



ESWT is able to change macromorphological and micromorphological parameters in patellar tendinopathy: a prospective cohort study

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Background: This study aimed to assess the mid-term effects of focused extracorporeal shockwave therapy (ESWT) on clinical symptoms and tendon structure in patellar tendinopathy. Ultrasound (US) evaluation and an innovative *in vivo* analysis of intra-tendinous morphology using validated spatial frequency analysis (SFA) software were employed to quantify the organization and density of collagen fascicles.

Methods: This prospective cohort study included 21 recreational athletes (mean age 29.9 ± 9.3 years) with chronic unilateral symptomatic patellar tendinopathy. ESWT was applied as monotherapy over four weekly sessions. Pain was assessed using the Numeric Rating Scale (NRS) and disease severity with the Victorian Institute of Sports Assessment – Patella (VISA-P) questionnaire. Morphological parameters, such as tendon diameter (TD), were assessed with US and analyzed using SFA software. The asymptomatic tendons served as controls. Follow-up assessments were conducted at the end of the treatment period and 3 months posttreatment.

Results: Baseline evaluations revealed increased TD in proximal part of the tendon ($P = 0.001$) and decreased organization of collagen fascicles ($P = 0.013$) in symptomatic tendons compared to asymptomatic controls. At the 3-month follow-up, symptomatic tendons showed significant reductions in TD ($P < 0.001$) and improvements in both organization and density of collagen fascicles throughout various parameters – peak spatial frequency radius (PSFR) ($P = 0.024$), P6 ($P = 0.05$), Q6 ($P = 0.016$), PPP ($P = 0.003$). No significant morphological changes were observed in asymptomatic tendons. Clinical evaluations demonstrated significant reductions in NRS ($P < 0.001$) and increases in Victorian Institute of Sports Assessment – Patella (VISA-P) scores ($P < 0.001$) at all time points.

Conclusion: The study suggests that ESWT may have the potential to induce positive structural changes in patellar tendinopathy, including improved organization and density of collagen fascicles. These findings indicate that ESWT could be a promising noninvasive approach to managing patellar tendinopathy, with observed improvements in clinical symptoms and tendon structure. However, further high-quality research is needed to confirm these results and establish their long-term efficacy.

Keywords: extracorporeal shockwave therapy, jumper's knee, patellar tendinopathy, spatial frequency analysis, ultrasound

Introduction

Patellar tendinopathy (PT) is a commonly used term for the clinical manifestation of patellar tendon pain and functional limitation with multifactorial etiology. It occurs in both athletes and general population in all age groups^[1,2]. It is often characterized as an overuse injury resulting from chronic failure of the healing response that is not strictly linked to inflammatory or degenerative processes^[1,3]. Structural changes, such as

HIGHLIGHTS

- To the authors' knowledge, this is the first study evaluating the structural changes in patellar tendinopathy at the intra-tendinous level after extracorporeal shockwave therapy (ESWT) *in vivo*.
- ESWT showed to be able to induce positive intra-tendinous changes in patellar tendinopathy.
- The improved organization and density of collagen fascicles three months after the last session may indicate a remodeling process associated with the biological effects of ESWT.

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enlargement of the tendon, can be present. Disorganization of the collagen fascicles is described as one of the main pathological processes at the intra-tendinous level^[1,3]. Understanding these

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changes is essential for identifying appropriate treatment strategies for PT.

Although resistance training is the gold standard in PT management^[2], extracorporeal shockwave therapy (ESWT) is a noninvasive, safe, and promising additive treatment^[4,5], albeit with inconsistent results in pain reduction and functional improvement among literature^[6–8]. On the other hand, ESWT is known to activate an intracellular signaling pathway that results in a variety of biological responses^[4]. In particular, ESWT stimulates tendon cell activity, modulates inflammation, upregulates the expression of angiogenic and osteogenic factors, and induces various protein synthesis, including collagen^[4,9]. These mechanisms support the potential of ESWT's role in enhancing the structural integrity of tendons.

Considering the conflicting evidence related to ESWT in PT and its biological effects, further investigation is warranted to determine whether these effects can lead to structural improvements in the tendon. Few studies using ESWT in PT have focused on structural changes or biomechanical properties (e.g. tendon diameter [TD] or stiffness), and none have focused on intra-tendinous changes in the organization of collagen fascicles^[8]. Understanding these changes is essential because improved tendon structure could potentially contribute to enhanced biomechanical properties, offering significant benefits for the comprehensive management of PT.

This prospective cohort study is the first to evaluate the impact of ESWT on micromorphological changes in PT, alongside clinical manifestations, and macro-morphology (e.g. TD). This includes the organization, spacing, and density of intra-tendinous collagen fascicles. It is quantified *in vivo* using valid spatial frequency analysis (SFA) software for ultrasound (US) picture analysis^[10,11]. It aims to demonstrate whether ESWT can effectively induce intra-tendinous changes and thereby contribute to improving the treatment of PT at a structural level.

