ORIGINAL ARTICLE

Frailty is associated with prolonged hospitalization and inferior patient-reported outcomes after acute quadriceps tendon rupture: A multicenter cohort study

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ABSTRACT

BACKGROUND: Quadriceps tendon rupture is a functionally devastating injury frequently affecting patients with high comorbidity burden and impaired physiological reserve. Frailty represents an age-independent construct of diminished physiological resilience; its impact on hospitalization and long-term functional outcomes after quadriceps tendon rupture remains poorly defined.

METHODS: We retrospectively analyzed 67 adults who underwent surgical repair or reconstruction for acute quadriceps tendon rupture (≤4 weeks) at four tertiary centers between 2019 and 2023. Pre-operative frailty was quantified using the 5-item modified frailty index (mFI-5) and the 9-point clinical frailty scale (CFS). CFS was assigned retrospectively by two orthopedic surgeons using dual-reviewer consensus (κ=0.82). Primary outcomes were length of hospital stay (LOS) and functional recovery at ≥12 months (Lysholm Knee Scoring Scale); Knee Injury and Osteoarthritis Outcome Score and complications were secondary. Multivariable models were a priori restricted (six predictors for LOS, four for Lysholm; observations-per-predictor ≈11:1 and ≈17:1) and adjusted for age, sex, body mass index, comorbidity burden, surgical technique, and follow-up.

RESULTS: Mean age was 57.5±12.1 years; 79.1% male. Higher mFI-5 scores were associated with prolonged LOS (r=0.404, p<0.001); in adjusted models, each 1-point increase in mFI-5 predicted a 1.26-day longer stay (95% confidence interval [CI] 0.61–1.90; adjusted R2=0.337). At a mean follow-up of 25.5 months, the mean Lysholm score was 52.2±17.5. CFS was independently associated with poorer recovery (r=−0.328, p=0.007); each 1-point CFS increase corresponded to a 4.32-point decrement in Lysholm (95% CI −6.98 to −1.67; adjusted R2=0.163). A sensitivity analysis excluding reconstruction cases (n=6) yielded essentially unchanged effect sizes (mFI-5 → LOS: β=1.22; CFS → Lysholm: β=−4.18). No significant association was detected between either frailty metric and complications (rate 10.4%, 7 events); however, this analysis was underpowered and should be interpreted with caution.

CONCLUSION: Frailty is associated with prolonged hospitalization and poorer patient-reported outcomes after surgical repair of quadriceps tendon rupture. Integration of mFI-5 and CFS into routine pre-operative evaluation may refine surgical planning, discharge coordination, and rehabilitation intensity.

Keywords: Frailty; functional recovery; hospital length of stay; orthopedic surgery; prognosis; quadriceps tendon rupture.

Cite this article as: Özdemir E, Altay N, Şen K, Akçaalan S, Güler Y, Serpi M, Şahbat Y, et al. Frailty is associated with prolonged hospitalization and inferior patient-reported outcomes after acute quadriceps tendon rupture: A multicenter cohort study. Ulus Travma Acil Cerrahi Derg 2026;32:1267-1277.

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Ulus Travma Acil Cerrahi Derg 2026;32(10):1267-1277 DOI: 10.14744/tjtes.2026.36602

Submitted: 17.03.2026 Revised: 22.04.2026 Accepted: 02.05.2026 Published: 06.10.2026

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INTRODUCTION

Quadriceps tendon rupture is a serious extensor mechanism injury that can lead to substantial and often persistent functional impairment.[1] Acute quadriceps tendon ruptures are a functionally devastating injury that is disproportionately observed in patients with a high comorbidity burden and impaired physiological reserve, independent of chronological age.[2,3] Despite successful surgical repair, post-operative recovery in this population is often unpredictable, with substantial variability in hospitalization requirements and long-term functional outcomes. Even in younger, active patients, long-term follow-up studies report residual pain, stiffness, and limitations in activity despite technically successful repair. Although early surgical repair remains the standard of care for acute quadriceps tendon ruptures, post-operative outcomes are heterogeneous, with marked variability in hospital length of stay, complication rates, and trajectories of functional recovery.[4]

Frailty has emerged as a key construct to capture global physiological vulnerability beyond chronological age.[5,6] Frailty indices are pragmatic, validated tools that quantify cumulative physiological burden using easily obtainable clinical variables and have been widely adopted in surgical risk stratification.[7-10] Across a wide range of orthopedic procedures, higher modified frailty index-5 (mFI-5) scores have been associated with increased risk of complications, prolonged hospitalization, readmission, and mortality.[8] In parallel, the 9-point clinical frailty scale (CFS) integrates comorbidity, functional status, and clinical judgment into a simple bedside assessment and has demonstrated strong prognostic value for mortality, major complications, and discharge disposition in surgical cohorts.[7] Systematic reviews indicate that frailty indices provide superior prognostic information compared with age alone, yet there is no consensus regarding the optimal frailty instrument in orthopedic surgery.[11,12]

In particular, it is unclear whether different frailty constructs differentially reflect short-term healthcare utilization versus long-term patient-reported functional recovery in this setting.[9] The purpose of this study was to evaluate the association between frailty and both perioperative resource utilization and long-term functional outcomes in patients undergoing surgical treatment for acute quadriceps tendon rupture.

MATERIALS AND METHODS

Study Design and Setting

In this retrospective multicenter cohort study, we reviewed the medical records of patients treated at four tertiary orthopedic centers between January 2019 and December 2023. Data collection and analysis were initiated only after approval of the study protocol by the institutional review boards of all participating centers (IRB approval number: 10.07.2025-41171), which also granted a waiver of informed consent due to the retrospective design. This study was approved by the Erzurum Medical Faculty Scientific Research Ethics Committee for Clinical Research and were approved by the committee (Date: 10.07.2025, Decision no: 10.07.2025-41171) and with the 1964 Declaration of Helsinki and its later amendments. Because of its retrospective nature and the use of existing clinical data, the study was not prospectively registered in a clinical trials registry.

Patient Selection Criteria

Adult patients (aged ≥18 years) who underwent surgical repair or reconstruction for acute quadriceps tendon rupture were retrospectively identified from the institutional databases of the participating centers. Acute rupture was defined as an injury-to-surgery interval of 4 weeks or less. The initial cohort comprised 88 consecutive patients who underwent surgery during the study period.

