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Longitudinal Quantitative Ultrasonic Analysis of Patellar Tendon in a Collegiate Athlete After Bilateral Debridement: A Case Report

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Context: A National Collegiate Athletic Association Division I female basketball athlete (age = 20 years, height = 190.5 cm, mass = 87 kg) had chronic patellar tendinopathy.

Intervention(s): After undergoing unsuccessful conservative treatments, the athlete underwent bilateral open patellar debridement surgery. Pain and dysfunction were assessed via the Victorian Institute of Sport-P (VISA-P) score with concurrently collected B-mode ultrasound images of the patellar tendon throughout a 12-month rehabilitation.

Results: Peak spatial frequency radius (PSFR), a quantitative ultrasound measure previously shown to be correlated with collagen organization, was compared with changes in VISA-P scores. Overall increases in PSFR values across 0°, 30°, 60°, and 90° of knee flexion were observed throughout recovery. Despite increased PSFR values and returning to sport, the athlete reported substantial pain.

Conclusions: In this level 3 exploration case report, we provide novel insight into ultrasonically measured structural changes of the patellar tendon after surgery and during rehabilitation of an athlete with chronic tendinopathy. Perceived pain measurements were not necessarily related to structural adaptations.

Key Words: patellar tendinopathy, knee, rehabilitation

Key Points

- The peak spatial frequency radius, a quantitative metric of tendon structure, increased throughout the 12-month rehabilitation and return-to-play progression, indicating an increase in the overall organization of the intratendinous morphology.
- Structural changes of the patellar tendon after surgery and during rehabilitation of an athlete with chronic tendinopathy are not necessarily related to pain.

Repetitive jumping performed in basketball can result in acute injuries or chronic tendinopathies.[1] Injury can substantially affect tendon structure, with incomplete rest or poor adaptation contributing to further deterioration of the collagen fibers.[2] Pain is often the most clinically addressed symptom but is not always the best indicator of damage.[3]

Typical imaging modalities including magnetic resonance imaging (MRI) and ultrasound are often used to aid in diagnosis and monitoring of tendinopathies. However, in most imaging studies, researchers who investigated tendon health assessed only macromorphologic changes,[4] which do not provide quantitative metrics for evaluating intratendinous tissue organization. Spatial frequency analysis (SFA) of ultrasound images allows researchers to quantitatively assess collagen bundle organization and differentiate healthy and degenerative tendons.[5] The SFA measures have also been related to tendon fiber density and mechanical properties in both adult and adolescent populations.[6,7] However, SFA has not previously been used in longitudinal studies to assess intratendinous tissue structure. This analysis could provide initial insight into the utility of this method for monitoring healing progression during rehabilitation or after invasive surgical procedures aimed at returning athletes to sport. In addition, no investigators have reported the effects of different knee-joint angles, which affect alignment of the collagen bundle orientation, on SFA measures. In this level 3 exploration case report, we present the intratendinous morphologic changes over 1 year at various joint angles in a collegiate basketball player after simultaneous bilateral open patellar tendon surgeries. We also describe how the structural changes related to measures of pain and function.

CASE PRESENTATION

Patient

The patient was a National Collegiate Athletic Association Division I female basketball player (age = 20 years, height = 190.5 cm, mass = 87 kg) who began participating in organized sport at 7 years of age and competitive travel sport at 10 years of age. The athlete first reported knee pain at 13 years of age and was diagnosed with bilateral Osgood-Schlatter disease.[8] As a freshman in high school, she was diagnosed by a physician with bilateral patellar tendinitis. Knee pain persisted as the patient entered collegiate athletics.

