Article

Clinical Outcomes and Functional Evaluation of Autologous Tendon Grafting for Acromioclavicular Joint Reconstruction

Ann. Ital. Chir., 2025 96, 11: 1494–1507
https://doi.org/10.62713/aic.4244

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AIM: To evaluate the clinical efficacy and functional outcomes of autologous tendon grafting in reconstructing Rockwood type III–V acromioclavicular (AC) joint dislocations, and to compare its performance with conventional titanium fixation.
METHODS: A total of 276 patients who underwent AC joint reconstruction between January 2019 and March 2024 were retrospectively analyzed. Following propensity score matching (PSM), 87 patients were included in the autologous tendon and titanium fixation groups. Primary outcome measures comprised radiographic parameters (acromioclavicular distance [ACD], coracoclavicular distance [CCD], magnetic resonance imaging [MRI] signal intensity), functional scores (Constant-Murley, University of California at Los Angeles [UCLA] shoulder score, visual analog scale [VAS]), biomechanical indices (horizontal motion displacement [HMD], range of motion [ROM] loss ratio, CCD maintenance rate), and complication rates. Prognostic factors were identified using Cox proportional hazards and logistic regression models. An extreme gradient boosting (XGBoost)-based machine learning model was constructed to predict postoperative functional recovery.
RESULTS: After matching, no significant differences in baseline characteristics were observed between groups (n = 87 each). Compared with the titanium group, autologous tendon grafting achieved significantly superior joint stability (ACD, CCD, HMD, ROM loss) and radiological outcomes (tendon signal intensity, bone remodeling score) (all $p < 0.01$). It was also associated with a lower incidence of redislocation and implant-related failures ($p < 0.05$). Cox regression identified four independent prognostic factors, including surgical technique, Rockwood classification, preoperative CCD, and ROM limitation. A multivariable risk scoring system demonstrated high predictive accuracy for recurrence at 12 months (area under the curve [AUC] = 0.91). Logistic regression revealed that titanium fixation, Rockwood type V, older age, and impaired bone healing capacity were significant risk factors for complications. The XGBoost model highlighted surgical technique and tissue quality as key predictors of functional recovery, though its external generalizability warrants further validation.
CONCLUSIONS: Compared to conventional titanium-based fixation, autologous tendon graft reconstruction yields superior joint stability, improved radiographic outcomes, and better functional scores within 12 months postoperatively, suggesting more favorable early clinical efficacy and biomechanical restoration.

Keywords: autologous tendon graft; acromioclavicular joint dislocation; functional evaluation; extreme gradient boosting; biomechanical stability

Introduction

Acromioclavicular (AC) joint dislocation is a common injury of the shoulder girdle, typically resulting from direct impact or a fall onto the shoulder, frequently encountered in sports trauma and traffic accidents [1]. The Rockwood classification system categorizes AC dislocations into six types, with type III–V often involving complete ligamentous disruption, for which conservative treatment typically fails to restore adequate shoulder stability and function [2]. A longitudinal study indicated that untreated high-grade dislocations may progress to subacromial impingement, scapular dyskinesis, and chronic pain, significantly impairing quality of life and physical performance [3].

Conventional surgical reconstruction of the AC joint predominantly employs rigid internal fixation using distal clav-

Submitted: 1 July 2025 Revised: 12 August 2025 Accepted: 25 August 2025 Published: 10 November 2025
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icle locking plates or titanium screws. However, these implants are associated with complications, including hardware loosening, fatigue failure, and the need for secondary removal surgery. Moreover, rigid fixation may disrupt ligament tension balance and generate stress concentrations at the bone-implant interface [4–6]. Recently, anatomical reconstruction with autologous tendon grafts, targeting both the coracoclavicular and acromioclavicular ligaments, has gained recognition as a biologically favorable alternative. This technique aims to restore the biomechanical integrity of the AC complex while promoting native bone-tendon healing [7–9]. Preliminary biomechanical investigations indicate that autografts perform comparably or even superiorly to synthetic constructs in terms of fatigue resistance and complication profile [10]. However, robust clinical evidence on the long-term safety and efficacy of autologous tendon grafting remains limited.

