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Prognostic Factors for Recovery from Patellar Tendinopathy in Jumping Athletes: An International Prospective Cohort Study

Abdulhamit Tayfur[1,2,3,4*], Halime Gülle[1,5], Mehmet Delen[1,6], Dominik Zenner[7], Stuart Charles Miller[1], Hazel Screen[8] and Dylan Morrissey[1,3,9*]

Abstract

Background There is no robust prognostic guides for patellar tendinopathy (PT), hence we do not understand who gets better, when and why. Therefore, we aimed to identify which combination of self-reported factors best predicts PT recovery. A previously validated, reliable online questionnaire battery yielded data from an international sample of professional and recreational jumping athletes with a one-year follow-up. Recovery was defined using Global Rating of Change, alongside full availability for training and competition. Data on > 100 plausible bio-psycho-social, demographic and sporting outcome predictors were collected; and a multivariable cox proportional-hazards model constructed.

Results 128 athletes with PT (30.9 ± 8.9 years; 77 males (60%); Victorian Institute of Sport Assessment Questionnaire-Patellar Tendon = 61.5 ± 16.2) provided 25,284 days at risk for analysis. Recovery rate was 45%, peaking at 6-month. The multivariable model partially predicted PT recovery with acceptable performance (optimism-corrected C-statistic:0.77, 95%CI:0.74–0.79) and internal validation. Recovery was associated with lower severity (Hazard Ratio (HR) = 1.03, 95%CI 1.02–1.05), a shorter time off sport (HR = 0.93, 95%CI 0.87–0.99), feeling more rested after sleep (HR = 1.93, 95%CI 1.13–3.28), not having multiple concurrent tendon problems (HR = 0.23, 95%CI 0.07–0.69), higher training duration (HR = 1.05, 95%CI 1.01–1.10) and symptoms being modifiable by movement (HR = 2.71, 95%CI 1.21–6.09).

Conclusions To the best of our knowledge, this is the first study investigating outcome predictors for PT recovery in a large international cohort of jumping athletes. The exploratory recovery model showed that a combination of self-reported sports-specific and biomedical variables were predictive of PT recovery. These findings can be used to support clinical judgements of prognosis.

Key Points

- To our knowledge, this is the first study to explore prognostic factors for patellar tendinopathy (PT) recovery in jumping athletes using a large international cohort.
- All identified predictors were self-reported and potentially modifiable, providing clinicians with actionable insights to inform rehabilitation and management strategies.

*Correspondence:
Abdulhamit Tayfur
a.tayfur@qmul.ac.uk
Dylan Morrissey
d.morrissey@qmul.ac.uk

Full list of author information is available at the end of the article

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- The findings offer a foundation for future research and support the development of targeted interventions to improve recovery outcomes in athletes with PT.

Introduction

Patellar tendinopathy (PT) is characterised by load dependent pain and tenderness at the inferior pole of the patella, and is especially common in athletes that perform repetitive jump-landing activities [1]. Observational studies [2, 3] have shown only ~ 65% recover at 6 months, irrespective of intervention. PT can be career-ending in up to 50% of affected jumping athletes [2]. Intriguingly, causal explanations of PT recovery remain elusive, despite the high prevalence.

To the best of our knowledge, there is no study investigating prognostic factors for PT so it is not known who gets better, when or why. For patellofemoral pain, Collins et al. [4] reported that poor recovery either at 3 (55%) or 12 months (40%) was associated with longer pain duration and greater pain severity. Another cohort of knee complaints in general practice [5] showed worse outcome at 3 (75%) and 12 months (56%) was associated with previous knee complaints, longer condition duration, other coexisting musculoskeletal complaints, and higher levels of distress. Recent reviews [6, 7] have concluded that psychosocial and contextual factors play an important role in rehabilitation outcomes and should be better understood to optimise management, support return to sport or activity, and improve long-term quality of life. Given the lack of evidence on who recovers from PT and why, identifying prognostic factors could help guide clinical decision-making and individualise treatment planning.

This study aimed to identify self-reported factors associated with recovery from PT in a large international cohort of jumping athletes. The exploratory model was used to assist in understanding the multifactorial nature of PT prognosis, rather than as a definitive predictive tool for clinical use. To do this, we planned to build an exploratory recovery model from one-year follow-up data collected with a large international cohort of jumping athletes that included training load descriptors and a range of biopsychosocial factors.

Methods

The STROBE statement [8] (Strengthening the Reporting of Observational Studies in Epidemiology) guided the design and reporting of this cohort study. PROBAST (Prediction model Risk Of Bias ASsessment Tool) [9, 10] guided the approach to minimise risk of bias and improve applicability.

Participants

A validated, reliable online questionnaire battery [11] was used to collect data from an international cohort of jumping athletes, including elite (e.g., Olympic or top-league), non-elite professional (e.g., lower-division), and recreational participants, recruited primarily from the United Kingdom, Türkiye, and other European countries, via social media, private practice, sporting teams and the NHS. Recruitment, screening, enrolment process and retention strategies are detailed in Supplement 1. Eligibility was checked after informed consent, with the inclusion criteria being: aged ≥ 18 years; involvement in any jump-related sport with a minimum of an hour of training per week (prior to or at symptom onset) allow recruitment of both recreational and professional athletes; and a clinical diagnosis of PT (load-dependent localized pain on inferior patella pole) confirmed by a physician within the last 6 months. Athletes were eligible regardless of current sport participation status, including those temporarily unable to train due to symptoms. The exclusion criterion was having neurological disorders affecting the lower limb. This study was performed in accordance with the ethical standards outlined in the Declaration of Helsinki. Ethical approval was obtained from Queen Mary Ethics of Research Committee (QMERC2018/92), the UK National Health Service (NHS) (264615) and University of Liège Hospital-Faculty Ethics Committee (2019/182).