Table 1. Postoperative Timeline of Clinical Goals and Specific Rehabilitation Interventions Throughout the 12-Month Study[a]

Weeks After Surgery	Clinical Goals	Examples of Specific Interventions	Exercises, Sets × Repetitions	Criteria for Progression
1–12	Pain management, improve range of motion and strength	Medication and cryotherapy (GameReady[b])	As needed	Attain full range of knee motion and normal gait with minimal pain
		Seated heel slides	2 × 10	
		Isometric quadriceps contractions with superimposed electrical stimulation on the Russian setting (Vectra Genisys[c])	10-s contraction followed by 40-s rest for 10 min (bilaterally); progress to 10-s contraction and 20-s rest	
		Seated active-assisted straight-leg raises	2 × 10	
13–24	Isotonic loading through entire knee range of motion, weight-bearing activities	Knee proprioceptive neuromuscular facilitation	To fatigue	Rehabilitation performed every 2 d, progressing to every other day; tolerate rehabilitation every other day with minimal pain
		Antigravity treadmill[d] running at 30%–60% body weight	Up to 20 min total run time	
		Open chain knee extension	2 × 10	
		Wall sits (double-legged quarter squats progressing to parallel squats)	5 × 30-s hold	
25–36	Functional movement	Body-weight step-ups and step-downs from boxes	2 × 10	Rehabilitation performed every other day; able to tolerate minimal pain with daily activities, jumping progression, and treadmill running; confidence in ability to perform sport-specific movements
		Single-legged lunges progressing to continuous walking lunges	2 × 10 Progression to 29 m (baseline to half-court and back on collegiate basketball court)	
		Skipping for distance	58 m (Full-court baseline to baseline on collegiate basketball court)	
		Wall jumps to squat jumps	3 × 10	
		Single-legged bound (stick landing on ipsilateral limb) progressing to continuous alternating bounding	29 m	
		Antigravity treadmill[d] running at 60%–100% body weight	≤30-min Total as tolerated	
37–52	Sport-specific training, return to participation	Team strength and conditioning with modified program	Bicycling or pool workout instead of on-court conditioning	Progression from 15 min to 1.5 h of total practice time (15-min weekly increment increase); full participation at 48 wk with tolerable pain levels during activity
		Position-specific sport training participation in practice	1 h of Individual/position-specific workout to tolerance	

[a] The focus of the specific interventions was limited to exercises specifically designed to load the surgically repaired tendons. Other exercises designed for general strength and conditioning were integrated as part of the athlete's overall treatment plan and return-to-sport progression.
[b] CoolSystems Inc.
[c] Chattanooga, DJO.
[d] AlterG Inc.

To determine a definitive diagnosis of the patellar tendon, magnetic resonance imaging (MRI) of both knees was obtained during the patient's freshman year in college. The images showed normal meniscal structures in both knees but focal lesions in the patellar tendons. The patient elected to undergo conservative treatment; however, her knee pain persisted, and MRI was repeated. Radiologic reports indicated central tendinopathy of the proximal portion of each patellar tendon with partial detachment of the deep fibers. The patient began a presurgical rehabilitation program for 3 weeks and participated in practice until the day before surgery. Bilateral open patellar debridement surgery, similar to that described by Bahr et al,[9] followed by platelet-rich plasma therapy and Tenex Health TX procedures were performed. The intent of the surgery was complete removal of the degenerated and detached fibers to stimulate growth of new and more normal fibers and restore the patellar tendons. After surgery, the patient underwent a guided rehabilitation program for 12 months.

Intervention

The patient's knee was immobilized in 0° of flexion at all times for 4 weeks except during rehabilitation and imaging sessions. Typical postoperative pain medications were prescribed by the attending physician to reduce postoperative inflammation. The attending athletic trainer (A.R.) implemented a modified anterior cruciate ligament rehabilitation protocol. An outline of the timeline, clinical goals, and sample rehabilitation interventions is given in Table 1.