To address this knowledge gap, we performed a single-center retrospective cohort study comparing autologous tendon graft reconstruction with conventional titanium fixation in patients with Rockwood type III–V AC joint dislocations. By employing propensity score matching (PSM) to adjust for baseline confounders and integrating radiological, functional, biomechanical, and machine learning analyses, this study aimed to generate comprehensive evidence on postoperative joint stability, pain relief, complication rates, and long-term functional recovery. The findings are expected to inform surgical decision-making and guide the development of individualized perioperative management strategies.

Materials and Methods

Study Design and Patient Selection

This single-center retrospective cohort study compared the clinical efficacy, biomechanical performance, and prognostic outcomes of autologous tendon grafting versus conventional titanium fixation in patients with Rockwood type III–V AC joint dislocations. The study period extended from January 2019 to March 2024. Data were extracted from the institutional orthopedic electronic medical record and imaging archive systems. Ethical approval was granted by the Ethics Committee of Tongliao People's Hospital (Approval No. TLPH-EC-2025-68). As this was a retrospective study based on anonymized clinical data, the requirement for informed consent was waived. The study adhered to the principles outlined in the Declaration of Helsinki.

A total of 276 eligible patients were identified, comprising 157 who underwent autologous tendon reconstruction and 119 treated with titanium fixation. To minimize selection bias, PSM was applied, resulting in 87 matched patients in each group for final analysis.

Inclusion criteria were: (1) age 18–60 years; (2) radiographically confirmed Rockwood type III–V AC joint dislocation; (3) first-time surgical reconstruction, with anatomically confirmed graft placement in the autologous tendon group; and (4) minimum postoperative follow-up of 12 months.

Exclusion criteria were: (1) polytrauma or concurrent traumatic brain injury; (2) history of previous shoulder surgery; (3) severe comorbidities (e.g., rheumatoid arthritis, advanced cardiopulmonary disease) that might influence functional evaluation; and (4) incomplete follow-up or missing critical outcome data.

Surgical Procedures

All procedures were performed by a senior orthopedic surgical team experienced in AC joint reconstruction, ensuring standardized operative techniques and consistency of outcomes. In the autologous tendon group, either the ipsilateral semitendinosus or gracilis tendon was harvested from the lower limb for reconstruction. Under general anesthesia, the graft was retrieved through a small incision at the posteromedial aspect of the knee. The tendon choice was guided by intraoperative evaluation of graft morphology, quality, and length: the gracilis tendon was preferred if its morphology was favorable and accessible; otherwise, the semitendinosus tendon was used, particularly in cases of gracilis hypoplasia or anatomical variation. Dual graft harvest was performed when necessary. Harvested tendons were decellularized, pre-tensioned, and trimmed to a standardized length of 60–80 mm and diameter of 4–6 mm for double-bundle anatomical reconstruction [11].

The reconstruction technique employed a "tunnel-passing method" for anatomical double-bundle reconstruction of the coracoclavicular (CC) and AC ligaments. Bone tunnels (4–5 mm diameter) were drilled in the coracoid base and lateral clavicle. The processed graft was passed through the tunnels. Fixation strategy was tailored based on intraoperative bone quality and tunnel stability: Endobutton suspension devices were used when bone stock was adequate and central tunnel alignment stable, whereas titanium interference screws with washers were employed in mild osteoporosis or cortical irregularities [12]. Intraoperative fluoroscopy assessed AC distance and graft tension, with preloading adjustments to maintain 15–20 N. Joint reduction was confirmed post-fixation, and the wound was closed in layers with placement of a vacuum drain. No bone cement or biological adhesives were applied.