Baseline Measures and Candidate Predictors

We tracked jumping athletes over a 12 month period. Baseline data consisting of over 100 plausible potential outcome predictors were derived from published literature suggesting an association with PT [1, 12–17] or other musculoskeletal problems [7, 18–25], and categorized as demographic; sports specific; biomedical; psychological or social (Tables 1 and 2).

10 patient reported outcome measures (PROMs) plus miscellaneous questions concerning demographics, condition details, treatments and training load in the preceding 3 weeks [11] were collected online using SmartTrial (version 4.0, MEDEI ApS, Aalborg, Denmark). The details of the PROMs were provided in Supplement 3 with their relevant references. The translation process into Turkish, Spanish and French was described in a previous study [17]. Survey available in PDF format (Supplement 4).

Recovery was collected as the primary outcome and defined as one of the two highest elements of the Global Rating of Change (GRoC) [26] plus full availability for

Table 1 Self-reported baseline participant characteristics (demographics, sports specific, psychological and social) and univariate Cox regression analysis for jumping athletes with PT

Variables (*n* = 128)	**Baseline characteristics**	**Univariate cox proportional-hazards**	
Recovery (non-recovered: recovered)	NA	70: 58 (recovery rate: 45%)	
		HR (95% CI)	**Prob > chi2**
(A) *Demographics*			
Age (years)	30.9 ± 8.9	0.98 (0.95–1.01)	0.19
Body Mass (kg)	79.5 ± 14.7	1.01 (1.00-1.03)	0.15
Height (cm)	182.8 ± 12.9	1.03 (1.01–1.05)	0.01*
Sex (Female: Male)	51: 77	Male:1.61 (0.92–2.81)	0.09[$]
Dominance (Right: Left: Not sure)	108: 19: 1	Left:0.82 (0.39–1.74)	0.45
Language (EN: TR: SP: FR)	26: 89: 6: 7	NA	NA
Ethnicity (White: Arab: Asian: Black: Mixed: Others: Prefer not to say)	68: 2: 6: 6: 5: 22: 19	NA	NA
(B) *Sports specific*			
Sporting Age (years)	13.2 ± 7.3	1.02 (0.99–1.06)	0.27
KOOS - sports subscale score (0–100)	55.8 ± 21.6	1.02 (1.01–1.04)	<0.001*
Player Level (Amateur: Professional)	46: 82	Professional:3.07 (1.55–6.06)	<0.001*
Sport Type (Other: Court based Jumping Sports)	58: 70	Court based:1.53 (0.90–2.63)	0.11
Training details (including competition)			
Weekly hours trained	5.5 ± 6.5	1.04 (1.01–1.08)	0.02*
Average 3-weekly hours trained	5.8 ± 5.8	1.07 (1.03–1.10)	0.001*
Weekly number of jumps	338 ± 686	1.00 (0.999–1.001)	0.08[$]
Average 3-weekly number of jumps	386 ± 634	1.00 (1.00-1.001)	0.01*
Weekly intensity (RPE)	4.4 ± 3.3	1.06 (0.98–1.15)	0.14
Average 3-weekly intensity (RPE)	4.4 ± 2.8	1.12 (1.01–1.23)	0.02*
Acute: Chronic Workload Ratio			
Minutes continuous (*n* = 108)	1.00 ± 0.63	1.67 (1.02–2.74)	0.04*
Jumps continuous (*n* = 107)	0.86 ± 0.78	1.96 (1.34–2.87)	0.001*
Minutes categorical (Low: Optimal: High) (*n* = 108)	30:53:25	Low:0.42 (0.19–0.93) High:0.69 (0.34–1.43)	0.07[$]
Jumps categorical (Low: Optimal: High) (*n* = 107)	47:36:24	Low:0.37 (0.18-0.74) High:0.82 (0.40–1.69)	0.01*
(C) *Psychological*			
Full availability (N: Y)	56: 72	NA	NA
KOOS-quality of life subscale score (0–100)	53.9 ± 20.5	1.03 (1.02–1.05)	<0.001*
Equation 5D5L index score (−1 to 1)	0.76 ± 0.20	28.6 (4.32–189.1)	<0.001*
Equation 5D5L VAS score (0–100)	77.3 ± 21.0	1.03 (1.01–1.05)	<0.001*
Pain Catastrophizing score (0–52)	13.8 ± 11.5	0.98 (0.95-1.00)	0.049*
Tampa-11 Kinesiophobia score (11–44)	23.6 ± 6.7	0.94 (0.90–0.97)	0.001*
General Self-Efficacy score (10–40)	31.8 ± 5.1	1.06 (1.01–1.12)	0.03*
Patient recovery predictions			
Get better: Stay the same: Get worse: DNK	80: 19: 9: 20	Get better:1.83 (0.82–4.08) Get worse:1.25 (0.36–4.28) DNK:0.49 (0.14–1.67)	0.02*
If better,			

Table 1 (continued)