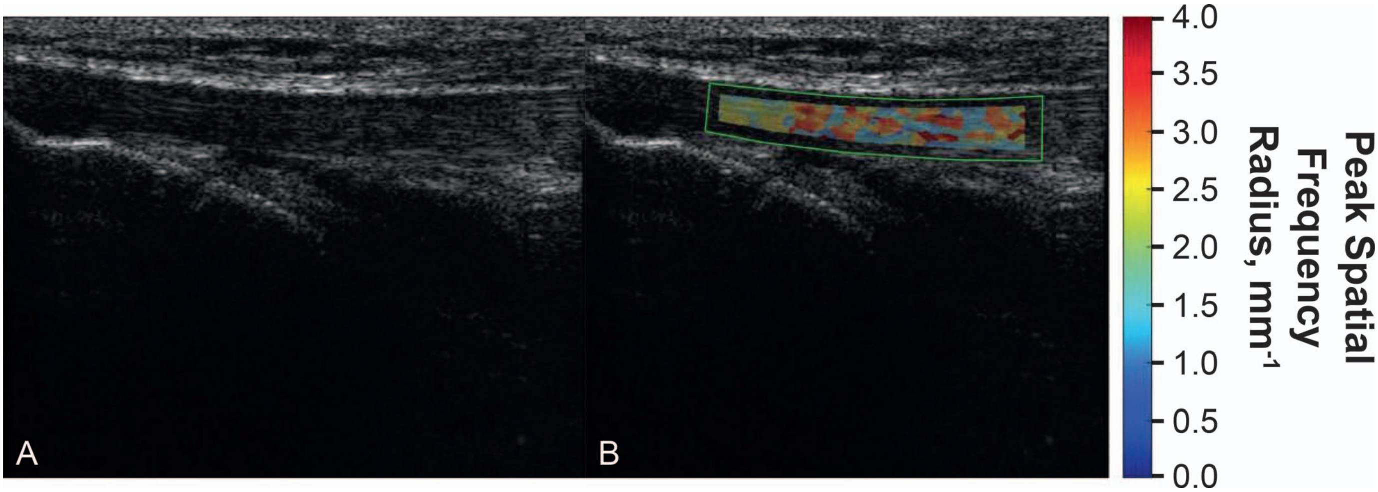

Figure 1. Spatial frequency analysis method. A, Representative B-mode image of the patellar tendon at 90° of knee flexion. B, B-mode image with overlaid region of interest (ROI) and color spectrum of the peak spatial frequency radius (PSFR) values. The ROI was drawn around the entire tendon thickness, beginning approximately 1 cm distal to the inferior pole of the patella and spanning approximately 2.5 cm in length. The PSFR values are visually represented by the color map and overlaid on top of the B-mode image. Note that the PSFR values are plotted at the centroid of the kernel. Therefore, a gap exists between the ROI boundary and overlaid PSFR values that correspond to one-half of the kernel size; however, the image within the entire ROI region was analyzed. All PSFR values with the ROI were averaged and used for subsequent analyses.

The outcome of intratendinous tissue structure (peak spatial frequency radius [PSFR]) was measured using ultrasonography. The PSFR reflects compaction of the striated pattern of the collagen fascicles.[5] The patient's knee was imaged bilaterally approximately every week for the first 2 months, every 3 weeks from 2 to 6 months after surgery, and every other month thereafter. The first imaging session (week 1) was conducted 5 days after the surgical procedure (week 0). The patient's knee was imaged on the same day of the week and at the same time of day for each session. Throughout the first 2 months, the patient missed 1 imaging session because of a schedule conflict and travel.

Ultrasound images were collected using a commercial research ultrasound machine (Vantage 256; Verasonics, Inc) with a 3- to 12-MHz (center frequency = 8 MHz) linear array transducer. Ultrasound settings were 2 transmit foci of 6 and 12 mm and an imaging depth of 30 mm. The transducer was oriented parallel to the tendon to minimize hypoechoic artifacts. Longitudinal images were collected below the knee between the patella and tibial tuberosity in the middle of the tendon. Images were acquired at 0°, 30°, 60°, and 90° of available knee flexion. Victorian Institute of Sport-P (VISA-P) scoring was collected on the same day as the imaging session and integrated as a qualitative and progressive metric to assess the patient's perceived level of pain and function.[10]

Comparative Outcomes

After the imaging sessions were completed, longitudinal images were extracted and processed using custom MATLAB (The MathWorks, Inc) algorithms. A polygonal region of interest (ROI) was placed around the entire tendon thickness, beginning approximately 1 cm distal to the inferior pole of the patella and spanning approximately 2.5 cm in length (Figure 1). All possible 32- × 32-pixel kernels (corresponding to a 2.1-mm-long by 1.2-mm-wide rectangle) that fit within the ROI were analyzed in the Fourier domain.[5] The PSFR was averaged over all kernels of the ROI to obtain a single value bilaterally for each knee-joint angle and imaging session. Weekly changes in VISA-P scores and PSFR were calculated. Simple linear regression was used to compare VISA-P scores as a function of weeks after surgery.