In the titanium fixation (control) group, patients underwent standard open reduction and internal fixation without ligament reconstruction [13]. Through an AC joint-oriented incision under general anesthesia, the distal clavicle was exposed. Fixation was guided by bone quality and stability: patients with osteoporotic bone or distal comminution received locking plate-screw constructs, whereas those with preserved anatomy and sufficient bone stock received a single 2.5 mm titanium transfixation pin. Fluoroscopy was used to confirm reduction, followed by layered closure and drain placement.

Postoperative Rehabilitation and Follow-Up

Rehabilitation was standardized across both groups. During the first 4 weeks, patients wore shoulder immobilizers (Velpeau sling or shoulder abduction brace) to restrict active motion. From week 5, passive-assisted exercises were initiated under physiotherapist supervision, including shoulder pendulum movements and scapular stabilization drills. Active training commenced at week 8, incorporating resistance-based movements and neuromuscular control exercises. Pain was monitored using the visual analog scale (VAS), alongside documentation of range of motion (ROM) progression.

Follow-up assessments were scheduled at 1, 6, and 12 months postoperatively. Evaluations included radiographic measurement of acromioclavicular distance (ACD) and coracoclavicular distance (CCD) via X-ray, MRI assessment of tendon signal intensity and bone tunnel integrity, clinical scoring (Constant-Murley, University of California at Los Angeles (UCLA), VAS), biomechanical parameters (ROM loss, horizontal motion displacement [HMD], and CCD maintenance rate), and surveillance for complications (redislocation, implant failure, wound infection).

Outcome Measures

All postoperative data, including imaging and functional assessments, were retrieved from the institutional electronic medical record system and outpatient follow-up archives. To ensure consistency and objectivity in data collection, functional scores, including Constant-Murley, UCLA, and VAS, as well as imaging parameters (coracoclavicular distance [CCD], acromioclavicular distance [ACD], HMD, and tendon signal intensity), were independently evaluated by two trained researchers using standardized protocols and validated assessment tools. In cases of interobserver disagreement, a senior orthopedic specialist with over 10 years of experience in shoulder and elbow surgery reviewed the data. Final values were determined through consensus discussion within the study team.

Radiological Parameters

All patients underwent preoperative, early postoperative (1 week), and 12-month follow-up imaging, including standard radiographs, computed tomography (CT), and magnetic resonance imaging (MRI). The following parameters were evaluated:

ACD: Measured on anteroposterior radiographs as the vertical distance between the clavicle and acromion, reflecting AC joint alignment and stability.

CCD: Measured as the vertical distance between the coracoid process and clavicle, used to evaluate CC ligament reconstruction integrity.

Axial stability of the AC joint: Determined on axial radiographs to assess residual joint instability.

Tendon signal intensity on MRI: Evaluated graft integrity, incorporation, and healing at the tendon-bone interface.

Bone remodeling score: Bone remodeling was qualitatively assessed at 12 months postoperatively by MRI of the bone-graft interface. The scoring system examined new bone formation along the tunnel margins, signal intensity patterns, and the extent of graft integration. Criteria were adapted from established anterior cruciate ligament (ACL) tunnel healing frameworks [14], notably the classification by Ge *et al*. [14], where low signal intensity indicates favorable healing and diffuse high signal reflects poor integration, as well as the coracoclavicular ligament healing assessment by Ihara *et al*. [15]. Specifically, a score of 0 indicates no visible evidence of bone remodeling; 1 denotes localized bone formation; 2 represents partial cortical fusion or moderate osseous ingrowth; and 3 reflects extensive bone remodeling with blurred tunnel margins or clear cortical reconstruction and graft incorporation.

Functional Assessment

Functional outcomes were evaluated using three standardized tools: the Constant-Murley shoulder score, the UCLA shoulder rating scale, and the visual analog scale for pain.

The Constant-Murley score is a 100-point composite tool assessing shoulder function across four domains: pain, range of motion, strength, and daily activities [16,17]. A higher score indicates better shoulder function. The UCLA shoulder rating scale is a 35-point measure of shoulder pain and functional capacity, with higher scores indicating better outcomes [18,19]. Pain intensity was further assessed using VAS, a 10-point patient-reported scale, where 0 represents no pain and 10 indicates the worst imaginable pain [20].

