [36].

$$\%MAXD = \frac{6d_{max}}{3?a+b?}*100\%$$

Modified thomas test (MTT)

Insufficient quadriceps muscle flexibility and strength have been identified as potential pathogenic factors in patellar tendinopathy [38]. Reduced quadriceps flexibility can lead to a larger knee flexion angle and a smaller hip flexion angle during landing [39], increasing tendon loading and potentially inducing degenerative changes in the patellar tendon [40]. To assess quadriceps flexibility, we employed the modified Thomas test. Participants sat at the edge of a treatment bed, leaned backward onto the bed, and brought both knees towards their chests. The lumbar spine was maintained flat against the bed, and the pelvis was kept in a posteriorly rotated position. The subject held the contralateral knee with both arms, ensuring the leg was in maximum flexion while the affected limb was relaxed and lowered towards the floor [41] (Figs. 4 and 5). The change in this angle was compared between baseline and after 8 weeks of training to determine if HSR training enhanced quadriceps flexibility in our subjects. Tests were conducted once at baseline and once after the 8-week intervention.

Fig. 5 Standing long jump tester

Maximum isometric strength of lower extremity extensors

Subjects were evaluated for isometric maximal strength of the lower extremities using the Leg-Check 626 lower extremity strength stirrup machine (Dr. WOLFF Sports & Prevention GmbH - Bachumer, Germany). Before beginning the test, participants were instructed to adjust the backrest angle and place their legs on the device's base plate with their knees at a 90-degree angle (Fig. 2-b). At the test's beginning, participants were asked to maintain their backs against the backrest and gradually exert their leg muscles to exhaustion, avoiding sudden bursts of force that could disrupt the experiment. Tests were conducted at baseline and after the 8-week intervention.

Horizontal jump

Jump tests are a standard method for evaluating a subject's functional performance [42]. Subjects were assessed using the standing long jump tester (Tsinghua Tongfang Electronics, CHINA). The therapist provided a verbal explanation and demonstration of the test, and participants were instructed to wear non-slip sports shoes. A 5-minute warm-up session preceded the test.

Participants then familiarized themselves with the jumping action before starting the test procedure. Subjects were instructed to stand behind the jumping line with their feet naturally apart, maintaining their initial position. They were then asked to jump forward simultaneously, ensuring no additional steps or preliminary jumps were taken. Each participant performed the test twice, and the highest value from the two valid attempts was recorded. Tests were conducted at baseline and after the 8-week intervention.

Musculoskeletal ultrasound image

Ultrasound imaging was conducted using a GE LOGIQ E11 ultrasound machine with an acquisition frequency of 9.0 MHz. The procedure adhered to the guidelines of the European Society of Musculoskeletal Radiology: subjects were positioned supine on an examination table with a pillow placed under the popliteal fossa, maintaining a knee flexion of approximately 30° [43]. The sensor probe was positioned longitudinally over the popliteal fossa. The transducer probe was placed longitudinally in the middle of the patellar tendon and maintained gentle contact with the skin without applying additional pressure to prevent interference with the measurement. Patellar tendon thickness was measured 1 cm from the patellar aponeurosis using the scanner's built-in software [44]. Color Doppler imaging was used to observe blood flow within the patellar tendon.

Statistical analysis

Data were presented as means±standard deviation (SD) and range. Statistical analyses were performed using GraphPad Prism Version 9.0.0 and G*Power version 3.1.9.4. The data passed the Shapiro-Wilk normality test, confirming a normal distribution and meeting the assumption of homogeneity of variance. Bartlett's test verified that the measurement data followed a normal distribution. Paired samples t-tests were conducted within the pre- and post-intervention groups. One-way repeated measures ANOVA by ranks was used to assess differences in values and relative change between groups. In cases of significant differences, a post hoc Tukey's multiple comparisons test was employed to determine significance between groups. All tests were conducted as two-tailed with an alpha level of 0.05.

The sample size was calculated using G*Power 3.1 software for the repeated ANOVA design. An F test was used with the following parameters: effect size f=0.25, α error probability=0.05, power (1-β error probability)=0.8, number of groups=3, number of measurements=6, and correlation among repeated measures=0 [45]. The software determined a minimum sample size of 45, requiring 15 participants per group. Recruitment successfully met this minimum sample size requirement. All statistical analyses were performed by X.L.F.

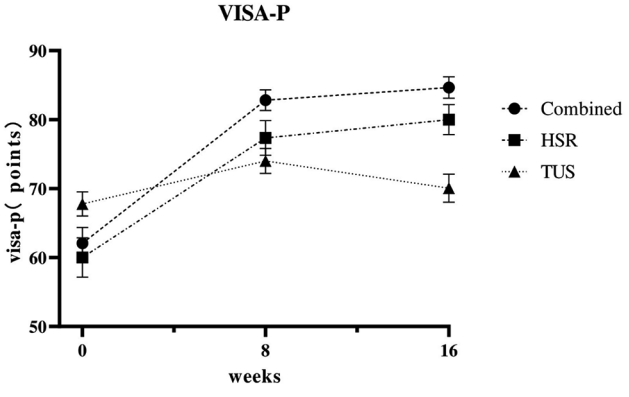

Fig. 6 Subjects' VISA-P scores before the intervention, at week 8 after the end of the intervention, and at week 16 follow-up

Results

Primary outcome measure

VISA-P

A two-factor repeated measures ANOVA was conducted to analyze VISA-P scores at baseline, 8, and 16 weeks of follow-up. The analysis assessed the treatment's impact over time. Results indicated a significant main effect of "group" on VISA-P scores ($F=39.16$, $p<0.001$), suggesting differences between the treatment groups. Additionally, a significant main effect of "time" was observed ($F=7.52$, $p=0.0016$), indicating score variations across time points. Furthermore, a significant interaction between "group" and "time" was identified ($F=28.4$, $p<0.0001$), demonstrating that the treatment effect on VISA-P scores differed based on the time of measurement.