We stated two hypotheses: (1) the organization and density of collagen fascicles within symptomatic tendons will significantly improve three months after the last session of ESWT, as measured by SFA; (2) asymptomatic tendons in the same patients are expected to exhibit no significant change in the organization of collagen fascicles over the same period.

Methods

Study description

This prospective, single-center, longitudinal cohort study monitors the effect of a low-energy focused ESWT on the tendon structure in patients with PT. The structure was evaluated both on the symptomatic and on the contralateral asymptomatic lower limb. The article is written in accordance with the STROCSS checklist^[12].

All participants signed an informed consent. The study was approved by the Ethics Committee of the University Hospital Motol with number EK-980/23 and was registered in the Clinical Trials database with number NCT06102421.

Patient recruitment

Potential research participants were contacted by a rehabilitation physician's office. Their suitability for the study was assessed during an initial examination, and those deemed eligible were subsequently enrolled.

The sample size was calculated using G*Power software (version 3.1.9.7., Heinrich-Heine-Universität Düsseldorf, Germany) previous to participants recruitment^[13]. The power analysis calculated with one-tailed Wilcoxon signed-rank test and Mann-Whitney *U* test (two groups) to deduce a sample size of no less than 21 participants (21 samples of symptomatic and asymptomatic tendon), based on calculated effect size 0.8, an α level of 0.05, a power of 80%, and an allocation ratio of 1.

Patient selection – inclusion and exclusion criteria

The patient was included in the study if they met the following criteria:

- is a recreational athlete performing intensive sport activity loading the patellar tendon (running, jumping, strength training, *etc.*) at least 3 days a week for a minimum of 1 hour per session;
- is aged between 18 and 40 years;
- has patellar tendon pain, which limits (at least in part) the quality of normal daily or sports activities;
- has clinical manifestation of PT (pain and impaired function) confirmed by a clinician; and
- has symptoms only in one leg, the other one is asymptomatic.

Patients were not included if:

- Any contraindication for ESWT is present (according to the International Society for Medical Shockwave Treatment [ISMST] consensus at <https://shockwavetherapy.org>).
- They were aware of any symptomatic mechanical tendon damage in the past (e.g. partial or complete rupture in relation to the injury), neurological, oncological, or systemic disease (e.g. neuropathy, lupus or rheumatic arthritis) coexists.
- They were already treated for PT elsewhere up to 3 months prior to the study (e.g. platelet-rich plasma therapy, physiotherapy incl. resistance training or ESWT).
- They are using blood thinning medications or statins.

Study timeline and procedures

Once enrolled, participants were examined by an experienced clinician and physiotherapist including US evaluation, and received the first application of ESWT (week 0). At weekly intervals, they received three more applications and on the day of the last application (week 3), a control clinical examination was performed. In the 12th-week follow-up after the last application (week 15), a final examination including US evaluation was performed.

Patients were not restricted in their usual daily or sports activities if pain was not limiting during or after activity. However, any therapeutic intervention was prohibited for the entire duration of the study (incl. injection therapy, resistance training, physical therapy, *etc.*). Thus, participants followed their normal regimen supplemented with ESWT as part of the study protocol. In addition, usually taken analgetic medication was not denied if necessary. However, this situation was monitored and if this type of medication was used, the results of this patient were excluded.

Examinations and variables

During the initial examination, basic anamnestic data were collected, and US evaluation was performed on both lower limbs.

All examinations included completion of a validated Victorian Institute of Sports Assessment – Patella (VISA-P) questionnaire. VISA-P is a commonly used questionnaire for assessing subjective perceptions of PT severity^[14]. It reaches values of 0–100 points. The more points the patient achieves, the better their condition is. A minimal change of 13 points indicates a significant clinical improvement. However, it is highly recommended to rely not only on VISA-P in the evaluation of PT improvement as its reliability is not very good^[15].

The examination also included an evaluation of patient-reported pain on NRS in the morning (NRS_m), maximum pain during daily activities (NRS_{day}), and in sport activity (NRS_{sport}).

US evaluation with objective measurements and subsequent analysis was performed in the initial and final examination and is described below.

US examination

The examination was performed by the same experienced US examiner (4 years of experience on a daily basis in musculoskeletal US diagnostics) in all cases and periods, with a linear probe type L12-3E with a frequency of 12 MHz using a Mindray DC-70 device in the preset mode MSK^[16,17]. The participant was placed in the supine position, and a knee flexion of 30° was achieved by using a custom-made knee pillow^[18,19]. The whole area of the patellar tendon was evaluated, from the apex patellae to the insertion on the tibia in long-axis imaging. The probe was placed as parallel to the tendon as possible. Findings were consulted and evaluated with experts in US diagnostics for greater relevance and reduced error rates. Only proximal or mid-portion tendinopathies were included.

The anteroposterior TD in mm was recorded in three areas: (1) just below the apex patellae in the anteroposterior widest area (TD_{apex}); (2) in the middle of the tendon (TD_{mid}); (3) just above the insertion (see Fig. 1a, b).