Biomechanical Performance

Biomechanical performance was assessed using radiographic and clinical parameters, including HMD, ROM loss rate, and CCD maintenance ratio at early (1 week) and mid-term (12 months) postoperative intervals. All measurements were derived from imaging and clinical documentation recorded at baseline and follow-up visits. Quantitative analysis was independently performed by two evaluators using the institutional Picture Archiving and Communication System (PACS), and results were expressed in millimeters or percentages. Discrepancies were resolved through consultation with an experienced orthopedic surgeon.

HMD: Defined as the horizontal offset of the distal clavicle relative to the acromion on axial shoulder radiographs. Measurements were obtained preoperatively, and at 1-week and 12-month time points using PACS digital tools to assess transverse joint stability. Results were reported in millimeters (mm).

ROM Loss Rate: Calculated as the percentage reduction in active shoulder flexion and abduction between baseline and 12-month follow-up. ROM values were obtained from standardized clinical records. The formula applied was:

Loss Rate (%) = (Preoperative ROM − Postoperative ROM)/Preoperative ROM $\times$ 100.

CCD Maintenance Ratio: Used to evaluate longitudinal joint stability, defined as the ratio of CCD at 12 months to CCD at 1 week postoperatively. CCD was measured on standardized anteroposterior radiographs using PACS tools. The formula was:

CCD Maintenance (%) = CCD at 12 months/CCD at 1 week $\times$ 100.

Complication Monitoring

Postoperative complications were systematically documented, including redislocation, wound infection, graft failure, clavicle fracture, and screw loosening. All complications were evaluated by attending orthopedic surgeons during scheduled follow-up visits and recorded in standardized follow-up charts.

Statistical Analysis

Data Presentation and Comparative Analyses

To reduce potential confounding from baseline imbalances, PSM was applied. Propensity scores were estimated using logistic regression incorporating age, sex, Rockwood classification, critical shoulder angle (CSA), and baseline functional scores. Scores were logit-transformed and matched 1:1 using a nearest-neighbor algorithm with a caliper of 0.1 standard deviations (SD) of the logit. Post-matching balance was evaluated by standardized mean differences (SMDs), with SMD $<$0.1 considered acceptable balance. All PSM analyses were performed in R (version 4.3.2; R Foundation for Statistical Computing) using the MatchIt package (version 4.5.2).

Matched datasets were used for subsequent analyses. Continuous variables were reported as mean $\pm$ standard deviation ($\bar{x} \pm$ SD) based on their distribution, while categorical variables were reported as counts (n) and percentages (%) (n [%]). The Shapiro-Wilk test assessed the normality of continuous variables. Normally distributed variables were compared with Student's *t*-test, while categorical variables were analyzed using chi-square or Fisher's exact tests, as appropriate. All statistical analyses and machine learning modeling were performed using R (version 4.3.2, R Foundation for Statistical Computing, Vienna, Austria) and Python (version 3.11.4, Python Software Foundation, Wilmington, DE, USA). All tests were two-sided, with $p < 0.05$ considered statistically significant.

Cox Proportional Hazards Modeling

Survival outcomes were evaluated using a Cox proportional hazards model implemented in R (survival package, version 3.5-8, R Foundation for Statistical Computing, Vienna, Austria), integrating survival time, event status, and relevant covariates to evaluate their prognostic significance. Model discrimination was quantified with the concordance index (C-index). The optimal cut-off for the RiskScore was determined using the maximally selected rank statistics method (maxstat package, version 0.7-25, R Foundation for Statistical Computing, Vienna, Austria), constraining group proportions between 25% and 75%, and stratifying patients into high- and low-risk groups. Kaplan-Meier survival curves were generated with the survfit function (survival package, version 3.5-8, R Foundation for Statistical Computing, Vienna, Austria), and differences between groups were assessed using the log-rank test. Receiver operating characteristic (ROC) curves at 5-, 9-, and 12-month intervals were constructed with the pROC package (version 1.18.5, R Foundation for Statistical Computing, Vienna, Austria), with corresponding area under the curve (AUC) and 95% confidence intervals calculated to evaluate model stability and predictive accuracy.