Post-hoc analysis using Tukey's multiple comparisons test revealed no significant pairwise differences among the groups at baseline. However, at the 8-week post-intervention assessment, the Combined group exhibited significantly higher VISA-P scores than the TUS group ($p=0.002$). At 16 weeks, both the Combined group and the HSR group demonstrated significantly higher VISA-P scores than the TUS group ($p<0.0001$ and $p=0.006$, respectively). These results are illustrated in Fig. 6; Table 3. Given that the VISA-P scores include an assessment of both pain symptoms and motor function, the findings suggest that the combined group experienced greater improvement in PT subjects compared to the TUS group.

Secondary outcome measure

VAS

A repeated-measures ANOVA was conducted on the collected VAS scores. Pre-intervention between-group comparisons of VAS scores among the three groups revealed no significant differences at baseline ($F=0.22$, $p=0.82$). However, post-hoc multiple comparisons

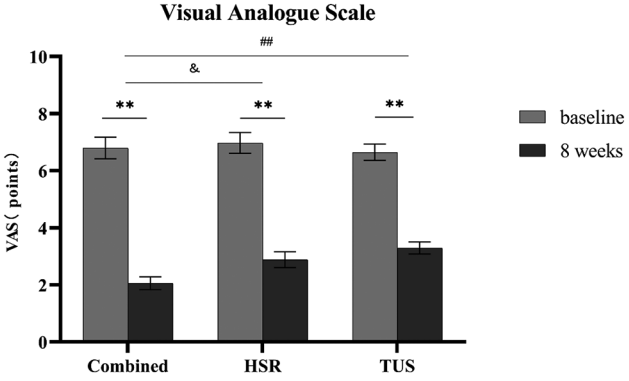

Fig. 7 Changes in VAS of three groups of subjects before and after intervention

Table 3 Changes in subjects'VISA-P scores at baseline, 8-week and 16-week follow-ups(values are means ± SD)

	Combined group (*N* = 17)	HSR group (*N* = 17)	TUS group (*N* = 17)
VISA-P-baseline	62.1 ± 9.4	60.0 ± 11.8	67.8 ± 7.3
VISA-P-8w	82.8 ± 6.2**	77.3 ± 10.4**	74.0 ± 7.5**
VISA-P-16w	84.7 ± 6.4**	80.0 ± 9.0**	70.0 ± 8.3

** means Pair t test significantly different from baseline(p<0.01)

analysis following the 8-week intervention demonstrated a significant difference (F = 6.97). Post-hoc multiple comparison tests identified significant differences between the combined group and both the HSR training group (p = 0.048) and the TUS treatment group (p = 0.001), indicating superior pain reduction efficacy in the combined group. Furthermore, paired-samples within-group t-tests revealed significant reductions in VAS scores for all three treatments from baseline to post-intervention, as shown in Table 4; Fig. 7.

YBT

A repeated measures ANOVA was conducted on the YBT data of the subjects collected before and after the intervention. The results indicated no significant difference in the subjects' YBT test ability between the groups before the intervention (F = 2.11, p = 0.13). Additionally, no significant difference was observed between the groups after the 8-week intervention (F = 0.85, p = 0.91). However, a within-group comparison of the three groups of subjects using paired-samples t-tests revealed a significant difference in YBT scores before and after the intervention for all three groups. This suggests that the subjects exhibited some degree of improvement in balance following the intervention, although these changes were not significant between groups, as shown in Table 4; Fig. 8.

MTT

A one-way repeated measures ANOVA was conducted on the MTT test data collected from subjects before and after the 8-week intervention. Between-group comparisons of the three groups prior to the intervention revealed no significant differences in MTT (F = 0.92, p = 0.40). Similarly, post-intervention comparisons showed no significant differences between the groups (F = 0.89, p = 0.43). However, following the 8-week intervention, a significant difference emerged between the groups (F = 5.18, p = 0.009), as detailed in Table 3. Post-hoc analysis indicated that the MTT results of subjects in the combined group significantly differed from those in the TUS group, suggesting that the combined treatment was more effective in improving quadriceps flexibility. A paired-sample t-test assessed within-group differences in MTT scores before and after the intervention. The combined group showed a significant improvement compared to the HSR

Table 4 Changes in selected indicators before and after intervention(values are means ± SD)