The patient consistently adhered to the rehabilitation program with specific postoperative rehabilitation milestones as follows: no pain with walking at 3 months, walking up and down stairs without pain by 7 months, and progression to functional and position-specific drills in individual workouts with a tolerable level of pain by 9 months. She progressed more quickly with the left than the right limb. During position-specific drills at 9 months after surgery, she experienced substantial bilateral joint effusion (MRI-confirmed chondromalacia patellae) and regressed in rehabilitation. The effusion was managed using nonsteroidal anti-inflammatory drugs and cryotherapy. The patient was cleared to progress to full activity (Table 1) by the physician at the end of 10 months after surgery (2 months before the season started). By 12 months after surgery (corresponding to the start of the competitive season), the patient participated in 1.5 hours of practice daily.

For the first week after surgery, the patient was limited to 30° of knee flexion. Imaging at 60° of knee flexion was performed during weeks 2 and 3. Imaging at 90° of knee flexion was performed at 4 weeks after surgery and every imaging session thereafter. The PSFR value increased slightly with increased knee flexion (Table 2). By 1 year after surgery, PSFR increased across all knee-joint angles (Table 2; Figure 2). Monthly percentage changes in PSFR values are shown in Table 2. Fluctuations in PSFR were most variable at 30° of knee flexion during the first 3 months after surgery but stabilized by 15 weeks after surgery. At 60° of knee flexion, PSFR was equivalent between limbs after the first month after surgery, followed by an acute divergence around 15 weeks after surgery. Despite the fluctuation in PSFR of the left patellar tendon, the difference between limbs was minimal by 6 months.

Table 2. Peak Spatial Frequency Radius as a Function of Knee-Joint Angle, Monthly Point Changes in Victorian Institute of Sport-P Score, Monthly Percentage Change in Peak Spatial Frequency Radius, and Overall Percentage Changes in Peak Spatial Frequency Radius Over the 12-Mo Rehabilitation[a]

Parameter	Mean ± SD	Change at (Mo)								Overall Increase in Peak Spatial Frequency Radius
		1–2	2–3	3–4	4–5	5–6	6–8	8–10	10–12	
Victorian Institute of Sport-P	NA	14	−8	21	7	6	11	2	−3	NA
Peak spatial frequency radius, knee flexion										
0°	1.95 ± 0.13	−5	−2	−2	−1	6	−6	11	2	7
30°	2.01 ± 0.12	1	1	−2	3	3	3	−3	1	4
60°	2.07 ± 0.14	4	0	−1	0	−3	4	1	1	4
90°	2.10 ± 0.13	NA	−3	−2	4	0	−9	16	−3	0

Abbreviation: NA, not applicable.

[a] Peak spatial frequency radius data from both limbs are pooled. A negative value indicates a decrease from the previous month.

The PSFR at 90° of knee flexion trended negatively for the left limb at 2 months after surgery and did not recover until 4 months after surgery. Another acute decline in PSFR occurred nearly 5 months after surgery, which did not resolve until approximately 3 months later.

The VISA-P scores increased consistently yet slowly throughout the first 2 months of rehabilitation, followed by an acute decrease around 3 months (Figure 3). The scores continued to increase throughout the remainder of the study but plateaued around 7 months at a score of 37 and a final score of 36 (normal = 100, tendinopathy = 80).

DISCUSSION

In this exploration case report, we investigated longitudinal changes in intratendinous tissue structure as determined from SFA of ultrasound B-mode images. The PSFR provided a quantitative metric for tracking tendon structure throughout rehabilitation and the return-to-play progression after bilateral open patellar tendon surgery (debridement, platelet-rich plasma therapy, and Tenex procedures). Overall, PSFR increased slightly over the 12 months in the more-extended knee-joint positions. The patient's pain and function improved throughout the study, but the former persisted and the latter remained low despite intensive rehabilitation.