		HR (95% CI)	Prob > chi2
Confidence on recovery prediction (%) ($n = 80$)	82.3 ± 20.2	1.03 (1.00–1.05)	0.01*
Time prediction (months) ($n = 55$)	4.5 ± 4.8	0.90 (0.81–1.01)	0.04*
Confidence on time prediction (%) ($n = 54$)	75.1 ± 24.4	1.02 (1.00–1.05)	0.01*
(D) *Social*			
E-Health Literacy score (8–40)	28.9 ± 6.2	1.00 (0.96–1.04)	0.99
Education level (Did not attend or Elementary school: High school: Undergraduate: Postgraduate)	3: 44: 61: 20	HighSchool:0.58 (0.14–2.46) Undergrad:0.52 (0.12–2.18) Postgrad:0.13 (0.02–0.75)	0.01*
Work Status (Full time: Part time: N)	65: 17: 46	Full time:1.26 (0.71–2.26)	0.50
Change in work participation (N: Y)	112: 16	Part time:1.59 (0.71–3.56) Yes:0.66 (0.28–1.54)	0.31

Mean ± SD values for the continuous variables, and proportions for the categorical variables in characteristics. Dependent variable is recovery vs. non-recovery. Hazards ratios were the likelihood of recovery, meaning > 1.00 increases the possibility of recovery, while < 1.00 decreases the possibility of recovery. Variables with *$p < 0.05$, $^{\S}p < 0.10$ were retained for multivariable regression. Higher score means worse outcome for Pain Catastrophizing and Tampa-11 Kinesiophobia, but better outcome for the rest of the PROMs

Keys: PT, patellar tendinopathy; n, number of participants; N, no; Y, yes; EN, English; TR, Turkish; SP, Spanish; FR, French; RPE, rating of perceived exertion; Eq. 5D5L, Health-related Quality of Life; VAS, visual analogue scale; NA, not applicable; DNK, do not know; HR, hazards ratio; CI, confidence interval

training and competition (Supplement 2). GRoC is an 11-point scale rating participants' perceived overall change in condition, as 'Worse', 'No Change', or 'Better', and is a clinically relevant, stable concept for identifying self-reported meaningful improvement [26]. Many athletes continue to play despite PT presence [17]; therefore an international consensus identified *'Full availability for training and competition at any time point'* as the preferred marker of recovery in athletic populations [27]. If an athlete is not fully available for training and competitions, they are considered non-recovered. Overall, if an athlete stated the top two categories of GRoC and being fully available for both training and competitions, they were considered to be recovered (Supplement 2). The primary outcome of recovery was collected at 3-weekly intervals [11].

Sample Size

The sample size was calculated using the area under the receiver operating characteristic curve (AUC), checked with events per variable [28]. The AUC gives information about the overall predictive accuracy of outcome, and is equivalent to discriminative model performance statistics such as R-squared or C-statistics [29]. We aimed to produce a tool for clinicians to more reliably predict patient outcome so an excellent score >0.8 [30] was chosen to indicate a useful model with a power of 80% and an alpha of 5%. Null hypothesis value was 0.7 as an acceptable accuracy threshold [30]. Ratio of sample sizes in non-recovery/recovery events was considered 0.54 (35%:65%) based on previous PT studies [2, 3] and MedCalc (version 18.6, MedCalc Software Ltd, Belgium) used for the calculation. Final sample size required was 242 (85 non-recovery/157 recovery) after adding 20% drop out.

Data Processing

Previously published total score calculations for PROMs were followed [11]. For training load details, duration and number of jumps were collected with categorical miscellaneous questions then the range mid-points were taken and treated as continuous data. We calculated acute: chronic workload ratio (ACWR) with the rolling average method in both minutes and jumps [20]. ACWR was categorised as low 0–0.8.8, optimal 0.8–1.3 and high >1.3 [20]. Other categories were shown in Tables 1 and 2. Sparsely populated sub-categories that were sufficiently similar were combined prior to analysis. For instance, injured side was categorised as unilateral (right or left) and bilateral (both sides), while sport type was categorised as court based jumping sports (volleyball, basketball and handball) and other jump related sports (athletics, football, running, dance, fitness etc.), which may include high tendon-loading actions such as sprinting, bounding, or plyometrics.

Table 2 Self-reported baseline participant characteristics (biomedical) and univariate Cox regression analysis for jumping athletes with PT