	Combined group (*N* = 17)	HSR group (*N* = 17)	TUS group (*N* = 17)	*P*-Value	F
VAS-baseline(points)	6.8 ± 1.6	7.0 ± 1.5	6.7 ± 1.2	0.8	0.22
VAS-8w(points)	2.1 ± 1.0**&##	2.9 ± 1.1**	3.3 ± 0.9**	0.002	6.9
YBT-baseline(ratio)	0.88 ± 0.07	0.93 ± 0.08	0.92 ± 0.07	0.13	2.11
YBT-8w(ratio)	0.97 ± 0.08**	0.99 ± 0.07**	0.96 ± 0.08**	0.43	0.92
MTT-baseline(degrees)	51.6 ± 1.3	51.7 ± 2.2	52.4 ± 1.9	0.4	0.9
MTT-8w(degrees)	54.8 ± 1.7**#	54.4 ± 2.2**	52.8 ± 2.0	0.009	5.18
MIMS-baseline(kg)	216.7 ± 56.0	254.4 ± 36.9	235.6 ± 46.1	0.07	2.73
MIMS-8w(kg)	295.4 ± 73.6**	326.7 ± 78.8**	282.4 ± 90.3*	0.27	1.33
Horizontal Jump-baseline(cm)	225.3 ± 25.7	231.1 ± 22.91	229.5 ± 32.09	0.81	0.20
Horizontal Jump-8w(cm)	232.1 ± 18.0	231.3 ± 21.5	231.1 ± 27.1	0.65	0.008

** means Pair t test significantly different from baseline(p<0.01)

*means Pair t test significantly different from baseline(p<0.05)

means Tukey's multiple comparisons test significantly different from TUS group(p<0.05)

##means Tukey's multiple comparisons test significantly different from TUS group(p<0.01)

&means Tukey's multiple comparisons test significantly different from HSR group(p<0.05)

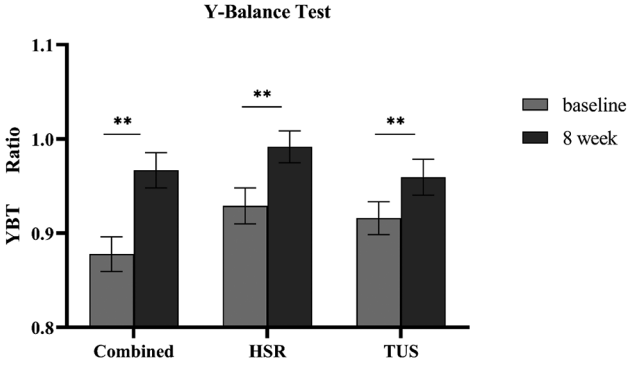

Fig. 8 Changes in YBT before and after intervention in three groups

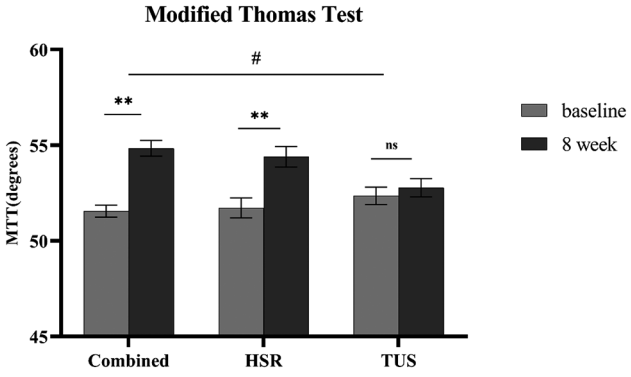

Fig. 9 Changes in MTT before and after intervention in three groups

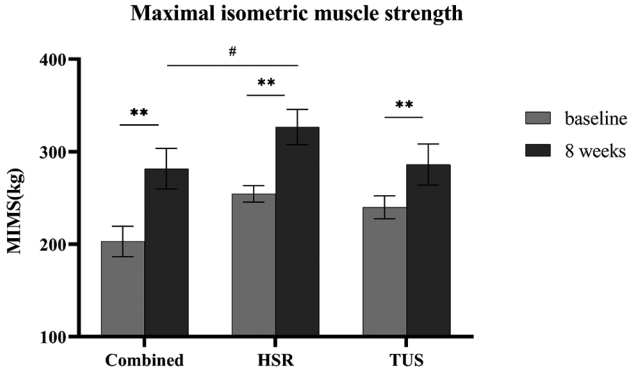

Fig. 10 Changes in MIMS before and after intervention in three groups

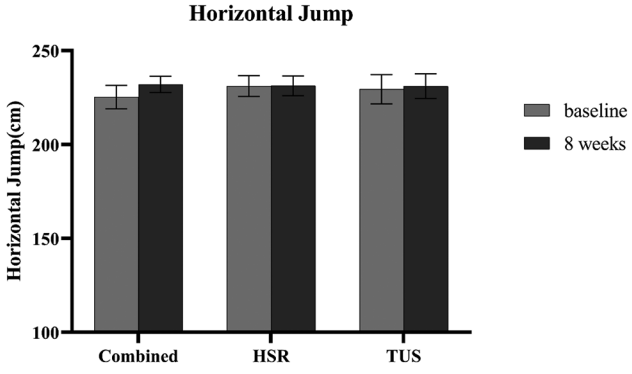

Fig. 11 The horizontal jump distance in the three groups before and after the intervention

group after 8 weeks, indicating that both the combined intervention and training regimen effectively enhanced quadriceps muscle flexibility. In contrast, no significant changes were observed in the TUS group, suggesting that the improvement in quadriceps flexibility following TUS treatment was relatively limited, as depicted in Fig. 9.