Logistic Regression for Complication Risk

Postoperative complications were modeled as the dependent variable within a logistic regression framework to identify independent predictors. The dataset was randomly divided into training (70%) and testing (30%) subsets, with potential confounders such as sex and dominant shoulder included as covariates. Univariate analyses were first performed in the training set, and variables with $p < 0.05$ were subsequently entered into a multivariable logistic regression model using the Enter method. Effects were expressed as odds ratios (ORs) with 95% confidence intervals (CIs). Model performance was validated in the testing set, with discrimination assessed by ROC-AUC, calibration examined through the Hosmer-Lemeshow test and calibration curves, and clinical utility quantified using decision curve analysis (DCA).

Extreme Gradient Boosting (XGBoost)-Based Prediction of Functional Recovery

An extreme gradient boosting (XGBoost) model was constructed to predict 12-month postoperative functional outcomes (Constant-Murley score $\geq$85 coded as 1; $<$85 coded as 0). Candidate variables were first screened using univariate logistic regression ($p < 0.05$), and those with multicollinearity (variance inflation factor $>$ 5) were excluded. Clinically relevant variables that remained after this process were included as model features. The model was implemented in Python (XGBoost package, version 1.7.6, Python Software Foundation, Wilmington, DE, USA), with 80% of the data allocated for training and 20% for independent testing. Hyperparameters, including learning rate, maximum depth, gamma, and subsample ratio, were optimized using five-fold cross-validation and grid search within the training set. Model performance was evaluated by ROC-AUC in both training and testing sets. Feature importance was calculated using the SHapley Additive exPlanations (SHAP) algorithm (version 0.44.1, Python Software Foundation, Wilmington, DE, USA) to quantify each variable's contribution to model output, and a feature importance plot was generated to visualize the relative influence of predictors on postoperative functional recovery.

Table 1. Baseline characteristics of patients in the autograft and titanium groups before and after PSM.

Variable	Before PSM					After PSM				
	Autograft group (n = 157)	Titanium group (n = 119)	Statistic	*p*-value	SMD	Autograft group (n = 87)	Titanium group (n = 87)	Statistic	*p*-value	SMD
Age (mean ± SD, years)	34.02 ± 8.74	40.29 ± 10.44	t = –5.427	<0.001	0.601	37.12 ± 8.24	37.95 ± 9.57	t = –0.617	0.538	0.087
BMI (mean ± SD, km/m^2)	24.46 ± 2.68	25.09 ± 3.11	t = –1.800	0.073	0.202	24.95 ± 2.54	24.68 ± 3.08	t = 0.612	0.541	–0.085
Injury mechanism, n (%)			χ^2 = 13.497	0.001				χ^2 = 0.035	0.983	
Fall	58 (36.94)	35 (29.41)			–0.165	29 (33.33)	29 (33.33)			0.0001
Sports	41 (26.11)	56 (47.06)			0.420	32 (36.78)	33 (37.93)			0.024
Traffic	58 (36.94)	28 (23.53)			–0.316	26 (29.89)	25 (28.74)			–0.025
Rockwood type, n (%)			χ^2 = 7.964	0.019				χ^2 = 0.376	0.829	
III	40 (25.48)	49 (41.18)			0.319	27 (31.03)	27 (31.03)			0.000
IV	84 (53.50)	53 (44.54)			–0.180	42 (48.28)	45 (51.72)			0.069
V	33 (21.02)	17 (14.29)			–0.192	18 (20.69)	15 (17.24)			–0.091
Gender, n (%)			χ^2 = 0.014	0.907				χ^2 = 0.045	0.500	
Female	36 (22.93)	28 (23.53)			0.014	21 (24.14)	18 (20.69)			0.083
Male	121 (77.07)	91 (76.47)			–0.014	66 (75.86)	69 (79.31)			–0.083
Dominant shoulder, n (%)			χ^2 = 11.965	<0.001				χ^2 = 0.060	0.412	
Right	47 (29.94)	60 (50.42)			0.410	36 (41.38)	37 (42.53)			–0.046
Left	110 (70.06)	59 (49.58)			–0.410	51 (58.62)	50 (57.47)			0.046

Notes: t, t-test; χ^2, Chi-square test; PSM, propensity score matching; SMD, standardized mean difference; BMI, body mass index.