Variables (*n* = 128)	Baseline characteristics	Univariate cox proportional-hazards	
Recovery (non-recovered: recovered)	NA	70: 58 (Recovery rate: 45%)	
(E) Biomedical			
Body Mass Index (kg/m^2)	23.7 ± 3.2	0.97 (0.90–1.05)	0.49
Injured side (Right: Left: Both)	54: 30: 44	Bilateral:1.13 (0.66–1.93)	0.66
VISA-P score (0–100)	61.5 ± 16.2	1.04 (1.02–1.06)	<0.001*
KOOS - symptom subscale score (0–100)	54.0 ± 12.5	1.03 (1.00–1.05)	0.02*
KOOS - pain subscale score (0–100)	73.2 ± 15.9	1.02 (1.00-1.04)	0.02*
KOOS - activity daily life subscale score (0–100)	82.3 ± 14.0	1.03 (1.01–1.05)	0.003*
KOOS - Patellofemoral score (0–100)	58.4 ± 20.8	1.03 (1.02–1.05)	<0.001*
Patient Acceptable Symptom State (N: Y)	74: 54	Yes:2.17 (1.29–3.65)	0.003*
Single Assessment Numeric Evaluation (0–100)	59.7 ± 24.0	1.02 (1.01–1.04)	<0.001*
Current condition duration (< 6M: >6 M)	35: 93	> 6 M:0.77 (0.44–1.35)	0.37
Current condition duration (months)	19.2 ± 13.3	0.98 (0.96-1.00)	0.08[$]
Time-off sport (weeks)	5.0 ± 5.0	0.89 (0.84–0.95)	<0.001*
Previous injury presence (N: Y)	88: 40	Yes:0.73 (0.42–1.29)	0.27
Current other injury presence (N: Y)	97: 31	Yes:0.52 (0.26–1.03)	0.045*
Adequate recovery time from previous injury (N: Y: No previous injury)	25: 25: 78	Yes:1.02 (0.43–2.41)	0.42
Direct hit to the knee (N: Y)	114: 14	Yes:0.89 (0.38–2.06)	0.77
Family tendon disorder history (N: Y)	110: 18	Yes:1.27 (0.58–2.81)	0.56
Family systemic disease history (N: Y)	92: 36	Yes:0.69 (0.30–1.61)	0.37
Having any systemic disease (N: Y)	66: 20	Yes:0.50 (0.25–0.99)	0.03*
Other tendon problems (Current: Previous: Never)	15: 32: 81	Current:0.40 (0.15–1.12)	0.048*
Symptoms (N: Y)			
Pain	10: 118	0.85 (0.34–2.12)	0.73
Stiffness	111: 17	0.95 (0.43–2.08)	0.89
Swelling	101: 27	0.87 (0.45–1.67)	0.66
Pain Onset (Sudden: Gradual)	50: 78	Gradual:0.84 (0.50–1.41)	0.51
Morning pain (N: Y)	35: 93	Yes:0.78 (0.45–1.37)	0.39
Morning stiffness (N: Y)	63: 65	Yes:0.54 (0.32–0.92)	0.02*
Pain at night (N: Y)	81: 47	Yes:0.84 (0.49–1.45)	0.53
Movement effect on symptoms (Get better: Get worse: No effect)	45: 57: 26	Get better:2.82 (1.23–6.48) Get worse:1.54 (0.66–3.58)	0.02*
Movement effect on symptoms (No effect: Effect)	26:102	Effect:2.04 (0.93–4.51)	0.053[$]
Medicine (Current: Previous: Never)			
Statin use	0: 1: 127	NA	NA
Glucocorticoid use	0: 1: 127	NA	NA
Fluoroquinolone use	0: 2: 126	NA	NA
Treatment (N: Y)	27: 101	Yes:1.61 (0.76–3.40)	0.19
Footwear changes	100: 28	Yes:1.49 (0.84–2.66)	0.19
Education	115: 13	NA	NA
Provision of information	117: 11	NA	NA
Physiotherapy	41: 87	Yes:1.37 (0.76–2.47)	0.28
Orthoses	120: 8	NA	NA
Injection	86: 42	Yes:1.06 (0.62–1.80)	0.83
Electrotherapy	103: 25	Yes:0.86 (0.45–1.66)	0.65
Medication	89: 39	Yes:1.23 (0.71–2.11)	0.47
Surgery	121: 7	NA	NA
Others			
Hormonal contraception use (NA: Y: N)	44: 6: 78	Yes:0.30 (0.04–2.20)	0.19
Menopausal status (NA: Pre: Current: Post)	91: 34: 2: 1	NA	NA
Hormone replacement therapy (NA: Y: N)	52: 1: 75	NA	NA
Low back pain presence (Current: Previous: Never)	16: 75: 37	Current:1.38 (0.56–3.39)	0.74
Low back pain association with leg pain (N: Y)	99: 29	Previous:1.21 (0.66–2.21) Yes:0.81 (0.43–1.53)	0.50

Table 2 (continued)

Variables ($n = 128$)	Baseline characteristics	Univariate cox proportional-hazards	
Smoking (Active: Passive: Ex-smoker: Never)	38: 16: 13: 61	Active:1.14 (0.63–2.07) Passive:1.53 (0.76–3.09) Ex:0.32 (0.08–1.36)	0.12
Daily sleep time (hours)	7.6 ± 1.0	1.10 (0.86–1.42)	0.46
Sleep difficulty (N: Y)	97: 31	Yes:1.00 (0.55–1.83)	0.99
Feeling rested after sleep (Y: Partially: N)	49: 65: 14	Yes:2.22 (1.33–3.73)	0.003*

Mean ± SD values for the continuous variables, and proportions for the categorical variables in characteristics. Dependent variable is recovery vs. non-recovery. Hazards ratios were the likelihood of recovery, meaning > 1.00 increases the possibility of recovery, while < 1.00 decreases the possibility of recovery. Variables with $^{*}p < 0.05$, $^{\$}p < 0.10$ were retained for multivariable regression. Higher score means better outcome for the PROMs

Keys: PT, patellar tendinopathy; n, number of participants; N, no; Y, yes; VISA-P, Victorian Institute of Sport Assessment Questionnaire-Patellar Tendon; KOOS, Knee injury and Osteoarthritis outcome score; NA, not applicable; HR, hazards ratio; CI, confidence interval

Statistical Analysis

Statistical analysis was conducted using STATA (version 16.0, StataCorp LP, College Station, TX, USA). To profile the sample, we calculated descriptive statistics and visualised the data. To calculate time to recovery, we conducted survival analysis by using univariate cox proportional-hazards regression with the number of days at risk as the time variable, and then analysed individual predictive associations between recovery and each plausible potential outcome predictors as independent variables at baseline.