Maximum isometric strength of lower extremity extensors

A one-way repeated measures ANOVA was used to analyze the maximum isometric contraction moments of the lower extremity extensors of the subjects before and after the intervention among groups. The results indicated no significant differences between the pre-intervention groups ($F=1.34$, $p=0.27$) or between the post-intervention groups ($F=2.74$, $p=0.07$). Subsequent within-group comparisons were conducted using paired samples t-tests to assess changes before and after the intervention. All three intervention modalities significantly improved the maximal isometric contraction strength of the lower extremity extensors, with p-values of <0.0001 in the combined group, 0.0018 in the HSR group, and 0.03 in the TUS group. The improvement was most pronounced in the combined group, as shown in Table 3; Fig. 10.

Horizontal jump

A within- and between-group comparison of pre- and post-intervention data was conducted. Results indicated no significant differences between groups at either pre-intervention ($F=0.21$, $p=0.81$) or post-intervention time points. Paired samples t-tests revealed no significant within-group differences among the three groups before and after the intervention ($p=0.23$, 0.95, and 0.77), as shown in Table 3; Fig. 11.

Musculoskeletal ultrasound imaging

At the conclusion of the 8-week intervention, patellar tendon thickness was measured in the subjects using an ultrasound device, following the same procedure as at baseline. Due to various reasons, some subjects were sent to competitions, so they could not participate in the final musculoskeletal ultrasound measurement. At baseline, the three groups (Combined group, $n=12$, HSR group, $n=10$, TUS group, $n=10$) had patellar tendon thicknesses of 0.51 ± 0.20 cm, 0.59 ± 0.15 cm, and 0.43 ± 0.12 cm, respectively ($p=0.10$, $F=2.52$). After 8 weeks of intervention, these values were 0.54 ± 0.54 cm, 0.63 ± 0.14 cm, and 0.49 ± 0.10 cm, respectively ($p=0.12$, $F=2.23$). The combined and HSR groups showed a slight increase in patellar tendon thickness from baseline, but this change was

not statistically significant. In contrast, the TUS group exhibited a more pronounced and significant increase in patellar tendon thickness from baseline ($p<0.05$). Comparative analysis of the three groups revealed no significant differences in tendon thickness before or after the intervention, as shown in Fig. 12. Additionally, compared to pre-intervention measurements, the blood flow signal within the patellar tendon decreased in all three groups, as illustrated in Fig. 13.

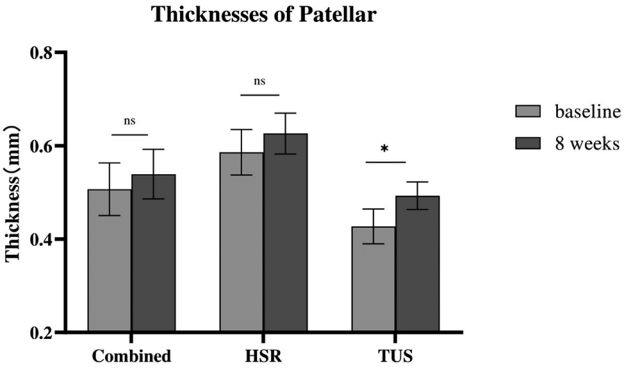

Fig. 12 Changes in patellar tendon thickness before and after intervention in three groups with musculoskeletal ultrasound imaging

Discussion

Heavy slow resistance training and therapeutic ultrasound are commonly used in musculoskeletal disorder rehabilitation. While both are often employed for patellar tendinopathy, their individual effectiveness can be limited in certain cases [20, 46]. Research suggests that HSR training can increase collagen production in the tendon, leading to pain relief [8]. However, this effect might be diminished in individuals with severe squatting difficulties or intense pain during squatting [47]. Conversely, high-dose TUS can elevate the tendon's internal temperature, promoting healing [13]. This study evaluated the efficacy of combining HSR training with high-dose TUS for treating patellar tendinopathy, focusing on pain reduction, strength, athletic performance, and balance. At the conclusion of the 8-week intervention, the VISA-P score questionnaire results indicated that participants in the HSR training group experienced an average improvement of 17 points compared to their baseline scores. In contrast, the TUS treatment group exhibited an average increase of 6 points, while the combined group demonstrated an average improvement of 21 points. Our study suggests that combining high-dose TUS with HSR training had a significant short-term positive effect on patellar tendinopathy. Although the high-dose TUS group exhibited significant improvements in VISA-P scores post-intervention, these improvements did not reach the minimum clinically important difference (MCID) of 13 points for PT symptom improvement [30]. The results revealed that the combined and HSR groups maintained more sustained improvements after the intervention ended, whereas the TUS group experienced a significant decrease in treatment effectiveness post-intervention. This suggests that in clinical settings using ultrasound therapy for patellar tendon disease, the continuity of treatment should be emphasized. Further research is necessary to determine the optimal treatment duration for tendon adaptive changes, as indicated in the supplementary data. Our study utilized a TUS dosage of 4920 joules; however, given the limited research on the optimal TUS dosage for tendinopathy treatment, it is highly conceivable that the lower dosage parameters employed may not have been sufficient to generate significant clinical effects.