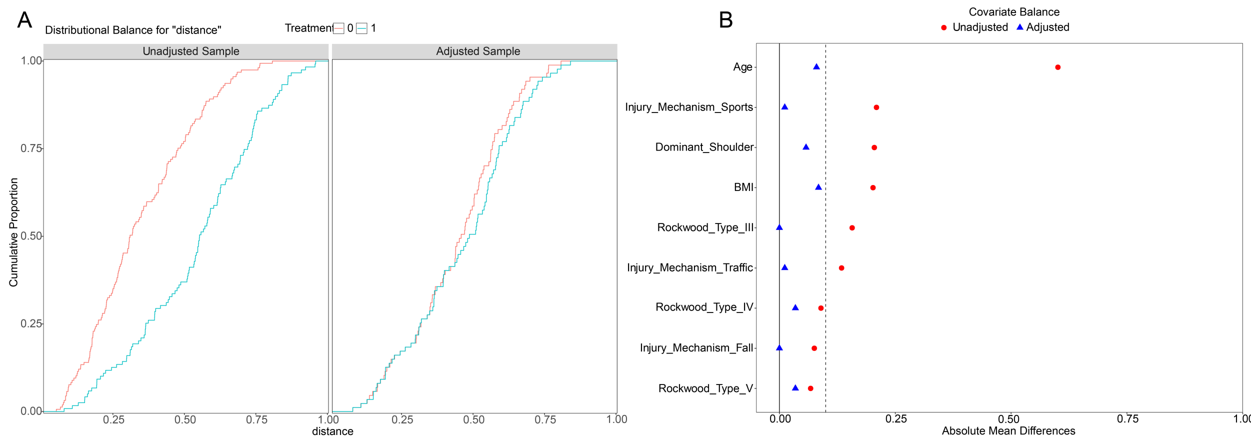

Fig. 1. Propensity score matching results. (A) Distribution of propensity scores before and after matching. (B) Standardized mean differences (SMDs) for baseline covariates before and after matching.

Table 2. Incidence of postoperative complications in the autograft and titanium groups (matched cohort, n = 174).

Complication type	Autograft group (n = 87)	Titanium group (n = 87)	Statistic	*p*-value
Redislocation, n (%)	3 (3.45)	10 (11.49)	$\chi^2 = 4.07$	0.044
Wound infection, n (%)	4 (4.60)	7 (8.05)	$\chi^2 = 0.87$	0.350
Graft failure, n (%)	1 (1.15)	8 (9.20)	$\chi^2 = 4.22$	0.040
Clavicle fracture, n (%)	2 (2.30)	8 (9.20)	$\chi^2 = 3.82$	0.051
Screw loosening, n (%)	1 (1.15)	4 (4.60)	$\chi^2 = 0.82$	0.364

Notes: χ^2, Chi-square test.

Results

Patient Characteristics and Propensity Score Matching

A total of 276 patients who underwent AC joint reconstruction were enrolled in this study, comprising 157 in the autologous tendon group and 119 in the titanium reconstruction group. To minimize potential confounding bias, 1:1 propensity score matching was performed based on key baseline variables. After matching, 87 patients remained in each group (Table 1). Before matching, significant intergroup differences were observed. Patients in the titanium group were older on average (40.29 ± 10.44 vs. 34.02 ± 8.74 years, $p < 0.001$; standardized mean difference [SMD] = 0.601), had a higher incidence of sports-related injuries (47.06% vs. 26.11%), and a greater prevalence of Rockwood type III dislocations (41.18% vs. 25.48%, $p = 0.019$). Conversely, dominant-side shoulder involvement was more common in the titanium group (50.42% vs. 29.94%, $p < 0.001$).