Inclusion criteria were: (1) Complete unilateral quadriceps tendon rupture confirmed intraoperatively; (2) Primary surgical repair or reconstruction performed within 4 weeks of injury; (3) Minimum follow-up duration of 12 months with complete clinical and functional outcome data; and (4) Availability of pre-operative frailty assessments (mFI-5 and CFS scores).

Exclusion criteria were: (1) Follow-up duration <12 months (n=15); (2) incomplete demographic, clinical, or outcome data (n=4); (3) bilateral quadriceps tendon ruptures (n=2); (4) chronic ruptures (>4 weeks from injury); (5) previous ipsilateral knee surgery; and (6) concomitant major lower extremity injuries requiring additional surgical interventions. After applying these criteria, 67 patients were included in the final analysis (Fig. 1).

Data Collection

Demographic and clinical data were extracted from electronic medical records by trained research personnel at each center. Collected variables included: age, sex, body mass index (BMI), comorbidities, American Society of Anesthesiologists (ASA) physical status classification, Charlson comorbidity index (CCI), smoking status, mechanism of injury, time from injury to surgery, surgical technique (primary repair vs. reconstruction), operation duration, and post-operative complications. All data were de-identified and entered into a centralized secure database. To ensure data quality, a random 10% sample of cases was independently cross-checked against the source medical records, with no systematic discrepancies identified. Missing data were uncommon (<2% of all analyzed fields) and involved isolated entries (BMI, n=1; operative time, n=1; smoking status, n=1); these were managed by complete-case analysis without imputation, given the very low proportion of missingness.

Frailty Assessment

Pre-operative frailty was assessed using two validated tools. The mFI-5, derived from the Canadian Study of Health and Aging Frailty Index and National Surgical Quality Improve-

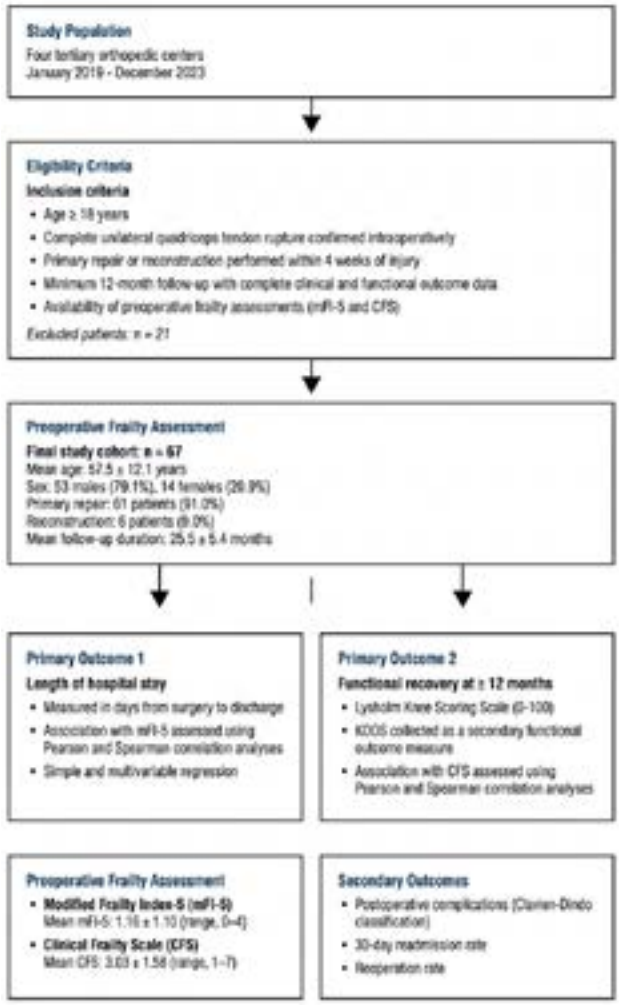

Figure 1. Study flowchart depicting patient selection and enrollment across four tertiary orthopedic centers. Of 88 patients initially screened between January 2019 and December 2023, 67 met inclusion criteria and completed a minimum 12-month follow-up with comprehensive frailty assessment and functional outcome data.

ment Program variables, allocates a binary score (0=absent, 1=present) to five items – diabetes mellitus, hypertension requiring medication, history of congestive heart failure or myocardial infarction, dependent functional status, and chronic obstructive pulmonary disease or pneumonia – resulting in a total score from 0 to 5, with higher scores indicating greater frailty. Scores were retrospectively calculated from pre-operative records by two independent reviewers blinded to outcomes, with discrepancies resolved by consensus. Global frailty was further evaluated using the nine-point CFS, which combines comorbidity burden, functional capacity and clinical judgment to classify patients from 1 (very fit) to 9 (terminally ill). Two fellowship-trained orthopedic surgeons independently assigned CFS scores based on comprehensive chart review, blinded to post-operative outcomes, and demonstrated substantial inter-rater agreement (κ=0.82). Although the CFS was originally developed as a prospective

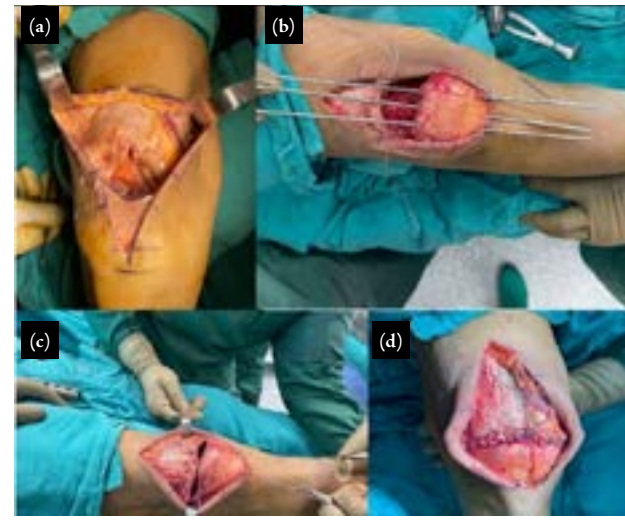

Figure 2. Intraoperative photographs of quadriceps tendon rupture. **(a)** Intraoperative view of a complete quadriceps tendon rupture. **(b)** Creation of transosseous tunnels in the patella. **(c)** Passage of the non-absorbable, continuous sutures through the patellar tunnels after repair of the tendon. **(d)** Final appearance of the tendon following repair.