We hypothesized that the combined group would exhibit more significant improvements in standing jump distance post-training, given that PT is often associated with pain during jumping and landing [20]. However, the results demonstrated considerable variability, without significant differences between pre- and post-intervention assessments ($p>0.05$). This variability could be attributed to the focus of HSR training on eccentric and concentric contractions, which may not fully align with the explosive nature of vertical jumps. Moreover, all three experimental groups exhibited significant improvements in balance abilities, particularly the combined group, suggesting the potential benefits of HSR training in enhancing dynamic stability and balance through improved muscle control over postural changes. In contrast,

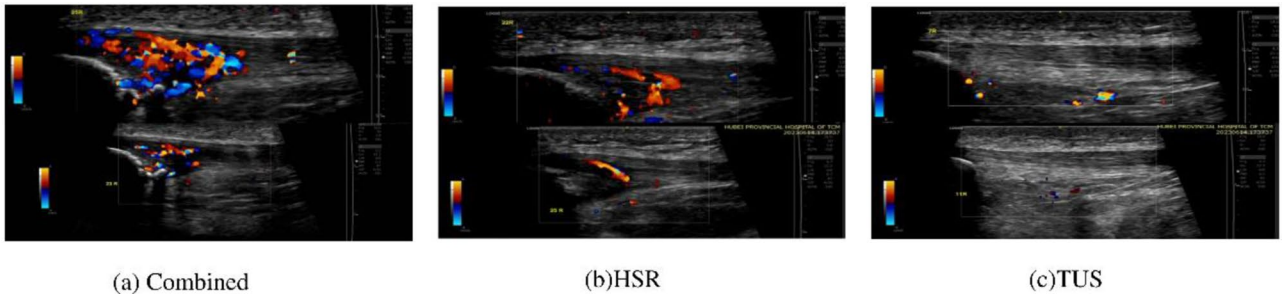

Fig. 13 Blood flow inside the patellar tendon in each group before and 8 weeks after intervention

therapeutic ultrasound therapy, a common physical therapy modality, primarily relies on thermal and mechanical effects to facilitate tissue repair and regeneration. While previous studies have shown some therapeutic effects of ultrasound therapy on certain musculoskeletal conditions [10, 13], its impact on balance abilities remains insufficiently studied and confirmed. Some participants initially reported pain hindering their performance in the YBT during baseline measurements, but this hindrance was notably reduced after 8 weeks of intervention. Consequently, the improvement in balance abilities among the TUS group participants may be linked to pain relief. However, further research and discussion are required to explore the influence of pain on test outcomes.

HSR training significantly contributed to the improvement of quadriceps flexibility, while the ultrasound group demonstrated limited improvements. This difference is likely attributable to the specific exercises chosen. These findings suggest that resistance training offers notable benefits for enhancing muscle flexibility [48]. The closed-chain lower limb exercises we employed not only directly impact the muscles but also influence the entire lower limb movement pattern, potentially modifying the flexibility of the quadriceps. However, whether these changes in movement patterns primarily lead to improved quadriceps femoris flexibility or if enhanced quadriceps femoris flexibility is the primary driver of changes in movement patterns remains an area requiring further exploration. Future research efforts could focus on rigorously investigating the causal connections between improvements in quadriceps femoris flexibility and modifications in lower limb movement patterns. By employing advanced research techniques and biomechanical assessments, a deeper understanding of the reciprocal influence mechanisms between muscle flexibility and movement patterns may be achieved.

About MIMS, the combined group demonstrated a 42% increase compared to pre-intervention levels, while the training group experienced a 30% increase, suggesting multiple factors may have contributed to this growth. The rise in strength can be partially attributed to neuromuscular adaptation effects. Through strength training, muscle tissue undergoes various adaptive changes, such as increased muscle fibers and enhancements in the nervous system, which enable muscles to generate force more efficiently [49]. These findings align with previous research indicating that prolonged training can enhance muscle strength [8, 46, 50]. This finding may be beneficial for in-season athletes, as the combined intervention program can both reduce pain and maintain muscle strength to ensure optimal athletic performance.