Independent variables associated with outcome in the univariate analysis ($p < 0.10$) [30] were retained for multivariable cox proportional-hazards regression using a manual forward approach [17, 25, 31, 32]. The order of forward inclusion of independent variables into multivariable model was from demographic to social factors. To avoid collinearity prior to multivariable analysis, correlations between independent variables were tested with Pearson or Cramer's V based on data type [30]. If correlation [30] was >0.75 for any two independent variables, each was tested and the variable with better explanatory power retained. Independent variables which improved the multivariable model were retained, as determined with the likelihood-ratio test ($p < 0.05$).

For the final multivariable model fit, we tested assumptions by estimating Schoenfeld residuals (estat phtest > 0.05), visualising the survival time proportional-hazards and constructing Kaplan-Meier survival plots. We used the hazard ratio (HR) values of individual items to interpret the model. Additionally, Akaike's information criterion (AIC) and Bayesian information criterion (BIC) were used for model comparisons.

We evaluated the model performance by conducting discrimination, calibration analysis and bootstrapping. For potential overfitting or underfitting, we used the optimism-corrected calibration slope as a uniform shrinkage factor to adjust the regression coefficients (effects) of variables in order to improve the model's calibration. Full details are in Supplement 5.

Results

We reached 168 international jumping athletes with PT between 5th April 2019 and 14th January 2021. 138 athletes consented to the study and 132 completed the baseline survey giving a completion rate of 95%. Four participants did not provide any follow-up surveys and were excluded prior to the analysis. Major milestone follow-up retention rates were 88%, 78%, 68% and 71%, at 3, 6, 9 and 12 months respectively. Retention rates for 3-weekly follow-up surveys ranged from 45 to 92%. Participant journeys are shown in Fig. 1. 128 participants (30.9 ± 8.9 years; 77 males (60%); Victorian Institute of Sport Assessment Questionnaire-Patellar Tendon (VISA-P) = 61.5 ± 16.2) provided 25,284 days total analysis time at risk in the survival analysis. Recovery rate was 45% occurring at around 6 months (198 ± 141 days). Baseline participant characteristics are shown in Tables 1 and 2.

Univariate analysis showed forty-one variables individually predicted PT recovery and were retained for multivariable model construction (Tables 1 and 2). The final multivariable model comprised six outcome predictors (Table 3); Knee injury and Osteoarthritis Outcome Score - Patellofemoral (KOOS-PF), time-off sport, feeling rested after sleep, concurrent tendon problem, average 3-weekly hours trained, and movement effect on symptoms.

Model fit was good as the proportional-hazards assumption was not violated (estat phtest = 0.69, $p < 0.001$ for the model). Additionally, KOOS-PF (AIC = 470.6, BIC = 487.7) was interchangeable with VISA-P (HR = 1.03, 95%CI = 1.01–1.05, $p = 0.002$, AIC = 480.6, BIC = 497.7, estat phtest = 0.43) in the model, but concurrent tendon problem was insignificant ($p = 0.07$) when VISA-P in instead of KOOS-PF.

For the model performance (Supplement 6), the apparent Harrell's C-statistic of 0.79 (95%CI: 0.71–0.88) showed that the model differentiated the outcome in almost 8 of 10 athletes. The calibration plot showed that most predictions lay around the reference line (Supplement 7). The optimism-corrected C-statistics and calibration slope were 0.77 (95%CI: 0.74–0.79) and 0.86 (Supplement 6), respectively, showing that the model