After that, the preset was changed to the specific setting for SFA, and the picture of each leg was saved in the long axis. Those pictures covered the proximal and mid-portion part of the tendon in the most pathological area defined by the US examination. This was repeated three times in a row. The output values were subsequently averaged to reduce the error rate, as each probe application may show a different intra-tendinous condition.

The US setting was adjusted in collaboration with experts in musculoskeletal US and SFA to increase the contrast between the hyperechoic structures within the tendon, representing collagen fascicles, and the hypoechoic parts of the tendon. These pictures were subsequently analyzed using SFA software. All picture settings in both presets (gain, TCG, dynamic range, depth, and focus) were maintained the same for all examinations. In addition, the asymptomatic limb was evaluated for reference values.

Spatial frequency analysis

SFA is a valid and reliable specialized noninvasive method which analyzes the US picture^[10,20]. In particular, it analyzes the anisotropic B-mode speckle pattern arising from within a tissue type

in the spatial frequency domain and is capable of detecting and comparing the organization, spacing, and density of collagen fascicles across various parameters^[10]. A list of parameters with their physiological correlates for tendon is shown in Table 1. Mathematical descriptions of parameters are well explained by Lesinski *et al*^[21].

The analysis procedure was as follows. Static pictures in B-mode with specific settings in the long axis were saved on a local computer and subsequently processed using custom MATLAB (Mathworks, USA R2021b) algorithms described by Bashford *et al*^[10,20]. Once the US picture was loaded into the software, a region of interest (ROI) was selected. The ROI was set as a polygon around the most pathological area, taking in as much of the tendon as possible with the upper and lower borders copying the anterior and posterior parts of the tendon without the epitenon (see Fig. 1c). Parts of the tendon where curvature appears were excluded. After ROI selection, the software automatically calculates the spatial frequency parameters of all 32 × 32 pixel kernels which fit within the polygonal ROI. The mean and standard deviation of these parameters were calculated and subsequently used for statistical analysis.

For asymptomatic tendons, the same area was chosen for the ROI as the contralateral symptomatic twin leg.

ESWT setting

The low-energy focused ESWT was applied using the BTL-6000 FSWT device with piezoelectric generator and a coupling pad which modulates penetration depth to 0–35 mm. The setting was chosen based on ISMST guidelines (<https://shockwavetherapy.org>). Energy flux density varied between 0.14 and 0.18 mJ/mm² due to patient tolerance, frequency was set at 5 Hz. A total of 2000 shocks were applied semi-statically to the most US defined pathological area in the patellar tendon followed by 2000 shocks dynamically to the quadriceps muscle by an experienced specialist in ESWT (4 years of clinical experience with ESWT on a daily basis). The application was performed in the same patient position as was used for the US examination. The set parameters did not change during the study and were the same for each patient.

Statistical analysis

Jamovi statistical software was used for data analysis. The normality of the data distribution was determined by calculating the Shapiro–Wilk *P* value. Subsequently, independent *t*-tests (or Mann Whitney *U* tests for nonparametric) were performed for each parameter to compare baseline values between the symptomatic and asymptomatic limb for the US and SFA parameters. In addition, paired *t*-tests (or Wilcoxon tests) were performed for each parameter, evaluated in each group separately (symptomatic, asymptomatic) between baseline and final values. To reach effect size, Cohen's *d* was calculated for paired *t*-tests and biserial rank correlation for nonparametric Wilcoxon test.

Intergroup statistical significance between baseline and follow-up values of the morphological parameters was evaluated using two-way analysis of variance (ANOVA) or nonparametric Kruskal–Wallis test. The statistical significance between time periods in VISA-P and NRS parameters was evaluated using repeated measures ANOVA or nonparametric Friedman test with repeated measures.