bedside instrument, recent orthopedic and perioperative literature has demonstrated that chart-based retrospective CFS assignment is feasible and yields acceptable reliability when standardized documentation and dual-reviewer consensus are applied.[6,13] To minimize classification bias, both reviewers used a pre-specified scoring template that mapped documented functional status, mobility, and instrumental activities of daily living to CFS anchors; any discordant score was adjudicated by a third senior reviewer. We nonetheless acknowledge the retrospective assignment of CFS as a methodological limitation (see Discussion). The predictive validity of both mFI-5 and CFS in surgical cohorts has been confirmed in recent studies.[8,11]

Surgical Technique

All operations were undertaken by high-volume orthopedic surgeons using a protocolized technique that was harmonized across participating centers. Primary tendon repair was performed through either transosseous bone tunnels or suture-anchor fixation, employing non-absorbable high-strength braided sutures to optimize construct durability (Fig. 2). In the setting of compromised tissue quality or substantive tissue loss, an anatomic reconstruction was executed with autograft or allograft augmentation, selected at the surgeon's discretion based on intra-operative findings. This standardized approach has recently been shown to afford favorable biomechanical integrity and clinical outcomes in complex extensor-mechanism reconstructions.[1]

Post-operative Rehabilitation Protocol

Post-operative rehabilitation was likewise standardized. Each limb was immobilized in full extension for 2 weeks to protect the repair, after which a structured, therapist-supervised pro-

gram of progressive passive-and-active range-of-motion exercises was initiated. Graduated weight-bearing as tolerated was introduced concomitantly, allowing patient-specific advancement contingent on pain, quadriceps control and repair stability. Between weeks 4 and 6, emphasis shifted toward closed-kinetic-chain strengthening, proprioceptive re-training and gait normalization, with subsequent integration of functional and, where appropriate, sport-specific drills as clinically indicated. Contemporary systematic review evidence supports this phased regimen in maximizing tendon healing while expediting return to activity. The protocol was harmonized across the four participating centers through a shared written protocol and periodic inter-center case reviews. Supervised physiotherapy sessions were documented in the institutional rehabilitation records; however, formal metrics of patient-level adherence (number of attended sessions, home-exercise compliance logs, wearable-based activity data) were not systematically recorded during the study period. This limitation is explicitly addressed in the Discussion, and unsupervised adherence should be considered when interpreting between-patient variability in functional recovery.

Outcome Measures

Primary outcomes

The primary outcomes of interest were: (1) Length of hospital stay (LOS) (days), defined as the time from surgery to discharge; and (2) functional recovery at 12 months or beyond, assessed using the Lysholm Knee Scoring Scale. The Lysholm score is a validated patient-reported outcome measure for knee function, ranging from 0 to 100, with higher scores indicating better function. Scores are categorized as excellent (91–100), good (84–90), fair (65–83), or poor (<65). The Knee Injury and Osteoarthritis Outcome Score (KOOS) was also collected as a secondary functional outcome measure.

Secondary outcomes

Secondary outcomes included: (1) Post-operative complications (surgical site infection, re-rupture, thromboembolic events, delayed wound healing, persistent pain); (2) 30-day readmission rate; (3) reoperation rate; (4) knee range of motion (ROM) at final follow-up; and (5) return to pre-injury activity level. Complications were graded according to the Clavien–Dindo classification system.

Power Analysis

A priori power analysis was conducted using G*Power 3.1.9.7 software. For correlation analyses with a medium effect size ($r=0.35$), $\alpha=0.05$, and power ($1-\beta$)=0.80, a minimum sample size of 64 patients was required. Our final cohort of 67 patients provided adequate statistical power (>80%) to detect clinically meaningful associations between frailty measures and primary outcomes. Post hoc power analysis confirmed achieved power of 85% for the mFI-5-hospitalization correlation ($r=0.404$) and 81% for the CFS-functional recovery correlation ($r=-0.328$).

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences version 27.0 (IBM Corp., Armonk, NY, USA) and Python 3.9 (Python Software Foundation). Normality was assessed using the Shapiro–Wilk test and Q-Q plots. Normally distributed continuous variables are reported as mean±standard deviation, non-normally distributed variables as median (interquartile range), and categorical variables as frequencies and percentages.

Bivariate associations between frailty measures (mFI-5 and CFS) and primary outcomes were evaluated using Pearson or Spearman correlation coefficients, as appropriate. Simple and multiple linear regression analyses quantified relationships between mFI-5 and hospital stay, and between CFS and functional recovery (Lysholm score), adjusting for age, sex, BMI, CCI, surgical technique, and follow-up duration. Model assumptions were verified through residual diagnostics. To mitigate the risk of overfitting in the context of a modest sample size, the number of covariates in each multivariable model was pre-specified and deliberately constrained. The mFI-5 → length-of-stay model included six predictors (mFI-5, age, sex, BMI, CCI, surgical technique), and the CFS → Lysholm model included four predictors (CFS, age, sex, and follow-up duration). These specifications yielded observations-per-predictor ratios of approximately 11:1 and 17:1, respectively, which satisfy conventional thresholds (≥10 observations per predictor) for multivariable linear regression. Model stability was additionally assessed by examining variance inflation factors (all <2.0), standardized residuals, Cook's distance, and a sensitivity analysis restricted to patients who underwent primary repair (n=61).

Patients were stratified by frailty scores: mFI-5 (0, 1, 2, ≥3) and CFS (1-3 [fit], 4-5 [vulnerable], ≥6 [frail]). One-way analysis of variance (ANOVA) with Tukey Honestly Significant Difference post hoc tests compared continuous outcomes across groups. Chi-square or Fisher's exact test (expected counts <5) assessed categorical outcomes.

Statistical significance was set at $\alpha=0.05$ (two-tailed). Effect sizes are reported using R^2 for regression and Cohen's d for group comparisons. All confidence intervals (CIs) are reported at 95%. Missing data (<2%) were handled using complete case analysis.