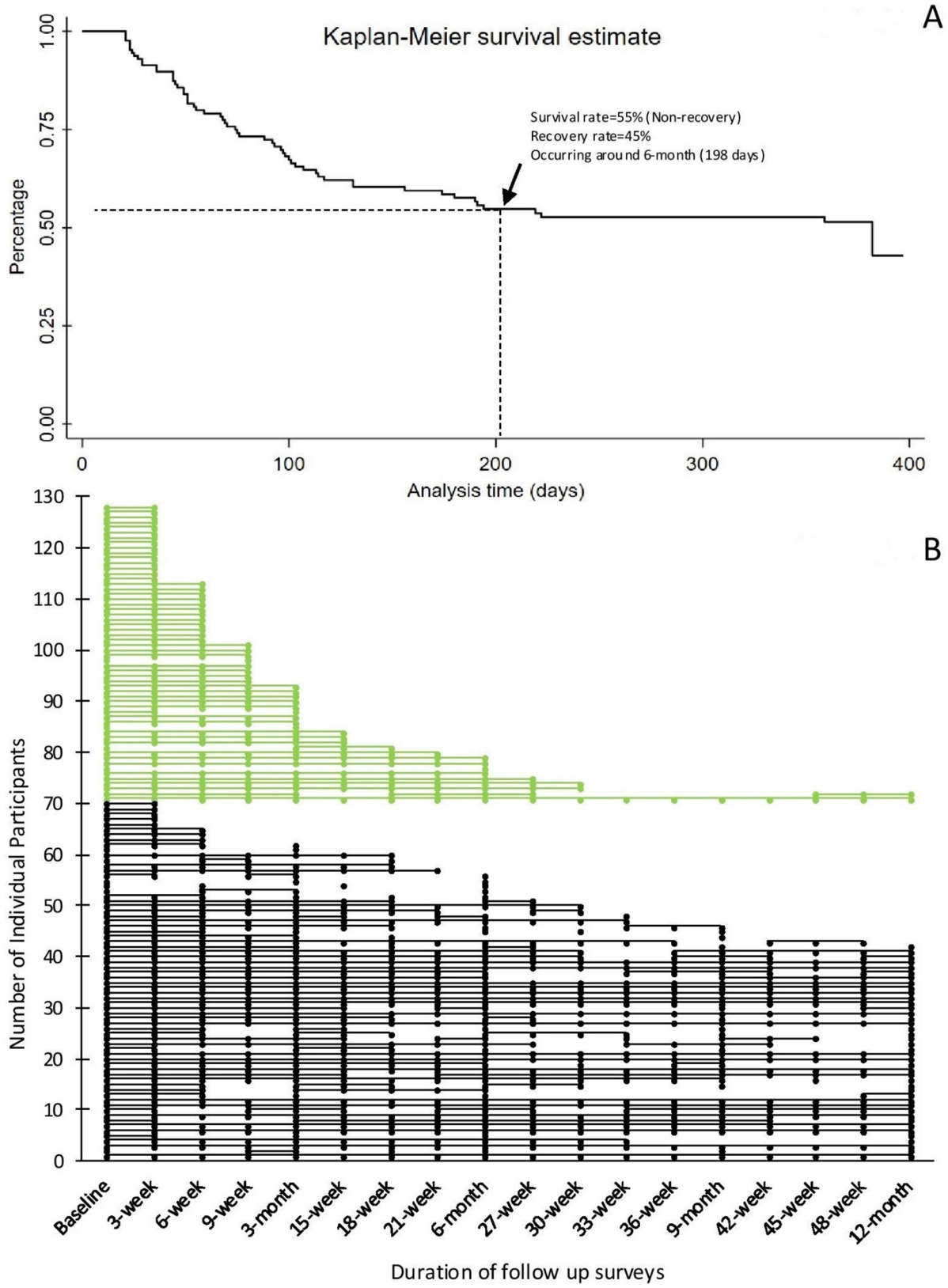

Fig. 1 **A** Kaplan-Meier survival estimate graph showing when recovery occurs with the relevant recovery rate and (**B**) recovery journey for each individual participant. Keys for colors: green; individual participants who recovered, black; those who did not recover. For instance, participant 10 (black color) did not recover in a year, while participant 110 recovered at week 6

Table 3 Final recovery model properties

Independent variables ($n = 128$)	HR (95% CI)	Beta coef.	Optimism-corrected coef.	$P > \|z\|$	Interpretation
KOOS-Patellofemoral (higher is better)	1.03 (1.02–1.05)	0.033	0.028	< 0.001	Lower severity is associated with recovery
Time-off sport (weeks)	0.93 (0.87–0.99)	− 0.072	− 0.062	0.03	Longer time-off sport is associated with less likelihood of recovery
Feeling rested after sleep (Yes)	1.93 (1.13–3.28)	0.655	0.565	0.02	Feeling rested after sleep is associated with recovery
Concurrent tendon problems (Yes)	0.23 (0.07–0.69)	− 1.494	− 1.288	0.01	Having current tendon problem other than PT is associated with less likelihood of recovery
Average 3-weekly hours trained	1.05 (1.01–1.10)	0.052	0.045	0.01	Higher training duration is associated with recovery
Movement effect on symptoms (Yes)	2.71 (1.21–6.09)	0.998	0.860	0.02	Change in symptoms with movement is associated with recovery

Dependent variable is recovery vs. non-recovery. Hazards ratios were the likelihood of recovery, meaning > 1.00 increases the possibility of recovery, while < 1.00 decreases the possibility of recovery

Key: HR, hazards ratio; CI, confidence interval; coef, coefficient values

systematically overestimated predicted outcomes. Therefore, we adjusted the regression coefficients of the variables using the optimism-corrected calibration slope as a uniform shrinkage factor (Table 3).

Discussion

This is the first study investigating outcome predictors for recovery of PT in a large international sample of professional (elite and non-elite) and recreational jumping athletes. While some demographic and biopsychosocial factors were associated with recovery when considered in isolation (univariate analysis), the exploratory multivariable causal model showed that a combination of 6 self-reported sports-specific and biomedical variables predicted PT recovery. Specifically, symptom severity, time-off sport, sleep quality, concurrent tendon problem presence, training duration, and movement effect on symptoms were retained in the model. These can all be measured in usual care. All identified predictors in our exploratory recovery model are self-reported and potentially modifiable, providing clinicians with actionable insights to inform rehabilitation and management strategies. The findings offer a foundation for future research and support the development of targeted interventions to improve recovery outcomes in athletes with PT.

Recovery of PT was partially predicted in our cohort, with the combination of a lower severity, a shorter time-off sport, feeling rested after sleep, not having multiple concurrent tendon problems, higher training duration and change in symptoms with movement. It is plausible that athletes with less severity are more likely to recover. Severity was an expected finding and is an important indicator of the prognosis and clinical decision making, as it is the most commonly used measurement of prognosis in randomised controlled trials (RCTs) and usual care. This finding is also consistent with other musculoskeletal conditions [4, 25].

Time-off sport and training duration represent different dimensions of an athlete's short-term training exposure. While these variables may reflect recovery-related behaviour, they do not directly measure symptom duration or overall availability. Although this may raise concerns of reverse causality, we used baseline responses to predict future outcomes. These results suggest that capturing detailed, context-specific training and sport participation data may support more accurate prognostic modelling in athletes with PT.