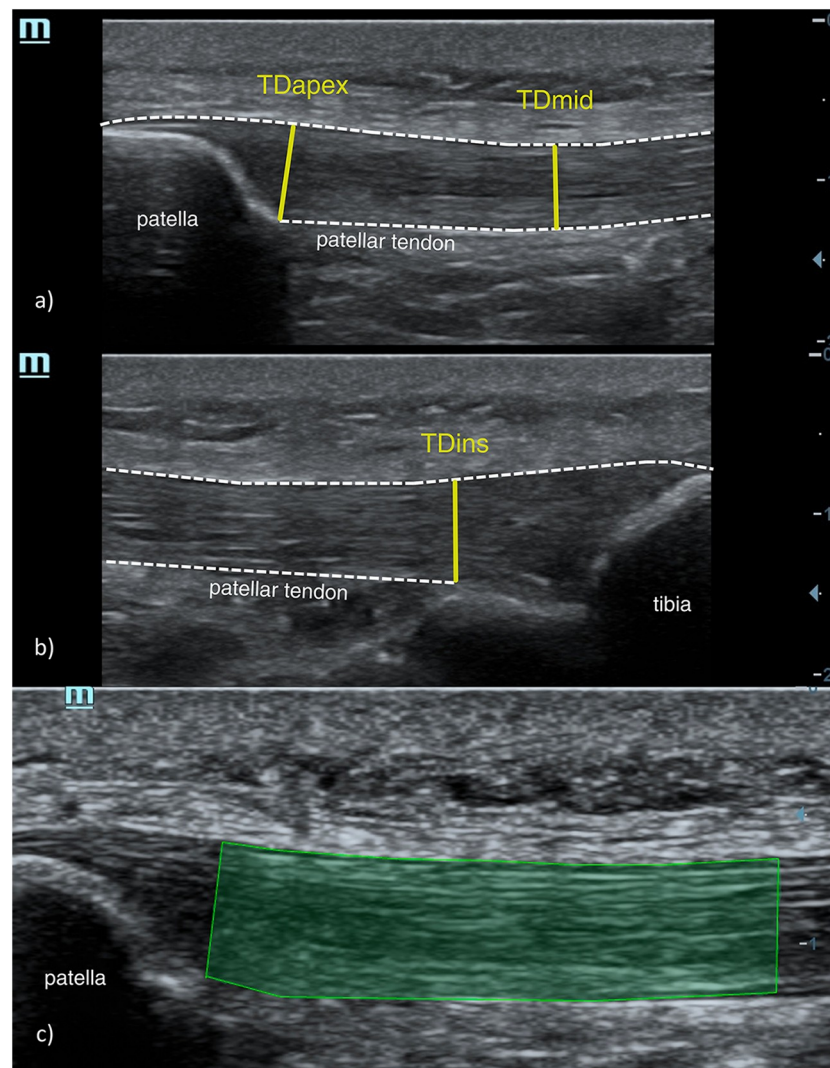


Figure 1. Demonstration of measured areas within the patellar tendon (outlined with dashed lines). Tendon diameter (TD) measurements are shown for the region below the apex (TDapex) and mid-tendon (TDmid) in part (a), and for the region above the insertion (TDins) in part (b). Part (c) presents an ultrasound image acquired in a special setting for spatial frequency analysis (SFA), highlighting the selected ROI with a green polygonal outline.

Results

Patient recruitment and data collection were performed between May 2023 and February 2024 in the Czech Republic. The course of the study is illustrated in Figure 2.

A total of 26 patients were assessed for eligibility, and 21 (80%) were included in the study based on inclusion and exclusion criteria. From the study population, 16 were males and 5 were females (mean age 29.8 ± 9.1), so in total 42 tendon samples (21 symptomatic, 21 asymptomatic) were evaluated. Other five (20%) patients were not included for following reasons – two reported previous tendon injury and three reported other interventions targeting PT less than 3 months prior to the baseline examination. During the study, no patient withdrew.

The demographic data with baseline values are shown in Table 2. Baseline values include patient-reported clinical

parameters (VISA-P, NRS_{sm}, NRS_{day}, NRS_{sport}), macro-morphological parameters (TD_{apex}, TD_{mid}, TD_{ins}), and micromorphological parameters (PSFR, P6, Q6, Amax, PWP, PPP). The baseline measurements of morphological parameters showed statistically significant difference between the symptomatic and asymptomatic legs in TD_{apex} ($P = 0.001$), P6 ($P = 0.009$), Q6 ($P = 0.018$), and PPP ($P = 0.013$).

There were a statistically significant positive changes in VISA-P, NRS_{sm}, NRS_{day}, and NRS_{sport} between all the time periods ($P < 0.001$). All subtests reached an effect size higher than 0.8 between exact time periods. The exact values of the intra-group changes are included in Table 3.

Morphological parameters were evaluated in both symptomatic and asymptomatic legs. In symptomatic legs, there were significant changes in TD_{apex} ($P < 0.001$), TD_{mid} ($P = 0.005$), TD_{ins} ($P = 0.025$), PSFR ($P = 0.024$), P6 ($P = 0.05$), Q6

Table 1
List of parameters from spatial frequency analysis (SFA) with its physiological correlates

Parameter	Full name	Physiological correlate
PSFR (mm ⁻¹)	Peak spatial frequency radius	• Most dominant spatial frequency within kernel. • Higher value primarily indicates a tighter packing of fascicles.
P6 (mm ⁻¹)	Peak -6 dB width	• Average spread of spatial frequencies which shows dis/organization. • Higher value indicates more disorganization.
Q6 (unitless)	PSFR/P6	• Normalization factor to facilitate comparison of fascicle spacing with its organization. • Higher value primarily indicates less disorganization relative to dominant fascicles/fibers spacing.
Amax (B/sample)	Normalized peak value of amplitude spectrum	• Strength of the most dominant spacing of fascicles/fibers. • Higher value primarily indicates higher fascicle/fiber density or lower water content.
PWP (B ²)	Power within peak	• Strength of the dominant fascicle/fiber spacings. • Higher value primarily indicates more scatterers that are organized.
PPP (%)	Peak power percent	• The power of organized fibers compared to all (organized + disorganized).

($P = 0.016$), Amax ($P = 0.008$), PWP ($P = 0.016$), and PPP ($P = 0.003$). These values show improvement at the structural level – decreasing TD and greater organization after ESWT. This can also be seen in Figure 3. No significant changes were observed in any morphological parameter in asymptomatic legs ($P > 0.05$), suggesting no natural changes in structure over time. Exact values of the intra-group changes in morphological parameters are shown in Table 4. Results of effect size and inter-group analysis are also included.