RESULTS

Patient Demographics and Baseline Characteristics

A total of 88 patients with quadriceps tendon rupture were initially identified across the four participating centers. After applying exclusion criteria (15 patients with follow-up <12 months, 4 with incomplete data, and 2 with bilateral ruptures), 67 patients were included in the final analysis. The cohort comprised 53 males (79.1%) and 14 females (20.9%), with a mean age of 57.5±12.1 years (range, 25–94 years) and mean BMI of 27.4±3.9 kg/m^2 (Table 1).

Table 1. Patient demographics and baseline characteristics

Characteristic	Total cohort (n=67)	Primary repair only† (n=61)
Age (years), mean±SD	57.5±12.1	56.9±12.3
Male sex, n (%)	53 (79.1)	48 (78.7)
BMI (kg/m^2), mean±SD	27.4±3.9	27.3±3.8
Primary repair, n (%)	61 (91.0)	61 (100)
Reconstruction, n (%)	6 (9.0)	0 (0)
mFI-5 score, mean±SD	1.16±1.10	1.11±1.09
Score 0, n (%)	19 (28.4)	18 (29.5)
Score 1–2, n (%)	40 (59.7)	37 (60.7)
Score ≥3, n (%)	8 (11.9)	6 (9.8)
CFS score, mean±SD	3.03±1.58	3.00±1.58
Score 1–3 (Fit), n (%)	39 (58.2)	36 (59.0)
Score 4–5 (Vulnera-ble), n (%)	24 (35.8)	21 (34.4)
Score ≥6 (Frail), n (%)	4 (6.0)	4 (6.6)
ASA score, mean±SD	2.1±0.7	2.0±0.7
CCI score, mean±SD	1.4±1.3	1.3±1.2
Operation time (min), mean±SD	73.3±22.8	72.1±21.5
Follow-up (months), mean±SD	25.5±6.4	25.7±6.2

Data are presented as mean±standard deviation (SD) or number (percentage). BMI: Body mass index; mFI-5: Modified Frailty Index-5; CFS: Clinical Frailty Scale; ASA: American Society of Anesthesiologists; CCI: Charlson comorbidity index. †Sensitivity analysis restricted to patients undergoing primary repair (n=61). Demographic characteristics are essentially unchanged, indicating that findings are not driven by the small reconstruction subgroup (n=6).

Primary surgical repair was performed in 61 patients (91.0%), while reconstruction was required in 6 patients (9.0%). Mean operative time was 73.3±22.8 min, and all patients completed a minimum follow-up of 12 months (mean, 25.5±6.4 months; range, 13–36 months).

Frailty Assessment Distribution

The mean mFI-5 score was 1.16±1.10 (range, 0–4). The distribution of mFI-5 scores was: score 0, 19 patients (28.4%); score 1, 30 patients (44.8%); score 2, 10 patients (14.9%); score 3, 4 patients (6.0%); and score 4, 4 patients (6.0%). No patients had an mFI-5 score of 5. The majority of patients (73.2%) had an mFI-5 score of 0 or 1, indicating relatively low frailty burden in this surgical cohort.

The mean CFS score was 3.03±1.58 (range, 1–7). The distribution of CFS scores was: score 1 (very fit), 15 patients (22.4%); score 2 (well), 13 patients (19.4%); score 3 (managing well), 11 patients (16.4%); score 4 (vulnerable), 16 patients (23.9%); score 5 (mildly frail), 8 patients (11.9%); score 6 (moderately frail), 3 patients (4.5%); and score 7 (severely frail), 1 patient (1.5%). Approximately 58.2% of patients were classified as fit to managing well (CFS 1–3), whereas 41.8% were classified as vulnerable to frail (CFS ≥4).

Primary Outcome: mFI-5 and Length of Hospital Stay

The mean LOS was 5.1±3.0 days (range, 1–15 days). Bivariate analysis revealed a statistically significant positive correlation between mFI-5 scores and LOS (Pearson r=0.404, p<0.001; Spearman rho=0.473, p<0.001) (Fig. 3a). Simple linear regression demonstrated that each one-point increase in mFI-5 score was associated with a 1.11-day increase in hospital stay (95% CI, 0.49–1.73 days; R2=0.163, p<0.001).

When patients were stratified by mFI-5 categories (Fig. 3b), those with an mFI-5 score of 0 had a mean hospital stay of 3.7±2.1 days, compared to 4.8±3.1 days for score 1, 6.6±3.5 days for score 2, and 7.6±1.7 days for score ≥3. One-way ANOVA confirmed significant differences across mFI-5 categories (F=4.81, p=0.004).

After adjusting for age, BMI, and surgical technique in a multiple linear regression model (Table 2), mFI-5 score remained a significant independent predictor of prolonged hospitalization (β=1.26, 95% CI, 0.61–1.90; p<0.001; adjusted R2=0.337). This model explained 33.7% of the variance in hospital length of stay. The full adjusted model incorporated six predictors (mFI-5, age, sex, BMI, CCI, and surgical technique), corresponding to an observations-per-predictor ratio of approximately 11:1. Variance inflation factors were all <1.8, and residual diagnostics supported model assumptions. A sensitivity analysis restricted to patients undergoing primary repair (n=61) yielded essentially identical findings (β=1.22, 95% CI 0.58–1.86, p<0.001).

Table 2. Correlation analysis and regression results for primary outcomes

Analysis	Coefficient (β)	95% CI	R2/r	p
A. mFI-5 and hospital length of stay				
Biva-riate corre-lation (Pear-son)	0.404	—	r=0.404	<0.001***
Simple linear re-gres-sion	1.11	[0.49, 1.73]	R2=0.163	<0.001***
Multi-ple linear re-gres-sion†	1.26	[0.61, 1.90]	R2=0.337	<0.001***
B. CFS and functional re-covery (Lysholm score)				
Biva-riate corre-lation (Pear-son)	−0.328	—	r=-0.328	0.007**
Simple linear re-gres-sion	−3.64	[−6.24, −1.04]	R2=0.107	0.007**
Multi-ple linear re-gres-sion‡	−4.32	[−6.98, −1.67]	R2=0.163	0.002**
CFS versus KOOS Score (corre-lation)	−0.283	—	r=−0.283	0.020*

†Adjusted for age and body mass index (BMI). ‡Adjusted for age and follow-up duration. CI: Confidence interval; mFI-5: Modified Frailty Index-5; CFS: Clinical Frailty Scale; KOOS: Knee Injury and Osteoarthritis Outcome Score. *p<0.05, **p<0.01, ***p<0.001.