Good quality sleep was reported as one of the best promotors of recovery, especially for elite athletes who often report chronic sleep deprivation [33]. This relationship was similarly reported by our cohort. We did not directly assess sleep patterns, but assumed that feeling rested after sleep indicates good quality sleep. Growth hormone, which plays a substantial role in tissue regeneration and repair, is secreted during non-rapid eye movement (NREM) sleep [34]. There is also a reported association between NREM sleep and accelerated healing by decreased oxygen consumption, building proteins, and transporting free fatty acids [34], which could explain the relation between sleep quality with recovery.

Having another concurrent tendon problem was associated with a lower probability of recovery in our model. This may reflect a more complex or systemic presentation of tendinopathy. Co-existing tendon pain in multiple locations may indicate a heightened overall load on the musculoskeletal system or an underlying predisposition to poor tendon adaptation. Clinically, the presence of multiple tendinopathies might complicate rehabilitation, as recovery strategies must account for multiple affected sites, potentially limiting training options and increasing the physiological burden on the athlete. These factors may explain the reduced likelihood of full recovery in individuals with more than one active tendon injury.

The relationship between recovery and symptom response to movement should be interpreted cautiously.

We found that recovery was more likely in those whose symptoms changed with movement, whether they improved or worsened. In our model, both directions were grouped under "modifiable" reflecting the presence of any symptom change. While improvement with movement might reflect a warm-up or beneficial loading effect, worsening could indicate symptom provocation; these may have distinct clinical implications. Nonetheless, the presence of any response could suggest a condition that is less entrenched and more amenable to intervention. This responsiveness may indicate a greater potential for recovery in individuals whose symptoms are influenced by mechanical loading or exercise strategies, which are core components of tendinopathy management [35]. However, we did not analyse the direction of change separately in the final model or assess the type and context of movement, limiting our ability to draw firm conclusions. Therefore, further investigation of such sports specific and biomedical factors in usual care could improve PT recovery prediction.

We were cautious about implying predictive causality. The Bradford-Hill criteria [36] were followed, with the most important being 'Temporality' (the outcome has to occur after the cause) which was achieved through a robust prospective design [36]. The model is predictive with ~ 80% accuracy and was rigorously internally validated, with biologically plausible relationships having been identified. The criteria currently missing are external validation and experimental checking of the model. However, these are further steps in epidemiological studies and their absence does not diminish the potential predictive value of our exploratory model.

This is the first study to investigate outcome predictors for PT recovery. In the absence of comparable prospective PT cohorts, we referred to the general practice knee cohort by van der Waal et al. [5], which examined prognosis in individuals with new knee complaints. Despite differences in population (general vs. athletic), some parallels exist. Their study found that male sex, shorter knee symptom duration, lower stiffness, and menopausal status predicted better 3-month outcomes (AUC = 0.77), while the absence of previous knee complaints and lower baseline pain predicted better 12-month outcomes (AUC = 0.72) [5]. In contrast, sex and previous injury were not predictive in our model, either individually or in combination. Sleep quality, movement effect on symptoms, and training duration were not investigated for knee complaints in the van der Waal study [5], likely because their sample included individuals from the general population rather than athletes.

Less pain and stiffness may reflect lower severity, while shorter time off sport could reflect better functional capacity or load tolerance. Although not equivalent to symptom duration, time-off sport may capture a related but distinct dimension of the condition's impact in athletic populations in our model. Another similarity was that psychosocial factors were not predictive in either prognostic model [5], suggesting limited prognostic value in both general and athletic knee-related cohorts. To complement this, a recent prospective cohort study on recovery from rotator cuff tendinopathy [31] found that the combination of two biopsychosocial factors—activity level and health status—partially predicted recovery. Both are modifiable factors, highlighting the potential value of targeting them in intervention strategies across different tendinopathy locations. Overall, severity- and duration-related biomedical factors remain the most consistent predictors across studies, while sports specific and tendon-specific variables may offer additional prognostic insight in athletic populations with PT.

It has been reported that increased symptom duration is associated with poorer improvement regardless of treatment [37]. However, current condition duration did not predict recovery in our cohort, but shorter time-off sport was associated with better outcomes. This may indicate that athletes who were able to return to sport more quickly had milder presentations or better prognosis, making time of sport a more practical and responsive indicator of recovery potential than overall symptom duration. Quality of life and self-efficacy individually predicting recovery was expected as psychosocial and contextual factors impact on facilitating recovery in sport-related knee injury [7], however, these variables did not contribute to the model, whereas univariate statistical approaches [14] would have incorrectly included these factors. Effectively, confounded or indirectly related measures were identified and removed prior to settling on the final model therefore giving robust findings suitable to guide practice.