No patient needed to take painkiller medication during the study, and no adverse effects were reported.

Discussion

To the authors’ knowledge, this is the first study evaluating the structural changes in PT at the intra-tendinous level after ESWT *in vivo*. SFA software was used for quantitative evaluation of

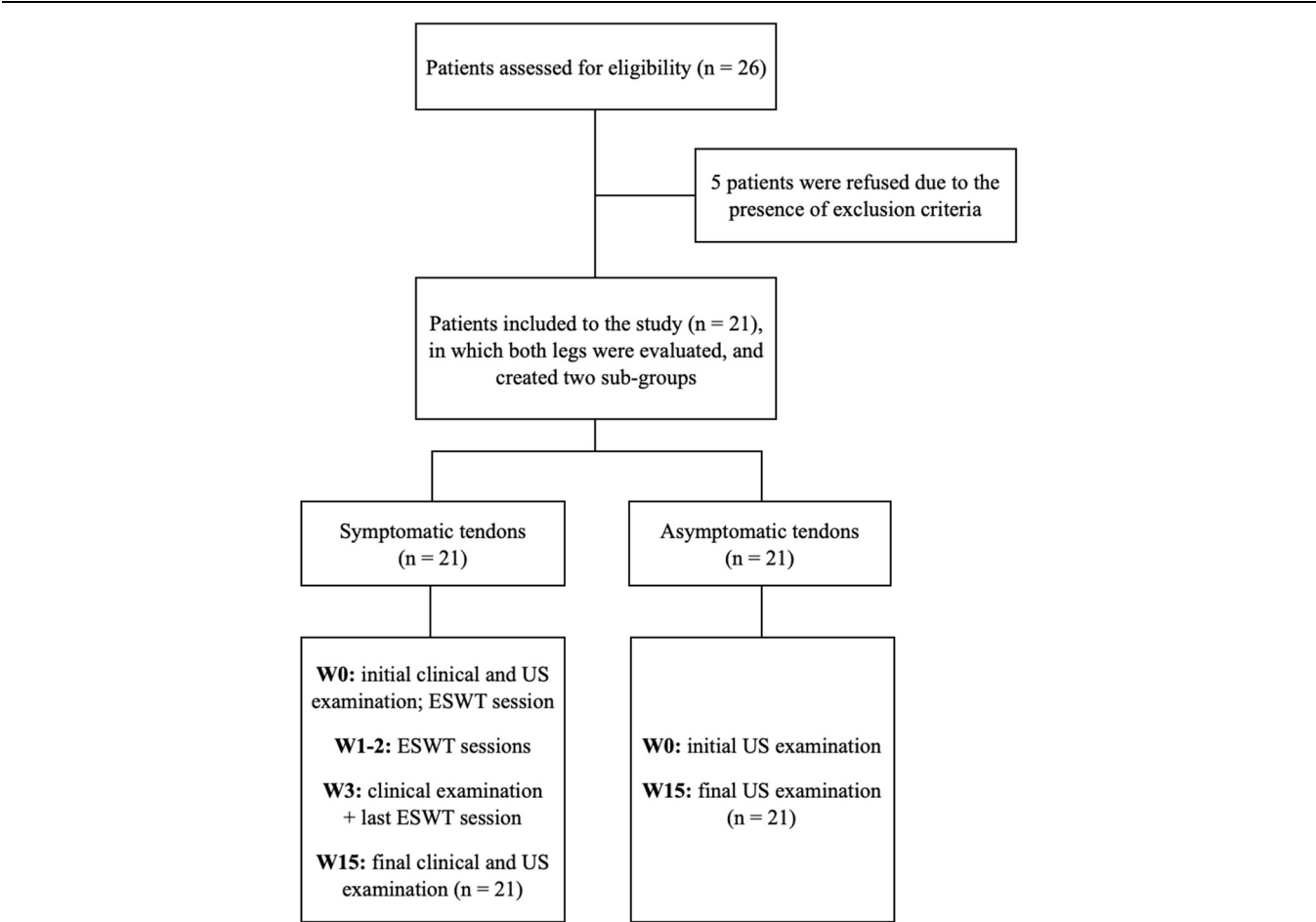


Figure 2. Flowchart illustrating the study course.