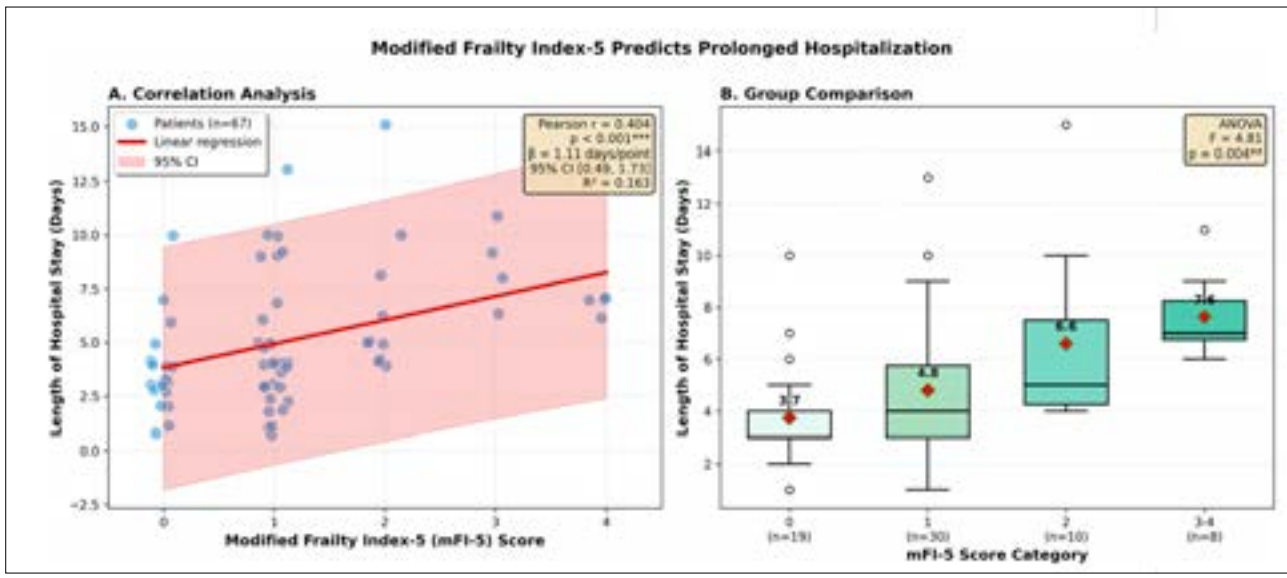

Figure 3. Correlation between Modified Frailty Index-5 (mFI-5) scores and length of hospital stay following quadriceps tendon rupture repair. Box plots demonstrate significantly prolonged hospitalization in patients with higher mFI-5 scores (Pearson r=0.404, p<0.001). Horizontal lines represent median values, boxes indicate interquartile ranges, and whiskers extend to 1.5× interquartile range.

Primary Outcome: CFS and Functional Recovery

At minimum 12-month follow-up, the mean Lysholm Knee Score was 52.2±17.5 (range, 20–89). The distribution of Lysholm scores by category was: excellent (91–100), 0 patients (0%); good (84–90), 2 patients (3.0%); fair (65–83), 14 patients (20.9%); and poor (<65), 51 patients (76.1%). Correlation analysis revealed a statistically significant negative association between CFS scores and Lysholm scores (Pearson r=−0.328, p=0.007; Spearman rho=−0.311, p=0.011) (Fig. 4a).

Simple linear regression demonstrated that each one-point increase in CFS score was associated with a 3.64-point decrease in Lysholm score (95% CI, −6.24 to −1.04; R2=0.107, p=0.007). This indicates that higher frailty burden, as measured by CFS, is associated with worse functional outcomes following quadriceps tendon repair.

When stratified by CFS categories (Fig. 4b), patients classified as fit (CFS 1–3, n=39) achieved a mean Lysholm score of 58.2±14.3, compared to 46.6±18.2 for those classified as vulnerable (CFS 4–5, n=24), and 27.2±8.8 for those classified as frail (CFS ≥6, n=4). One-way ANOVA confirmed highly significant differences in functional outcomes across CFS categories (F=9.45, p<0.001).

After adjusting for age, sex, and follow-up duration in a multiple linear regression model, CFS remained an independent