The addition of regular imaging in this case study was designed to quantify the progression of structural adaptation in vivo. Given that PSFR is a measure of tissue organization, we expected to see an increase in PSFR over time as the patient healed. We did observe an overall increase in PSFR throughout the 12-month rehabilitation and return-to-play progression, indicating an increase in the overall organization of the collagen fascicles. This finding supports the idea that quantitative image analysis may be useful for monitoring rehabilitation progress.

Previous researchers[11] who used PSFR did not investigate the effects of various knee-joint angles on PSFR and only studied 90° of knee flexion. We noted that PSFR appeared to depend on the knee-joint angle, as a minimal change in

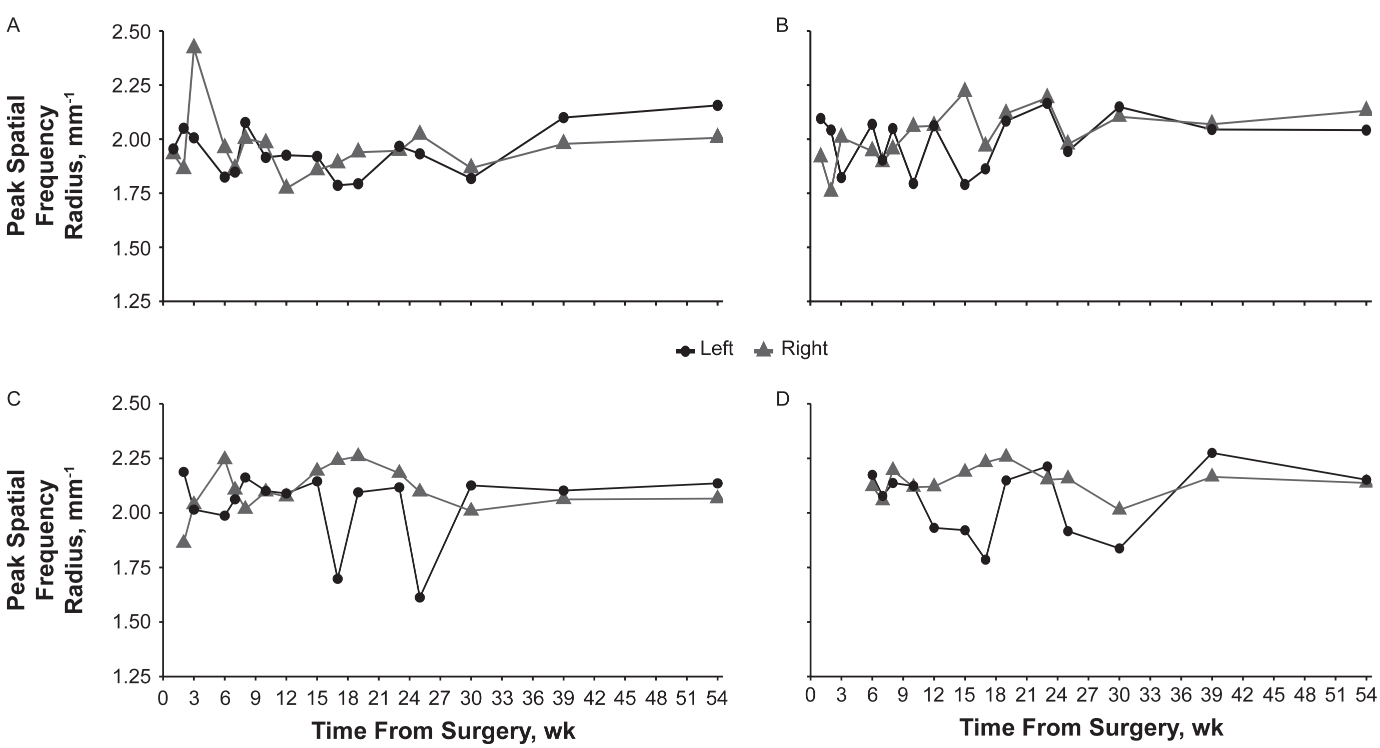

Figure 2. Changes in bilateral peak spatial frequency radius across knee-flexion angles throughout the study. A, 0°. B, 30°. C, 60°. D, 90°.