Table 2
Demographic characteristics of the groups

Variable	Symptomatic	Asymptomatic	P-value
N (male/female)	21 (16/5)	21 (16/5)	Not applicable (1.000)
Age		29.8 ± 9.1	
BMI (kg/m ²)		24.2 ± 3.2	
Symptom duration (months)		19.6 ± 16.1	
Training frequency (h/w)		5.6 ± 3.2	
NRS _m (pts)	3.6 ± 2.3	Not applicable	
NRS _{day} (pts)	4.7 ± 2.2		
NRS _{sport} (pts)	4.8 ± 2.1		
VISA-P (pts)	68.4 ± 8.2		
TD _{dapex} (mm)	4.87 ± 0.74	3.92 ± 0.83	0.001
TD _{mid} (mm)	4.12 ± 0.86	3.64 ± 0.82	0.070
TD _{ins} (mm)	4.26 ± 0.90	3.70 ± 0.90	0.050
PSFR (mm ⁻¹)	2.119 ± 0.148	2.215 ± 0.192	0.080
P6 (mm ⁻¹)	1.119 ± 0.022	1.102 ± 0.016	0.009
Q6 (unitless)	1.926 ± 0.136	2.046 ± 0.183	0.018 ^a
GOF (unitless)	0.948 ± 0.008	0.954 ± 0.007	0.024 ^a
Amax (B/sample)	2.522 ± 0.494	2.789 ± 0.358	0.057
PWP (B ²)	18 201 ± 5990	21 343 ± 4838	0.076
PPP (%)	48.91 ± 3.40	51.67 ± 3.30	0.013

BMI, body mass index; NRS_m, numeric rating scale of pain in the morning; NRS_{day}, numeric rating scale of maximal pain during basic daily activities; NRS_{sport}, numeric rating scale of maximal pain during sport activities; TD, tendon diameter; VISA-P, Victorian Institute of Sports Assessment – Patella.

^aMann-Whitney *U*-test was used.

collagen fascicles organization, spacing, and density. Focusing on these alterations is crucial, as they represent one of the main pathological findings in tendinopathy. Results of this study can enhance our understanding of ESWT in PT treatment, particularly its impact on the tendon structure over a 3-month follow-up.

Notable improvements were observed in symptomatic legs across both clinical (VISA-P and pain score) and morphological parameters (TD, PSFR, P6, Q6, Amax, PWP, PPP), highlighting the potential of ESWT to induce positive structural changes within the pathologically altered patellar tendon.

Current literature favors resistance training as the primary treatment for PT and does not support ESWT as monotherapy^[2,6]. However, this study evaluated ESWT alone to clarify its effects without the influence of other interventions. ESWT is considered a valuable adjuvant treatment but with conflicting evidence in management of PT symptoms^[7,8]. On the other hand, previous literature has often focused primarily on clinical outcomes, while only

a limited number of studies have evaluated macro-morphological changes or biomechanical properties such as TD or stiffness^[8,22]. None of these studies have examined intra-tendinous changes.

Long-standing tendinopathy is characterized by a series of structural changes at the intra-tendinous level, notably the synthesis of collagen III and disorganization of collagen fascicles^[3]. Prior studies have shown that tendinopathic tendons have worse values in micromorphological parameters using SFA, indicating greater disorganization compared to healthy tendons^[10,11,23,24]. For example, Kulig *et al*^[23] demonstrated that a reduced PSFR in US pictures of degenerated tendons is indicative of reduced collagen organization, a hallmark of tendinopathy. In another study, volleyball athletes with PT exhibited significantly greater collagen fascicles disorganization at the proximal patellar tendon compared to both asymptomatic athletes and nonathletes, indicating that this change might be the factor associated with pain^[11]. The same method was also used for muscle tissue characterization due to its good

Table 3
Comparison of the clinical manifestation parameters values in all time periods for symptomatic tendons

Variable	W0	W4	W15	<i>F</i> / χ^2	P-value	Post hoc
NRS _m (pts)	3.6 ± 2.3 (3)	1.7 ± 1.6 (1)	0.8 ± 1.3 (0)	34.2 ^a	<0.001 ^b	a ,b ,c
NRS _{day} (pts)	4.7 ± 2.2 (5)	3.0 ± 1.6 (2)	2.0 ± 1.5 (2)	34.1 ^a	<0.001 ^b	a ,b ,c
NRS _{sport} (pts)	4.8 ± 2.1 (5)	2.4 ± 1.7 (2)	1.1 ± 1.1 (1)	39.0 ^a	<0.001 ^b	a ,b ,c
VISA-P (pts)	68.4 ± 8.2 (71)	79.8 ± 7.2 (82)	83.3 ± 7.1 (85)	95.1	<0.001 ^b	a ,b ,c

Mean ± SD (median) is shown. In *post hoc* tests, "a" shows statistical significance ($P < 0.01$) between W0 and W4, "b" between W0 and W15, and "c" between W4 and W15; "^{||}" shows effect size (rank biserial correlation or Cohen's *d*) >0.8, and "^{|||}" >0.99.

NRS_{day}, maximal pain during daily activities; NRS_m, numeric rating scale of pain in the morning; NRS_{sport}, maximal pain during sport activity; SD, standard deviation.

^aNonparametric Friedman test with repeated measures was used, and therefore χ^2 is given.

^bP-value is <0.001.