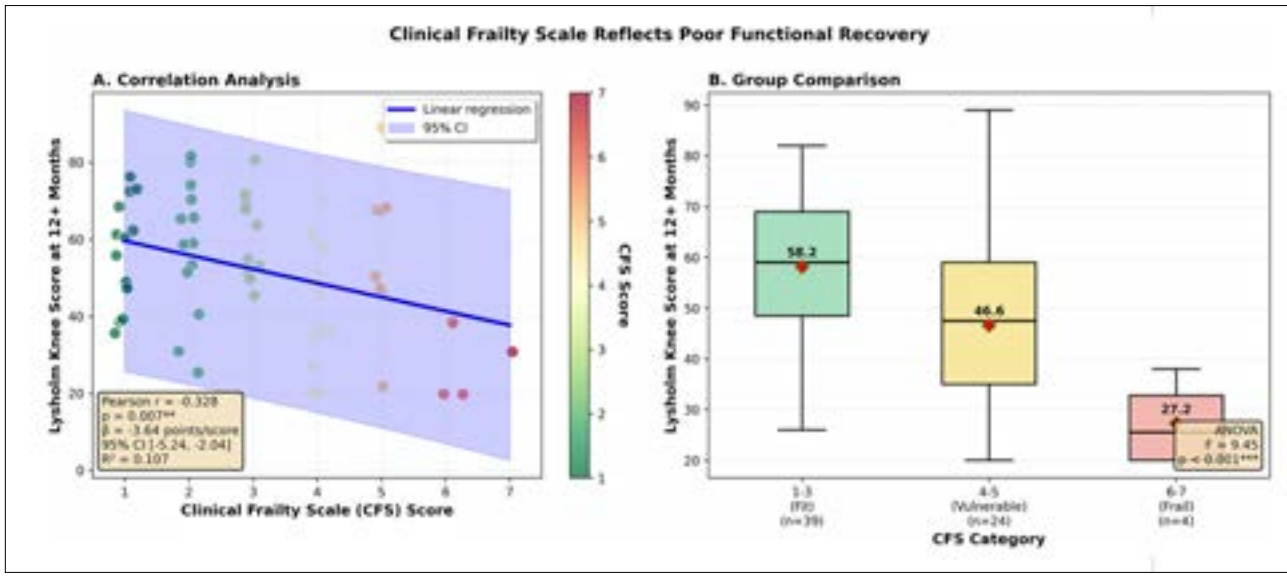

Figure 4. Association between clinical frailty scale (CFS) scores and functional recovery at minimum 12-month follow-up, measured by Lysholm Knee Scoring Scale. Higher CFS scores correlated with significantly worse functional outcomes (Pearson r=−0.328, p=0.007). Box plots show median values (horizontal lines), interquartile ranges (boxes), and whiskers extending to 1.5× the interquartile range.

Table 3. Complications analysis and secondary outcomes

Outcome	Overall (n=67)	Statistical test	p
A. Complications			
Overall complica-tions, n (%)	7 (10.4)	—	—
By mFI-5 category, n (%)			
Score 0	3/19 (15.8)	χ^2=2.95	0.400
Score 1–2	4/40 (10.0)		
Score ≥3	0/8 (0.0)		
By CFS category, n (%)			
Score 1–3	3/39 (7.7)	χ^2=1.33	0.514
Score 4–5	3/24 (12.5)		
Score ≥6	1/4 (25.0)		
B. Other second-ary outcomes			
Readmis-sion, n (%)	6 (9.0)	—	—
Reopera-tion, n (%)	4 (6.0)	—	—
Length of stay (days), mean±SD	5.1±3.0	F=4.81	0.004**
Lysholm score (12mo), mean±SD	52.2±17.5	F=9.45	<0.001***
KOOS score, mean±SD	52.6±18.3	—	—
Smoking rate, n (%)	28 (41.8)	—	—
Follow-up (months), mean±SD	25.5±6.4	—	—

Data are presented as number (percentage) or mean±standard deviation. mFI-5: Modified frailty index-5, CFS: Clinical frailty scale; KOOS: Knee injury and Osteoarthritis outcome score; ANOVA: Analysis of variance. Chi-square test used for categorical variables; one-way ANOVA for continuous variables across groups. **p<0.01, ***p<0.001.

predictor of functional recovery (β=−4.32, 95% CI, −6.98 to −1.67; p=0.002; adjusted R2=0.163). Similarly, CFS score showed a significant negative correlation with KOOS scores (r=-0.283, P=0.020), confirming the relationship between frailty and functional outcomes across multiple assessment tools. The CFS → Lysholm model contained four predictors

(observations-per-predictor ratio ≈17:1), VIFs <1.5, and the sensitivity analysis excluding reconstruction cases produced essentially unchanged estimates (β=–4.18, 95% CI –6.80 to –1.56, P=0.002).

Complications and Secondary Outcomes

The overall complication rate was 10.4% (7/67 patients). Specific complications included superficial wound infection (n=2), persistent pain (n=2), deep infection (n=1), re-rupture (n=1), and stiffness requiring manipulation under anesthesia (n=1). The 30-day readmission rate was 9.0% (6/67), and the reoperation rate was 6.0% (4/67) (Table 3). Given that only seven complication events were observed in the cohort, any inferential test involving complications carries substantially reduced statistical power. Findings in this section should therefore be regarded as hypothesis-generating rather than confirmatory.

No statistically significant association between either frailty metric and post-operative complications was detected; however, this analysis was underpowered. When analyzed by mFI-5 categories, complication rates were: Score 0, 15.8% (3/19); score 1–2, 10.0% (4/40); and score ≥3, 0% (0/8) (χ^2=2.95, p=0.400). Similarly, when stratified by CFS categories, complication rates were: CFS 1–3, 7.7% (3/39); CFS 4–5, 12.5% (3/24); and CFS ≥6, 25.0% (1/4) (χ^2=1.33, p=0.514). Pearson correlation analyses confirmed the absence of significant relationships between mFI-5 and complications (r=−0.186, p=0.131) and between CFS and complications (r=0.149, p=0.227). Because the overall event rate was low, these findings should not be interpreted as evidence that frailty is unrelated to complications; rather, a larger prospective cohort is required to assess this question adequately.

Summary of Key Findings

In summary, this multicenter cohort study of 67 patients with quadriceps tendon rupture demonstrated that: (1) mFI-5 score is a significant predictor of prolonged hospital length of stay (r=0.404, p<0.001), with each one-point increase associated with approximately 1.1 additional days of hospitalization; (2) CFS score is a significant predictor of poor functional recovery as measured by Lysholm scores (r=−0.328, p=0.007), with higher frailty associated with worse 12-month outcomes; and (3) neither frailty measure showed a significant association with post-operative complications (p>0.05), although this analysis was limited by the small number of events and should be interpreted as underpowered rather than as definitive evidence of no association.