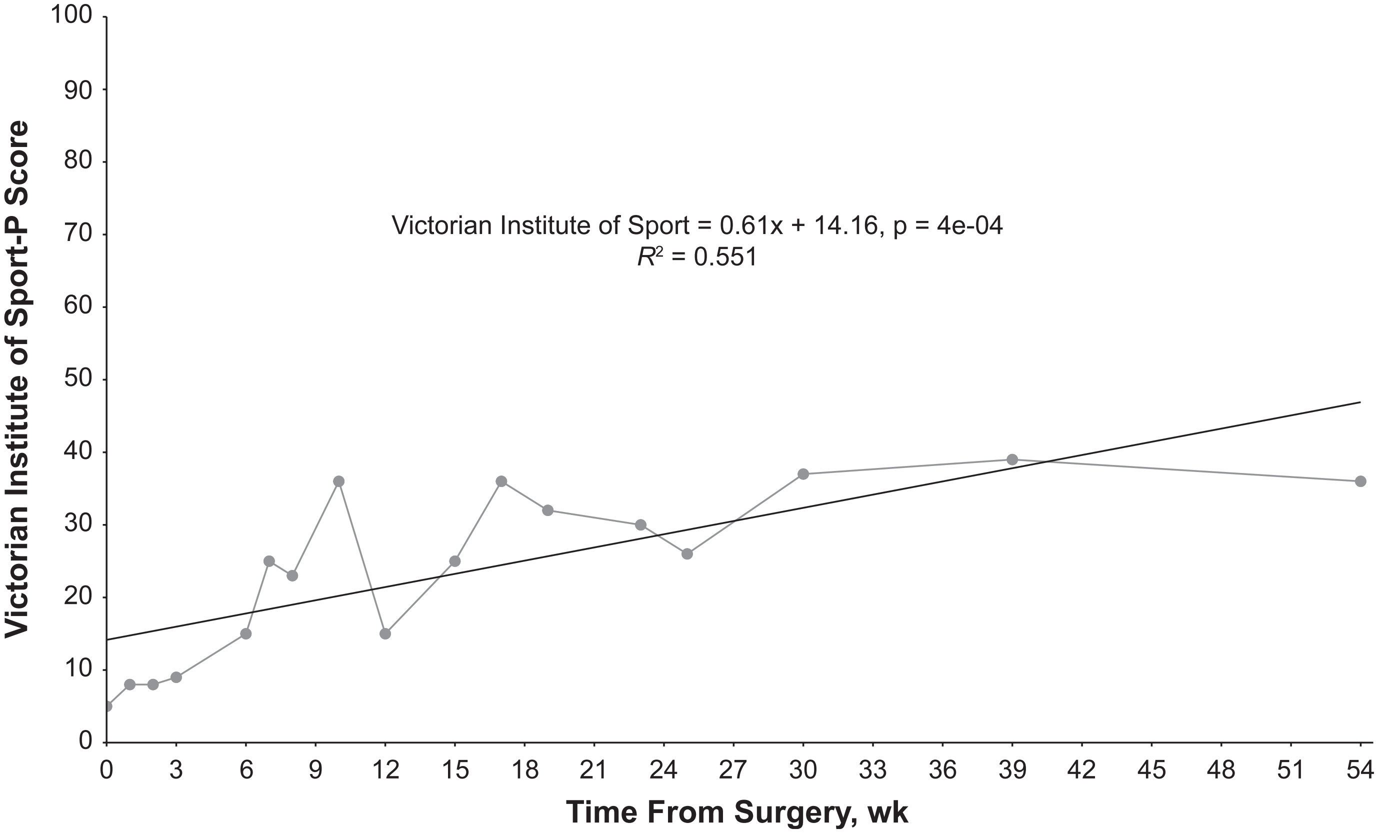

Figure 3. Recovery of Victorian Institute of Sport-P scores throughout the 12-month study. The scores are plotted in gray, with the linear regression line plotted in black. The linear regression equation and the associated *P* value are also shown.

PSFR was evident at 90° of knee flexion compared with other knee-joint angles. This observation could be attributed to the fact that the collagen in the patellar tendon is under tension and more aligned in a lengthened position as the knee is flexed, which is consistent with earlier PSFR results with isometric loading[12] and the basic tendon response to lengthening.[13] Moreover, the fluctuations, especially at 0° and 30° of knee flexion, could have been due to immature, unaligned collagen fascicles that matured throughout the healing process and rehabilitation program.