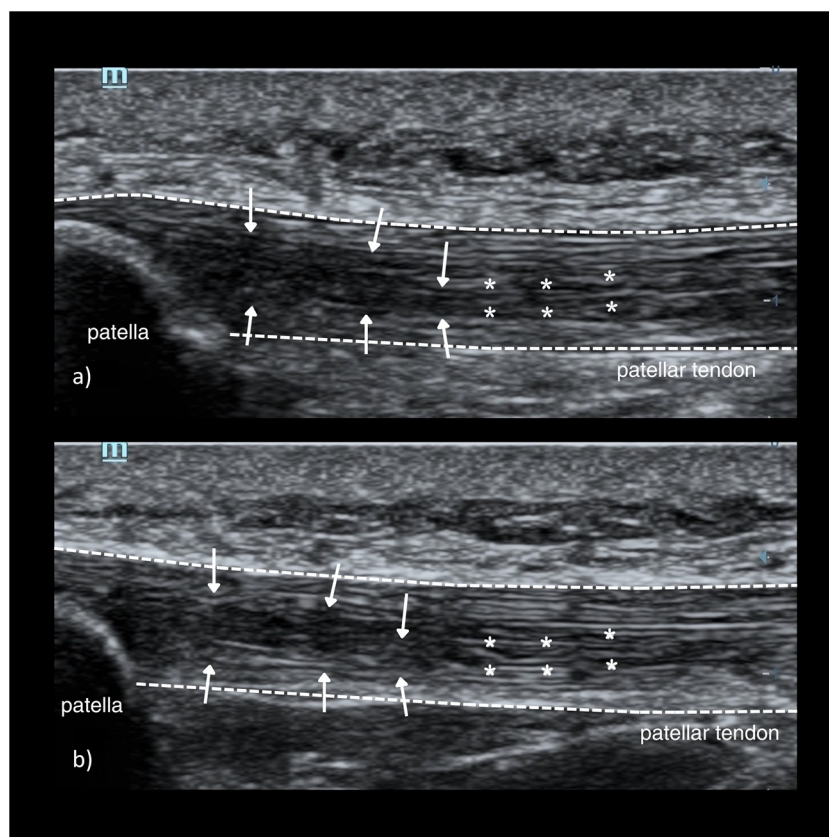


Figure 3. Ultrasound demonstration of the symptomatic patellar tendon (outlined with dashed lines) at baseline (a) and follow-up (b), performed using settings optimized for subsequent spatial frequency analysis (SFA). In part (a), a hypoechoic area is visible in the proximal region (arrows), with notable collagen disorganization extending distally into the central portion of the tendon (asterisks). In part (b), the hypoechoic area in the proximal region has decreased, and improved collagen organization is observed in both the proximal and central tendon regions (arrows and asterisks).

reliability^[21,25]. An increase in TD is one of the next negative alterations in tendinopathies^[19,26]. The result of this study acknowledges these findings, showing that PT exhibits increased TD and collagen fascicles disorganization compared to asymptomatic, likely healthy tendons.

However, there is no study that has evaluated the therapeutic effect on micro-morphology in tendinopathies. Addressing this gap is crucial for understanding how different treatments influence intra-tendinous structure and how this correlates with clinical outcomes. This knowledge could lead to more effective therapeutic strategies. Our study builds on existing literature that has provided insights for exploring biomechanical changes and intra-tendinous changes analyzed by SFA^[27–32]. We extend this knowledge by being the first to explore the effects of ESWT on intra-tendinous structure *in vivo*, aiming to bridge the gap between structural understanding and therapeutic impact.

The biological effects of ESWT are known to initiate several intracellular processes leading to tendon healing and remodeling, including collagen I neosynthesis and induction of collagen III transformation to collagen I^[4,9]. In this study, significant positive changes in both the macromorphological and micro-morphological parameters occurred in symptomatic tendons. As chronic tendinopathies are mostly characterized by increased disorganization of the collagen fascicles due to the failure of the healing function of tenocytes^[3], it is unlikely that these processes would naturally recover. Therefore, it is more likely that positive

changes resulted from increased collagen synthesis and remodeling processes initiated by ESWT^[7,9].

These findings suggest that ESWT can contribute to both symptomatic relief and structural remodeling in chronic tendinopathies, providing a mechanism for targeted biological intervention.

Limitations

Small sample size may limit the statistical power of the study, the short duration of the follow-up restricts the ability to observe long-term effects, and the lack of a placebo/sham control group introduces potential biases, limiting the generalizability of these results.

It should also be noted that different US devices, while maintaining the same settings, may have different spatial resolutions and other picture quality factors that affect the detailed echogenicity and speckle pattern used for SFA. Therefore, absolute values cannot be compared between devices, however, mean differences, percent change, or effect size have been shown to be relevant.

Suggestions

Based on the positive structural changes observed, along with ESWT's safety, noninvasive nature, and its role in pain reduction, ESWT shows promise not only for future research but also for clinical practice. Specifically, ESWT may be recommended as an adjunct treatment to improve tissue quality in chronic tendinopathy cases, particularly in patients not fully responding to conventional therapies.