DISCUSSION

In this multicenter cohort of 67 patients undergoing quadriceps tendon rupture repair with a minimum 12-month follow-up, we found that the mFI-5 was significantly associated with prolonged hospitalization, whereas the CFS was more closely related to poorer functional recovery, and neither frailty measure showed a significant relationship with post-operative complications. These findings are consistent with prior work demonstrating that deficit-accumulation frailty indices are robust predictors of length of stay and healthcare resource utilization across multiple surgical subspecialties.[9,12]

By contrast, the stronger association between CFS and patient-reported functional outcomes suggests that clinical frailty assessments capture domains such as baseline mobility, muscle strength, and exercise tolerance that more directly influence long-term rehabilitation trajectories.[12] This differential predictive utility aligns with systematic reviews indicating that while deficit-accumulation indices perform well for predicting perioperative mortality and readmission, judgment-based frailty scales may more accurately reflect baseline functional reserve and patient-centered recovery endpoints.[13] With respect to complications, the absence of a statistically significant association between either frailty measure and adverse events should be interpreted with caution: only seven complication events occurred in the entire cohort, rendering this analysis underpowered. A more appropriate interpretation is that our study did not detect a significant association, rather than that frailty is truly unrelated to perioperative complications. Larger prospective cohorts, ideally powered with complication as the primary endpoint, are required to resolve this question. Previous series on extensor mechanism tendon repair have reported similarly low complication and rerupture rates, often in the range of 6–10%, suggesting that standardized techniques and contemporary perioperative protocols have mitigated many historically prevalent adverse events.[14]

The mean Lysholm score of 52.2±17.5 and the 76.1% rate of poor outcomes observed in our cohort appear lower than those reported in several prior series on quadriceps tendon repair, and this discrepancy warrants explicit discussion. Several factors likely contribute. First, our cohort had a substantially older mean age (57.5 years) and greater frailty burden (41.8% with CFS ≥4) than the predominantly young, active populations (mean age typically <45 years) reported in earlier series such as Rao et al.[1] Second, a considerable proportion of patients carried cardiometabolic comorbidities captured by the mFI-5, which are known to impair muscle healing, protein metabolism, and rehabilitation capacity. Third, although the rehabilitation protocol was harmonized across centers, rehabilitation in our regional healthcare context is primarily delivered on an outpatient, community basis, and variability in access and adherence may have limited the ceiling of functional recovery. Fourth, our study intentionally enrolled an unselected, real-world surgical cohort with a wide spectrum of baseline physiological reserve rather than restricting inclusion to athletic or highly active populations, which inherently shifts the distribution of Lysholm outcomes toward the lower range of the published literature. Taken together, these cohort-level characteristics – rather than a technical deficiency of surgical repair – most plausibly account for the observed functional results.

Surgical heterogeneity is a further consideration. Our cohort included both primary repair and reconstruction, as well as transosseous tunnel and suture-anchor fixation, with occasional graft augmentation at the surgeon's discretion. Because reconstruction was performed in only 6 patients (9.0%), a formal subgroup analysis between repair and reconstruction was statistically underpowered. We therefore pre-specified surgical technique as a covariate in all multivariable models and performed a sensitivity analysis restricted to patients undergoing primary repair (n=61). This sensitivity analysis yielded essentially unchanged effect estimates (mFI-5 → LOS: β=1.22, 95% CI 0.58–1.86, p<0.001; CFS → Lysholm: β=–4.18, 95% CI –6.80 to –1.56, p=0.002), indicating that the principal findings are unlikely to be driven by the small reconstruction subgroup. Nonetheless, larger cohorts are required to directly compare technique-specific outcomes in frail patients.

The negative correlation between CFS scores and Lysholm outcomes underscores the prognostic importance of pre-operative frailty phenotyping for functional recovery. Patients with higher baseline frailty may require more intensive and prolonged rehabilitation to achieve comparable milestones and may still fail to attain the same level of function as fitter counterparts.[8,15]

Clinically, our results suggest a complementary role for the two frailty tools. Specifically, routine pre-operative frailty screening may be leveraged along three practical axes. (i) Pre-operative planning: mFI-5 and CFS can inform anesthesia risk stratification, nutritional and medical optimization (e.g., glycemic control, anemia correction, pre-habilitation referral), and shared decision-making with patients and families regarding realistic expectations. (ii) Discharge planning: because higher mFI-5 scores are associated with prolonged length of stay, early engagement of case management, social services, and home-care pathways at the time of admission may compress avoidable inpatient days and improve care transitions. (iii) Rehabilitation guidance: Higher CFS scores identify patients likely to experience slower and less complete functional recovery; such patients may benefit from extended or intensified therapist-supervised protocols, earlier reassessment, and expectation-setting regarding return to pre-injury activity, whereas fit patients (CFS 1–3) may be safely advanced along standard pathways. The mFI-5 may be particularly useful for pre-operative counseling regarding expected hospital length of stay, discharge planning, and allocation of in-hospital resources, whereas the CFS may better inform discussions about likely recovery timelines, rehabilitation intensity, and the probability of regaining pre-injury activity levels.[16] From a health-systems perspective, routine mFI-5 assessment could facilitate early identification of patients at risk for prolonged hospital stays, enabling proactive medical optimization and closer coordination with discharge and rehabilitation services.[17]

This study has several limitations. First, its retrospective design introduces the potential for selection bias and measurement error and precludes firm causal inference. In particular, although the CFS was originally validated as a prospective bedside tool, it was assigned here retrospectively from chart documentation; despite the use of a pre-specified scoring template, dual-reviewer consensus, and substantial inter-rater agreement (κ=0.82), residual classification bias cannot be fully excluded, and findings derived from CFS should be interpreted in this light.[6,13] Second, the relatively modest sample size of 67 patients may have limited our ability to detect associations between frailty and infrequent complications, indicating that larger, prospective multicenter studies are needed to more fully characterize these relationships and provide adequate power for secondary endpoints. With only seven complication events, the null association between frailty and complications should be interpreted as an underpowered finding rather than as evidence of true independence. To limit overfitting risk, multivariable models were pre-specified with a constrained number of predictors (six and four, respectively), yielding observations-per-predictor ratios of ≈11:1 and ≈17:1; nevertheless, external validation in independent cohorts remains necessary. Third, although a minimum 12-month follow-up is adequate for short- to intermediate-term functional assessment, longer-term complications, functional decline, or changes in patient-reported outcome trajectories may not be fully captured within this observation window.[18] Fourth, differences in surgical technique, rehabilitation protocols, and patient demographics across centers and regions may limit the generalizability of our findings to other healthcare settings with different case-mix or care pathways. Fifth, surgical heterogeneity (primary repair vs. reconstruction, transosseous tunnels vs. suture anchors, graft augmentation) could theoretically influence outcomes; although surgical technique was adjusted for in all multivariable models and a sensitivity analysis restricted to primary-repair cases yielded unchanged conclusions, technique-specific subgroup analyses were underpowered and should be addressed in future larger cohorts. Sixth, while supervised rehabilitation was protocolized, formal patient-level adherence metrics were not systematically documented, which may have contributed to variability in recovery independent of frailty status. Finally, while the Lysholm score and KOOS are well-validated, responsive measures of knee function, incorporation of objective performance-based tests (e.g., strength, gait analysis, and return-to-activity metrics) would provide a more comprehensive characterization of functional recovery. Future studies should also explore whether comprehensive geriatric assessment encompassing nutrition, cognition, psychological status, and social support can complement frailty indices to yield a more holistic pre-operative risk profile in older orthopedic patients.[5,19]