In addition, PSFR appeared to detect acute changes (Figure 2) in intratendinous structure due to acute trauma (eg, during week 12, the patient slipped while exiting a vehicle) and increased tissue loading (eg, during week 25, she returned to sport-specific training). Consistent with previous literature[14] in which tendon morphology was characterized, we did not demonstrate any relationship between changes in PSFR and VISA-P scores. Changes in PSFR may be more indicative of tendon loading than clinical presentations of pain,[11] although this needs to be validated in a larger sample size.

The patient's pain and function increased throughout rehabilitation and the return-to-play progression (Table 1). The volume and load of exercises intended to stress the tendon were dictated by ongoing pain. The patient did not perform warmups before practice with the team and instead warmed up on a stationary bicycle. In addition, she did not participate in an entire practice or in consecutive drills. She performed a selection of drills that were chosen for her and totaled approximately 1.5 hours. With regard to specific measures of her pain and function, we noted 3 acute decreases in VISA-P scoring at weeks 12 and 25. The decrease in VISA-P at week 12 coincided with a fall. The second decrease around week 25 occurred after a week of inactivity. It is well known that optimal loading is an important factor in tendon health in rehabilitation.[15] This period of inactivity at the 6-month mark may have negatively affected her progress in rehabilitation. The third decrease in VISA-P occurred as the patient began to progress to sport-specific skill workouts, strength training in the weight room, and daily rehabilitation. This final acute decrease possibly occurred because of the increasing physical demands on the knees despite progressive rehabilitation.

The patient's final VISA-P score of 39 (an increase of 34 from baseline) was considerably lower than a normal score of 100 and a score of 80 indicating tendinopathy. This was a substantial increase (Figure 3) and greater than the minimal detectable change for improvement.[16] One contributing factor to the prolonged recovery could have been the bilateral surgical procedure. Maffulli et al[17] reported that patients who underwent bilateral surgery for patellar tendinopathy returned to sport later than their counterparts who underwent unilateral surgery.[17] It is also possible that the chronicity of pain contributed to the poorer outcome than the outcome reported earlier,[14] as this patient had clinical evidence of tendinopathy for nearly a decade before this investigation. Researchers[18] found that more athletic exposure increased the risk of young dancers sustaining knee injuries, which is consistent with this patient's athletic history. The intensity of the patient's participation and her high level of competition, even in the presence of continuing pain, may have prevented proper recovery of the tendon before the study and also influenced the poorer outcome. Despite the low VISA-P score, she did return to full participation in sport, albeit at a substantially reduced activity level with limited involvement in competitions.

CLINICAL BOTTOM LINE

Spatial frequency analysis has been related to mechanical properties of the tissue and shown to differentiate between pathologic and healthy tendons.[5,6,11] In this exploration case report, we observed that SFA provided objective metrics to the progression of tendon healing after patellar tendon surgery in a female Division I collegiate athlete. Given the unique nature of this patient's condition, including chronic pain and athletic participation, these findings should not be generalized. We provide initial observations that SFA may be a useful complement to clinical treatments that address both the structural and functional recovery of injured tissue. The PSFR supplies an additional objective measure of the tendon structure that can potentially aid clinicians in making rehabilitation decisions. Because a different type of collagen is laid down in an unorganized fashion at the site of injury, those fibers need to be able to withstand the stresses that will be applied. This is particularly important, as the sites of initial injury are often the sites of reinjury. For clinicians without access to these image-analysis methods, our findings could support the concept of load management and its implications on tissue structural adaptations. However, we reported only a single case and do not know how changes in PSFR will influence rehabilitation progression in a broader population. Based on our observations, we suggest that structural changes in the patellar tendon after surgery and during rehabilitation of an athlete with chronic tendinopathy are not necessarily related to pain. Although tendon structure and pain are not necessarily related, the objective information gained from SFA measures provides the clinician and patient with confidence that the tendon can be progressively loaded and withstand stresses during activity. Future researchers should investigate the relationships among structural adaptations, PSFR, reinjury risk, and specific joint function for a more complete view of recovery.

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