Table 4

Comparison of the baseline and follow-up (W15) values of macromorphological (TDapex, mid, and ins) and micromorphological (other) parameters for both groups – symptomatic and asymptomatic patellar tendon

Variable	Group	W0 mean ± SD (median)	W15 mean ± SD (median)	Intra-group <i>P</i> -value	Effect size	Inter-group <i>P</i> -value
TDapex	Symp. ^a	4.87 ± 0.74 (4.9)	4.40 ± 0.73 (4.3)	<0.001 ^b	1.000	0.147
	Asymp. ^a	3.92 ± 0.83 (3.9)	3.91 ± 0.86 (3.9)	0.944	0.056	
TDmid	Symp. ^a	4.12 ± 0.86 (4.1)	3.92 ± 0.82 (3.9)	0.005 ^c	0.809	0.628
	Asymp. ^a	3.64 ± 0.82 (3.6)	3.67 ± 0.84 (3.6)	0.174	0.470	
TDins	Symp. ^a	4.26 ± 0.90 (4.1)	4.11 ± 0.94 (3.9)	0.025 ^d	0.590	0.537
	Asymp.	3.70 ± 0.90 (3.8)	3.75 ± 0.92 (3.9)	0.162	0.317	
PSFR	Symp.	2.119 ± 0.148 (2.121)	2.234 ± 0.133 (2.259)	0.024 ^d	0.550	0.125
	Asymp.	2.215 ± 0.192 (2.236)	2.215 ± 0.184 (2.228)	0.995	0.001	
P6	Symp. ^a	1.119 ± 0.022 (1.112)	1.099 ± 0.022 (1.104)	0.050 ^d	0.505	0.027 ^d
	Asymp.	1.102 ± 0.016 (1.103)	1.101 ± 0.016 (1.101)	0.881	0.034	
Q6	Symp. ^a	1.926 ± 0.136 (1.927)	2.066 ± 0.131 (2.071)	0.016 ^d	0.619	0.051
	Asymp. ^a	2.046 ± 0.183 (2.066)	2.046 ± 0.175 (2.052)	0.897	0.044	
GOF	Symp. ^a	0.948 ± 0.008 (0.949)	0.957 ± 0.006 (0.956)	0.001 ^c	0.819	0.006 ^c
	Asymp. ^a	0.954 ± 0.007 (0.955)	0.954 ± 0.006 (0.953)	0.856	0.059	
Amax	Symp.	2.522 ± 0.494 (2.598)	2.851 ± 0.379 (2.783)	0.008 ^c	0.663	0.028 ^d
	Asymp.	2.789 ± 0.358 (2.780)	2.712 ± 0.378 (2.675)	0.338	0.220	
PWP	Symp.	18 201 ± 5990 (18 466)	22 174 ± 5400 (20 888)	0.016 ^d	0.591	0.043 ^d
	Asymp.	21 343 ± 4838 (20 986)	20 336 ± 5299 (19 650)	0.349	0.215	
PPP	Symp.	48.91 ± 3.40 (49.51)	52.25 ± 3.79 (52.06)	0.003 ^c	0.753	0.031 ^d
	Asymp. ^a	51.67 ± 3.30 (51.38)	51.52 ± 3.75 (50.80)	0.938	0.029	

SD, standard deviation; TDapex, tendon diameter – apex region; TDins, tendon diameter – insertional region; TDmid, tendon diameter – middle of the tendon.

^aWilcoxon test and rank biserial correlation for effect size were used.

^b*P*-value is <0.001.

^c*P*-value is <0.01.

^d*P*-value is <0.05.

Future investigations should include randomized clinical trials with longer follow-up periods, larger sample sizes including general population, and control groups (placebo or other treatment modalities). Additionally, assessing intra-tendinous morphology *in vivo* using SFA should be used as it may help determine how these changes relate to improved clinical outcomes. This will be crucial for validating our findings and determining ESWT's long-term benefits for tendon healing and recovery.

Conclusion

This study suggests that low-energy focused ESWT is an effective therapy for PT, improving both pain and tendon structure. The findings indicate significant improvements in pain, function, and morphology, particularly in the organization of intra-tendinous collagen fascicles. These results support the use of ESWT as adjunctive treatment for PT. While promising, further research with larger and more diverse cohorts is needed to confirm these findings and establish the effect of ESWT on intra-tendinous structure and its correlation with clinical outcomes.

Ethical approval

The study was approved by Ethics Committee of the University Hospital Motol with number EK-980/23.

Consent

Consent for publication was obtained from all authors. A written informed consent was obtained from all the patients

for their willingness to participate in this study and for their data to be used for research purposes.

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Author contributions

Concept/idea/research design: J.K., P.P., T.N.; Writing: J.K.; Data collection: J.K., P.P.; Data analysis: J.K., T.K.; Project management: J.K., P.P.; Fund procurement: J.K.; Providing participants: T.N., J.K., P.P.; Providing facilities/equipment: T.N., G.B.; Consultation (including review of manuscript before submitting): G. Bashford, S. Machac, K. Volesky, T.K.

Conflicts of interest disclosure

The authors declare they have no competing interests or other interests that might be perceived to have influenced the results and discussion reported in this paper.

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Data availability statement

The data from this study are not publicly available due to privacy and/or technical reasons.

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