Patellar tendon color Doppler ultrasonography in the present study revealed a notable reduction in blood flow within the tendon following an 8-week exercise intervention compared to pre-intervention. This finding aligned with the results of Koenig et al.'s research [8, 51]. Exercise intervention may facilitate the normalization of blood vessel distribution around the tendon, diminish the formation of abnormal vessels within the patellar tendon, and lower the concentration of specific neurotransmitters in the tendon blood vessels [52], potentially contributing to the observed decrease in pain levels. Regarding changes in patellar tendon thickness, participants in all three groups exhibited varying degrees of increased thickness post the 8-week intervention period [53]. Nonetheless, Kongsgaard et al.'s study [8] noted a significant 45% decrease in tendon thickness among subjects in the HSR exercise group by week 12, approaching the original fiber morphology of healthy tendons [16]. It is highly conceivable that between the 8th and 12th weeks post-intervention, the tendons underwent adaptive changes, resulting in a reduction in thickness for tendons that initially thickened during the early intervention period. Agergaard et al. [54] conducted musculoskeletal ultrasound measurements of patellar tendons in two high-speed resistance exercise intervention groups at baseline, 6 weeks, 12 weeks, and 52 weeks. They observed an initial increase in tendon thickness in both groups from baseline to 6 weeks, followed by a decrease in tendon thickness from 6 to 12 weeks, aligning with our initial hypothesis. However, it is important to acknowledge that variations in ultrasound measurement techniques can contribute to discrepancies in results. Future studies should consider employing standardized musculoskeletal ultrasound measurements. Tsai et al. [55] proposed that extracorporeal ultrasound can promote tendon healing; however, the specific mechanisms underlying this process remain unclear. Our study demonstrated a significant increase in patellar tendon thickness in participants after 8 weeks of extracorporeal high-energy ultrasound treatment compared to baseline measurements. Since we did not conduct ultrasound assessments at 12 weeks, the potential effects of prolonged extracorporeal ultrasound intervention on tendon thickness are still unknown. In summary, we hypothesize that damaged tendons undergo a thickening process during recovery, leading to the formation of healthy tendon structures, possibly due to the development of new scar tissue. Further comprehensive studies are needed to elucidate the precise timeline of scar tissue formation and regression within the tendon.

A key strength of this study was the high adherence of most participants to a thrice-weekly supervised exercise program. Training and rest periods were closely monitored to ensure compliance and follow-up assessments were conducted in controlled environments at 16 weeks to minimize external interference. The sample consisted of university athletes from Wuhan Sports University, representing a representative population.

Several limitations of this study should be acknowledged. The instructors were not blinded, which may have influenced outcomes, although additional training was provided to ensure consistency. Despite efforts to restrict unrelated physical activities, some participants may have engaged in other sports, potentially affecting results. Kinematic evaluations involved squatting on an inclined platform, with a few participants experiencing patellar tendon pain during baseline testing. Adjustments were made for safety, but all participants could squat to the specified angle in the post-intervention test, potentially increasing the risk of Type I errors. The VISA-P follow-up was limited to 16 weeks, restricting the assessment of long-term intervention effects on patellar tendon disorders. Further research is necessary to evaluate long-term efficacy.

In conclusion, our research findings demonstrate that the combination of Heavy Slow Resistance training and high-dose ultrasound therapy significantly improves pain and functionality among patients with patellar tendinopathy. This combined approach is particularly effective in reducing symptoms in chronic patients, making it a suitable protocol for individuals with severe symptoms or those seeking enhanced athletic performance.

Abbreviations

BF	Biceps femoris
ESWT	Extracorporeal shockwave therapy
EET	Eccentric exercise training
EMG	Electromyography
HSR	Heavy slow resistance
MTT	Modified Thomas Test
MVIC	Maximum Voluntary Isometric Contraction
MIMS	Maximal isometric muscle strength
RMS	Root mean square
TLT	Tendon-loading training
TUS	Therapeutic ultrasound
VAS	Visual Analogue Scale
VISA-P	Victorian Institute of Sport Assessment-Patella
VLO	Vastus lateralis obliquus
VMO	Vastus medialis obliquus
PT	Patellar tendinopathy
YBT	Y-Balance Test

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Author contributions
Xiao Liufeng was responsible for the writing and comparison of manuscripts, Zhou heng was responsible for recruiting and screening the subjects, He jia was responsible for the intervention and management of the subjects, Liu hua Evaluating and directing the training program of the study, Liu ziyi and Li yongchao were responsible for the randomization of subjects and the baseline assessment, Hu hao was responsible for mobilizing intervention sites and comparing manuscripts.

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Data availability
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Ethical approval
The experimental protocol was established, according to the ethical guidelines of the Helsinki Declaration and was approved by the Human Ethics Committee of Wuhan Sports University. Written informed consent was obtained from individual or guardian participants.

Consent for publication
Not applicable.

Informed consent
Prior to the start of the experiment, informed consent forms should be provided, requiring participants to know the specific protocol and risks of the experiment, and to sign informed consent forms after understanding the protocol

Competing interests
The authors declare no competing interests.