Following matching, baseline characteristics were well-balanced between groups, with no statistically significant differences (all $p > 0.05$), and SMDs for all covariates below 0.10, confirming adequate comparability. Variables including age, body mass index (BMI), sex distribution, injury mechanism, Rockwood classification, and affected side were comparable post-matching. The density plot of propensity scores (Fig. 1A) demonstrated improved overlap, and SMD plots (Fig. 1B) confirmed reduced baseline imbalance across covariates.

Radiological Recovery and Biomechanical Stability

In the matched cohort (n = 87 in each group), postoperative radiological and biomechanical outcomes showed significant improvement in both groups. However, the degree of recovery varied according to the surgical technique (Fig. 2). The autologous tendon group achieved greater improvement in acromioclavicular distance (ACD, $p = 0.002$) and coracoclavicular distance (CCD, $p = 0.01$) compared to the titanium group. Axial stability scores also improved more markedly in the autologous tendon group ($p < 0.001$), indicating superior joint stabilization.

Furthermore, graft signal intensity on postoperative imaging was significantly higher in the autologous tendon group ($p < 0.001$), whereas the titanium group exhibited reduced signal intensity. Bone remodeling scores were also greater in the autologous tendon group ($p < 0.001$), suggesting enhanced physiological bone healing processes.

Additional analyses revealed significantly better HMD and reduced loss of range of motion (ROM loss) in the autologous tendon group ($p < 0.001$ for both), indicating superior biomechanical stability and functional preservation. The CCD maintenance rate was also higher in the autologous tendon group ($p < 0.001$), further supporting the long-term anatomical durability of this reconstruction method.

Clinical Functional Recovery and Complications

Functional outcomes improved significantly in both groups following surgery, with greater benefits observed in the