The variables in our exploratory recovery model are all modifiable, and doing so may improve outcomes. Clinicians should consider treating concurrent tendon problems to improve PT recovery as ignoring other tendon problems may result in poor recovery. A systematic review reported that individuals with less severe symptoms at baseline often experience greater improvements in pain and function following exercise therapy in clinical trials [37]. This is consistent with our finding that lower baseline severity—measured using KOOS-PF/VISA-P, which assess pain and function during activity—was associated with higher likelihood of recovery in this cohort. This aligns with our finding that symptoms modifiable by movement were associated with recovery, indicating that clinicians might be able to target this factor through tailored exercise strategies. Nonetheless, given that both improvement and worsening responses were grouped together, further work is needed to explore whether the direction of change differentially influences

prognosis. Monitoring and modifying time-off sport and training duration could help professionals individualise management strategies as part of load management. Correlating severity during training with changing load is also essential [38]. Thus, time could be used and modified as an indicator of dose and frequency in the severity and load management either during training or time-off period. Lastly, professionals could modify feeling rested after sleep by using sleep hygiene education to improve sleep quality in athletic populations [39]. Therefore, alongside understanding the prognosis, professionals could also modify predictors to potentially improve PT outcome. Future RCTs may consider these factors as part of complex interventions.

Strengths and Limitations

Despite being the largest cohort ever studied in the field of patellar tendinopathy, the study was underpowered due to the low number of recovery events. This may have increased the risk of both overfitting and Type II error, where true associations could remain undetected. However, robust statistical analysis addressed the overestimation by adjusting model calibration. Lack of external validity was another limitation as the whole dataset was used for internal validation. Although bootstrapping is the best option for internal validation, it requires using the whole dataset for model building to avoid dividing the dataset and losing events, so external validity is needed, ideally by other researchers to avoid confirmation bias. At the time of study design, the sample size calculation was based on the AUC framework assuming an anticipated C-statistic >0.8. We acknowledge this does not align with current best practices, which recommend methods accounting for the number of candidate predictors to minimise overfitting [40]. This study's primary contribution is identifying potentially modifiable prognostic factors, rather than providing a clinically usable prediction tool. Additionally, while baseline survey completion was high (95%), participant retention declined over time. Missing data from follow-up surveys may have introduced bias, which should be considered when interpreting the findings. The main limitation was the lack of variables from physical examination, imaging and biomechanical assessments which could add more to understanding. These assessments were initiated but data collection had to be curtailed due to pandemic restrictions.

Conclusion

This is the first study investigating outcome predictors for PT recovery in a large international cohort of professional (elite and non-elite) and recreational jumping athletes. The exploratory causal model showed that the combination of sports-specific (training duration) and biomedical variables (severity, time-off sport, sleep, multiple concurrent tendon problems, and movement effect on symptoms) were potentially predictive of recovery. The sampling and analysis mean the findings are generalizable to any level of athletes. Importantly, all the predictors in our exploratory model are potentially modifiable which could help better management of jumping athletes with PT, hence ultimately improving recovery rates. These findings should support clinical decision making by helping clarify who gets better, when and why.

Abbreviations

ACWR	Acute:chronic workload ratio
AIC	Akaike's Information Criterion
AUC	Area under the receiver operating characteristic curve
BIC	Bayesian Information Criterion
EQ5D5L	Health-related quality of life
HR	Hazard ratio
GRoC	Global rating of change
KOOS	Knee injury and osteoarthritis outcome score
NREM	Non-rapid eye movement
PROBAST	Prediction model Risk Of Bias ASsessment Tool
PROMs	Patient reported outcome measures
PT	Patellar tendinopathy
RCTs	Randomised controlled trials
STROBE	Strengthening the reporting of observational studies in epidemiology
VAS	Visual analogue scale
VISA-P	Victorian Institute of Sport Assessment Questionnaire-Patellar Tendon

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors contributions

AT and DM were responsible for the concept of the study. AT was the first author of the manuscript and revised it after the review of the study team. HG, MD, DZ and SCM advised on the appropriate statistical design. AT and DZ carried out the statistical analysis for the study. HS and DM supported AT in preparing the paper for publication, including performing the literature search and drafting parts of the manuscript. AT, HG, MD, DZ, SCM, HS and DM contributed to the study design, reporting and review of the paper in meetings and reviewed the paper prior to submission. All authors read and approved the final version and agree to be accountable for the work.

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Data availability

Data are available upon reasonable request. To request access to the underlying research data, please contact Professor Dylan Morrissey: d.morrissey@qmul.ac.uk.

Declarations

Ethics approval and consent to participate
This study was performed in accordance with the ethical standards outlined in the Declaration of Helsinki. Ethical approval was obtained from Queen Mary Ethics of Research Committee (QMERC2018/92), the UK National Health Service (NHS) (264615) and University of Liège Hospital-Faculty Ethics Committee (2019/182). Informed consent was obtained from all participants.

Consent for publication
Informed consent for publication was obtained from all participants.

Competing interests
Abdulhamit Tayfur, Halime Gulle, Mehmet Delen, Dominik Zenner, Stuart Charles Miller, Hazel Screen and Dylan Morrissey declare that they have no competing interests.

Author details
[1]Sports and Exercise Medicine, Queen Mary University of London, London, UK
[2]School of Physical Therapy and Rehabilitation, Kırşehir Ahi Evran University, Kırşehir, Türkiye
[3]London Barts Health NHS Trust, London, UK
[4]Athlete Health and Thermal Rehabilitation Application and Research Center, Kırşehir Ahi Evran University, Kırşehir, Türkiye
[5]School of Physical Therapy and Rehabilitation Sciences, University of South Florida, Tampa, USA
[6]Physiotherapy and Rehabilitation, Ankara Yıldırım Beyazıt University, Ankara, Türkiye
[7]Institute of Population Health Sciences, Queen Mary University of London, London, UK
[8]School of Engineering Material Sciences, Queen Mary University of London, London, UK
[9]Mile End Hospital, Bancroft Road, E1 4DG London, UK

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