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References

1. Scott A, Squier K, Alfredson H, Bahr R, Cook JL, Coombes B et al. ICON 2019: International Scientific Tendinopathy Symposium Consensus: Clinical Terminology. Br J Sports Med. 2020;54(5):260-2.
2. Xu Y, Murrell GA. The basic science of tendinopathy. Clin Orthop Relat Res. 2008;466(7):1528–38.
3. Lian OB, Engebretsen L, Bahr R. Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. Am J Sports Med. 2005;33(4):561–7.
4. Hannington M, Rio E, Padua D, Stanley L, Berkoff D, Edwards S, et al. Prevalence and impact of patellar tendinopathy on elite basketball athletes: quantifying injury beyond the time-loss definition. J Sci Med Sport. 2017;20:17–8.
5. Cook JL, Khan KM, Harcourt PR, Grant M, Young DA, Bonar SF. A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. The Victorian Institute of Sport Tendon Study Group. Br J Sports Med. 1997;31(4):332–6.
6. Millar NL, Silbernagel KG, Thorborg K, Kirwan PD, Galatz LM, Abrams GD, et al. Tendinopathy Nat Rev Dis Primers. 2021;7(1):1.
7. Breda SJ, Oei EHG, Zwerver J, Visser E, Waarsing E, Krestin GP, et al. Effectiveness of progressive tendon-loading exercise therapy in patients with patellar tendinopathy: a randomised clinical trial. Br J Sports Med. 2021;55(9):501–9.
8. Kongsgaard M, Kovanen V, Aagaard P, Doessing S, Hansen P, Laursen AH, et al. Corticosteroid injections, eccentric decline squat training and heavy slow resistance training in patellar tendinopathy. Scand J Med Sci Sports. 2009;19(6):790–802.
9. Purdam CR, Jonsson P, Alfredson H, Lorentzon R, Cook JL, Khan KM. A pilot study of the eccentric decline squat in the management of painful chronic patellar tendinopathy. Br J Sports Med. 2004;38(4):395–7.
10. van der Windt DAWM, van der Heijden GJMG, van den Berg SGM, Ter Riet G, de Winter AF, Bouter LM. Ultrasound therapy for musculoskeletal disorders: a systematic review. Pain. 1999;81(3):257–71.
11. Andres BM, Murrell GA. Treatment of tendinopathy: what works, what does not, and what is on the horizon. Clin Orthop Relat Res. 2008;466(7):1539–54.
12. Smallcomb M, Khandare S, Vidt ME, Simon JC. Therapeutic Ultrasound and Shockwave Therapy for Tendinopathy: a narrative review. Am J Phys Med Rehabil. 2022;101(8):801–7.