CONCLUSION

This multicenter cohort study provides novel evidence that the mFI-5 and CFS offer differential but complementary prognostic information after quadriceps tendon rupture repair,

with the mFI-5 primarily associated with hospitalization duration and the CFS more closely linked to functional recovery. These findings support the integration of multimodal frailty assessment strategies that leverage both deficit-accumulation and clinical judgment-based instruments to enhance risk stratification, patient counseling, and perioperative care pathways in orthopedic trauma populations.

Ethics Committee Approval: This study was approved by the Erzurum Medical Faculty Scientific Research Ethics Committee for Clinical Research and were approved by the committee (Date: 10.07.2025, Decision No: 10.07.2025-41171).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: E.Ö., N.A., K.Ş; Design: S.A., Y.G.; Supervision: M.S., C.Y., H.C.; Resource: Y.Ş.; Materials: E.Ö., K.Ş., S.A.; Data Collection and/or Processing: M.S., H.C., Y.Ş.; Analysis and/or Interpretation: Y.G., C.Y.; Literature Review: N.A., K.Ş., Y.Ş.; Writer: E.Ö., N.A., K.Ş., S.A., Y.G., M.S., C.Y., H.C., and Y.Ş.; Critical Review: E.Ö., N.A., K.Ş., S.A., Y.G., M.S., C.Y., H.C., Y.Ş.

Informed Consent: Written informed consent was obtained from each participant prior to inclusion.

Conflict of Interest: None declared.

Financial Disclosure: The author declared that this study has received no financial support.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Akut kuadriseps tendon rüptürü sonrasında kırılganlık, uzamış hastanede yatış ve daha kötü hasta bildirimli sonuçlarla ilişkilidir: Çok merkezli kohort çalışması

AMAÇ: Kusadriseps tendon rüptürü, yüksek ek hastalık yükü ve azalmış fizyolojik rezervi olan hastalarda sık görülen, fonksiyonel açıdan yıkıcı bir yaralanmadır. Kırılganlık, yaştan bağımsız fizyolojik dayanıklılık kaybını yansıtır; ancak kuadriseps tendon rüptürü sonrası yatış ve uzun dönem fonksiyonel sonuçlar üzerindeki etkisi yeterince tanımlanmamıştır.

GEREÇ VE YÖNTEM: Bu geriye dönük, çok merkezli kohort çalışmasında, 2019–2023 yılları arasında dört üçüncü basamak merkezde akut kuadriseps tendon rüptürü (≤4 hafta) nedeniyle cerrahi onarım veya rekonstrüksiyon uygulanan 67 erişkin hasta analiz edildi. Ameliyat öncesi kırılganlık, 5 maddelik Modifiye Kırılganlık İndeksi (mFI-5) ve 9 puanlık Klinik Kırılganlık Ölçeği (CFS) ile nicelendirildi. CFS, iki bağımsız ortopedi cerrahı tarafından standart belgelemeye dayalı çift-gözlemci konsensus yöntemiyle (κ=0.82) geriye dönük puanlandı. Birincil sonlanımlar hastanede kalış süresi ve ≥12. ayda Lysholm Diz Skorlama Ölçeği; ikincil sonlanımlar KOOS ve komplikasyonlardı. Çok değişkenli modeller önceden belirlenmiş sınırlı değişken setiyle kuruldu (yatış modeli için 6, Lysholm modeli için 4 ön görücü; ön görücü başına ≈11:1 ve ≈17:1 gözlem) ve yaş, cinsiyet, VKİ, ek hastalık yükü, cerrahi teknik ve takip süresine göre düzeltildi.

BULGULAR: Ortalama yaş 57.5±12.1 yıl; %79.1 erkek. Daha yüksek mFI-5 skorları uzamış yatış ile ilişkiliydi (r=0.404; p<0.001); düzeltilmiş modelde mFI-5'teki her 1 puanlık artış 1,26 günlük uzamayı öngördü (%95 GA: 0.61–1.90; düzeltilmiş R2=0.337). Ortalama takip 25.5 ay; ortalama Lysholm 52.2±17.5. CFS daha kötü fonksiyonel iyileşme ile bağımsız olarak ilişkiliydi (r=−0.328; p=0.007); CFS'deki her 1 puanlık artış Lysholm skorunda 4.32 puanlık azalmaya karşılık geldi (%95 GA: −6.98 ile −1.67; düzeltilmiş R2=0.163). Rekonstrüksiyon olgularını (n=6) dışlayan duyarlılık analizi benzer etki büyüklükleri verdi (mFI-5 → yatış: β=1.22; CFS → Lysholm: β=−4.18). Her iki kırılganlık ölçütünün de komplikasyonlarla (oran %10.4; 7 olay) anlamlı ilişkisi saptanmadı; ancak analiz yetersiz güçtedir ve dikkatle yorumlanmalıdır.

SONUÇ: Kırılganlık, kuadriseps tendon rüptürünün cerrahi onarımı sonrasında uzamış yatış ve daha düşük hasta bildirimli sonuçlarla ilişkilidir. mFI-5 ve CFS'nin rutin preoperatif değerlendirmeye entegrasyonu cerrahi planlama, taburculuk koordinasyonu ve rehabilitasyon yoğunluğunun bireyselleştirilmesinde klinik fayda sağlayabilir.

Anahtar sözcükler: Fonksiyonel iyileşme; hastanede kalış süresi; kırılganlık; kuadriseps tendon rüptürü; ortopedik cerrahi; prognoz.

Ulus Travma Acil Cerrahi Derg 2026;32(10):1267-1277 DOI: 10.14744/tjtes.2026.36602