13. de Jesus JF, de Albuquerque TAB, Shimba LG, Bryk FF, Cook J, Pinfildi CE. High-energy dose of therapeutic ultrasound in the treatment of patellar tendinopathy: protocol of a randomized placebo-controlled clinical trial. BMC Musculoskelet Disord. 2019;20(1):624.
14. Fu SC, Shum WT, Hung LK, Wong MW, Qin L, Chan KM. Low-intensity pulsed ultrasound on tendon healing: a study of the effect of treatment duration and treatment initiation. Am J Sports Med. 2008;36(9):1742–9.
15. Kongsgaard M, Reitelseder S, Pedersen TG, Holm L, Aagaard P, Kjaer M, et al. Region specific patellar tendon hypertrophy in humans following resistance training. Acta Physiol (Oxf). 2007;191(2):111–21.
16. Kongsgaard M, Qvortrup K, Larsen J, Aagaard P, Doessing S, Hansen P, et al. Fibril morphology and tendon mechanical properties in patellar tendinopathy: effects of heavy slow resistance training. Am J Sports Med. 2010;38(4):749–56.
17. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH. Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. J Neurophysiol. 2001;86(4):1764–72.
18. Enoka RM. Eccentric contractions require unique activation strategies by the nervous system. J Appl Physiol (1985). 1996;81(6):2339–46.
19. Morrison S, Cook J. Putting heavy into heavy slow resistance. Sports Med. 2022;52(6):1219–22.
20. Schwartz A, Watson JN, Hutchinson MR. Patellar Tendinopathy. Sports Health. 2015;7(5):415–20.
21. Leadbetter WB. Cell-matrix response in tendon injury. Clin Sports Med. 1992;11(3):533–78.
22. Crossley KM, Stefanik JJ, Selfe J, Collins NJ, Davis IS, Powers CM, et al. 2016 Patellofemoral pain consensus statement from the 4th international Patellofemoral Pain Research Retreat, Manchester. Part 1: terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome measures. Br J Sports Med. 2016;50(14):839–43.
23. Zwerver J, Kramer T, van den Akker-Scheek I. Validity and reliability of the Dutch translation of the VISA-P questionnaire for patellar tendinopathy. BMC Musculoskelet Disord. 2009;10(1).
24. Visentini PJ, Khan KM, Cook JL, Kiss ZS, Harcourt PR, Wark JD. The VISA score: an index of severity of symptoms in patients with jumper's knee (patellar tendinosis). Victorian Institute of Sport Tendon Study Group. J Sci Med Sport. 1998;1(1):22–8.
25. Cook JL, Khan KM, Kiss ZS, Purdam CR, Griffiths L. Reproducibility and clinical utility of tendon palpation to detect patellar tendinopathy in young basketball players. Victorian Institute of Sport Tendon study group. Br J Sports Med. 2001;35(1):65–9.
26. van der Worp H, van Ark M, Zwerver J, van den Akker-Scheek I. Risk factors for patellar tendinopathy in basketball and volleyball players: a cross-sectional study. Scand J Med Sci Sports. 2012;22(6):783–90.
27. Kulig K, Landel R, Chang YJ, Hannanvash N, Reischl SF, Song P, et al. Patellar tendon morphology in volleyball athletes with and without patellar tendinopathy. Scand J Med Sci Sports. 2013;23(2):e81–8.
28. Schulz KF, Altman DG, Moher D. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. BMJ. 2010;340:c332.
29. Association GGHNTTNNSaC. Essentials of Strength Training and Conditioning. Fourth Edition ed2015.
30. Hernandez-Sanchez S, Hidalgo MD, Gomez A. Responsiveness of the VISA-P scale for patellar tendinopathy in athletes. Br J Sports Med. 2014;48(6):453–7.
31. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. Pain. 1983;17(1):45–56.
32. Zwerver J, Bredeweg SW, Hof AL. Biomechanical analysis of the single-leg decline squat. Br J Sports Med. 2007;41(4).
33. Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. N Am J Sports Phys Ther. 2009;4(2):92–9.
34. Kang M-H, Kim G-M, Kwon O-Y, Weon J-H, Oh J-S, An D-H. Relationship between the kinematics of the trunk and lower extremity and performance on the Y-Balance test. PM R. 2015;7(11):1152–8.
35. Robinson RH, Gribble PA. Support for a reduction in the number of trials needed for the star excursion balance test. Arch Phys Med Rehabil. 2008;89(2):364–70.
36. Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. Meas Phys Educ Exerc Sci. 2003;7(2):89–100.
37. Lee DK, Kang MH, Lee TS, Oh JS. Relationships among the Y balance test, Berg Balance Scale, and lower limb strength in middle-aged and older females. Braz J Phys Ther. 2015;19(3):227–34.
38. Witvrouw E, Bellemans J, Lysens R, Danneels L, Cambier D. Intrinsic risk factors for the development of patellar tendinitis in an athletic population. A two-year prospective study. Am J Sports Med. 2001;29(2):190–5.
39. Whitehead CL, Hillman SJ, Richardson AM, Hazlewood ME, Robb JE. The effect of simulated hamstring shortening on gait in normal subjects. Gait Posture. 2007;26(1):90–6.
40. Scattone Silva R, Nakagawa TH, Ferreira AL, Garcia LC, Santos JE, Serrao FV. Lower limb strength and flexibility in athletes with and without patellar tendinopathy. Phys Ther Sport. 2016;20:19–25.
41. Harvey D. Assessment of the flexibility of elite athletes using the modified Thomas test. Br J Sports Med. 1998;32(1):68–70.
42. Barber SD, Noyes FR, Mangine RE, McCloskey JW, Hartman W. Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees. Clin Orthop Relat Res. 1990;255:204–14.
43. Beggs IBS, Bueno A, Cohen M, Court-Payen M, Grainger A et al. Musculoskeletal ultrasound technical guidelines: V. Knee. European Society of Musculoskeletal Radiology Accessed 05-01-2012 on. 2012 [https://www.essr.org/content-essr/uploads/2016/10/knee.pdf
44. Skou ST, Aalkjaer JM. Ultrasonographic measurement of patellar tendon thickness–a study of intra- and interobserver reliability. Clin Imaging. 2013;37(5):934–7.
45. Cohen J. A power primer. Psychol Bull. 1992;112(1):155–9.
46. Malliaras P, Cook J, Purdam C, Rio E. Patellar tendinopathy: clinical diagnosis, load management, and advice for Challenging Case presentations. J Orthop Sports Phys Ther. 2015;45(11):887–98.
47. Arnoczky SP, Lavagnino M, Egerbacher M. The mechanobiological aetiopathogenesis of tendinopathy: is it the over-stimulation or the under-stimulation of tendon cells? Int J Exp Pathol. 2007;88(4):217–26.
48. Morton SK, Whitehead JR, Brinkert RH, Caine DJ. Resistance training vs. static stretching: effects on flexibility and strength. J Strength Cond Res. 2011;25(12):3391–8.
49. Folland JP, Williams AG. The adaptations to strength training: morphological and neurological contributions to increased strength. Sports Med (Auckland NZ). 2007;37(2):145–68.
50. Frohm A, Saartok T, Halvorsen K, Renstrom P. Eccentric treatment for patellar tendinopathy: a prospective randomised short-term pilot study of two rehabilitation protocols. Br J Sports Med. 2007;41(7):e7.
51. Koenig MJ, Torp-Pedersen S, Qvistgaard E, Terslev L, Bliddal H. Preliminary results of colour doppler-guided intratendinous glucocorticoid injection for Achilles tendonitis in five patients. Scand J Med Sci Sports. 2004;14(2):100–6.
52. Alfredson H, Forsgren S, Thorsen K, Lorentzon R. In vivo microdialysis and immunohistochemical analyses of tendon tissue demonstrated high amounts of free glutamate and glutamate NMDAR1 receptors, but no signs of inflammation, in Jumper's knee. J Orthop Research: Official Publication Orthop Res Soc. 2001;19(5):881–6.
53. Ohberg L, Lorentzon R, Alfredson H. Eccentric training in patients with chronic Achilles tendinosis: normalised tendon structure and decreased thickness at follow up. Br J Sports Med. 2004;38(1).
54. Agergaard AS, Svensson RB, Malmgaard-Clausen NM, Couppe C, Hjortshoej MH, Doessing S, et al. Clinical outcomes, structure, and function improve with both heavy and moderate loads in the treatment of Patellar Tendinopathy: a Randomized Clinical Trial. Am J Sports Med. 2021;49(4):982–93.
55. Tsai WC, Tang ST, Liang FC. Effect of therapeutic ultrasound on tendons. Am J Phys Med Rehabil. 2011;90(12):1068–73.

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