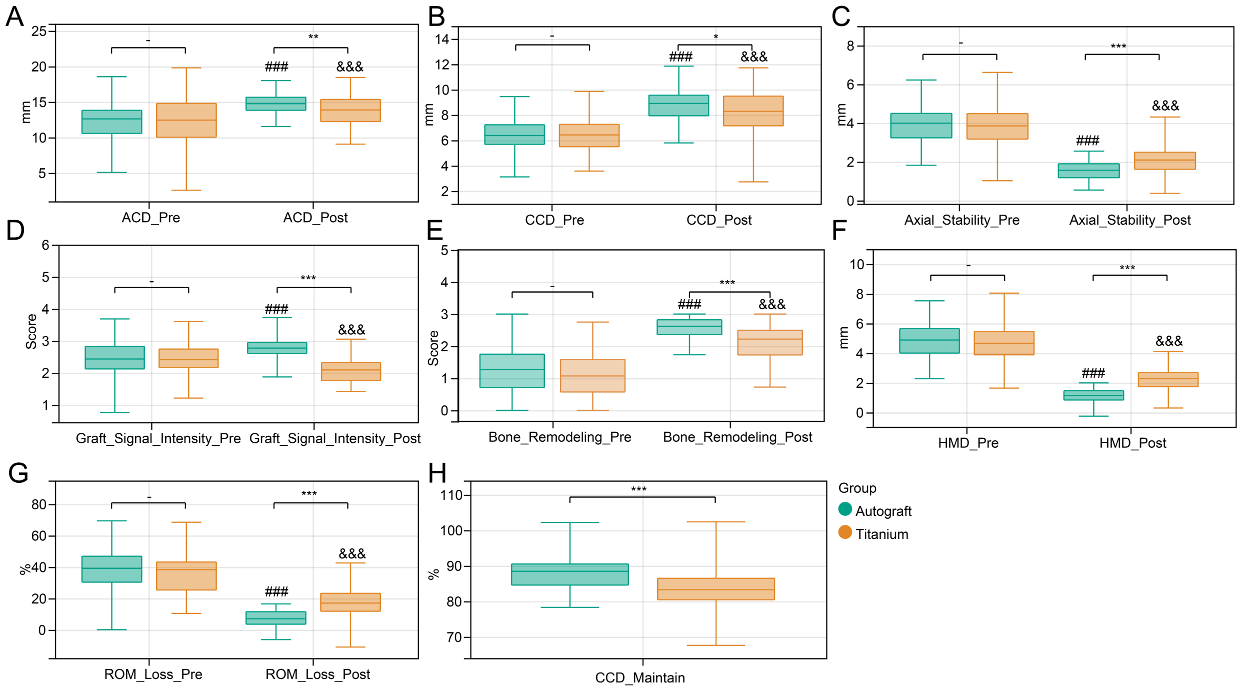

Fig. 2. Radiological and biomechanical outcomes pre- and post-surgery. (A) Changes in acromioclavicular distance (ACD). (B) Changes in coracoclavicular distance (CCD). (C) Axial stability improvement. (D) Tendon signal intensity. (E) Bone remodeling score. (F) Horizontal motion displacement (HMD) postoperatively. (G) Range of motion (ROM) loss. (H) CCD maintenance rate. Group comparisons: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; "–" indicates no significant difference. Within-group comparisons: Autograft group, pre- vs. post-surgery: $^{\#\#\#}p < 0.001$; Titanium group, pre- vs. post-surgery: $^{\&\&\&}p < 0.001$.

autologous tendon group. The Constant-Murley score increased more substantially ($p < 0.001$), and the UCLA shoulder score likewise favored the autologous tendon group ($p < 0.001$), reflecting superior outcomes in pain relief, strength, and mobility. VAS scores indicated significantly less postoperative pain in the autologous tendon group ($p < 0.001$), suggesting a more comfortable recovery process (Fig. 3).

No major infections or disabling complications were reported in either group. However, complication profiles differed meaningfully. The autologous tendon group exhibited a significantly lower incidence of redislocation (p = 0.044) and graft failure (p = 0.040), indicating enhanced structural integrity. Differences in clavicle fracture incidence approached statistical significance (p = 0.051), again favoring the autologous tendon group. No significant group differences were observed in screw loosening or wound infection rates (Table 2).

Risk Prediction of Recurrent Dislocation Using Cox Proportional Hazards Model

A multivariable Cox proportional hazards model was constructed to identify predictors of postoperative redislocation. Four independent prognostic variables were retained in the final model: preoperative coracoclavicular distance (CCD_Pre, hazard ratio (HR) = 0.35, p = 0.0014), Rockwood classification (types IV-V vs. type III, HR = 1.89, p = 0.0042), surgical method (autograft vs. titanium, HR = 0.31, p = 0.0108), and preoperative range-of-motion loss (ROM_Loss_Pre, HR = 1.06, p = 0.0099) (Fig. 4A).

The resulting risk score model demonstrated strong predictive performance. Time-dependent ROC curve analyses revealed areas under the curve of 0.90, 0.92, and 0.91 at 5, 9, and 12 months postoperatively, respectively, indicating consistently high predictive accuracy over time (Fig. 4B). Patients were stratified into high-risk (H) and low-risk (L) groups based on the median risk score. Kaplan–Meier survival analysis revealed a marked difference in redislocation-free survival between the two groups (Fig. 4C). At 12 months, redislocation was rare in the low-risk group, whereas the high-risk group showed a significantly elevated recurrence rate (HR = 16.48, $p < 0.001$).

Independent Predictors of Postoperative Complications: Logistic Regression Analysis

Univariate logistic regression was performed in the training cohort to identify potential risk factors for postoperative complications (Table 3). All analyses were conducted using the matched cohort of 174 patients. Seven significant variables were included in the multivariate model, of which four independent predictors remained in the final analysis. The other three variables lost their significance after adjusting for confounding variables (Table 4). Compared with autograft reconstruction, titanium-based fixation emerged as a

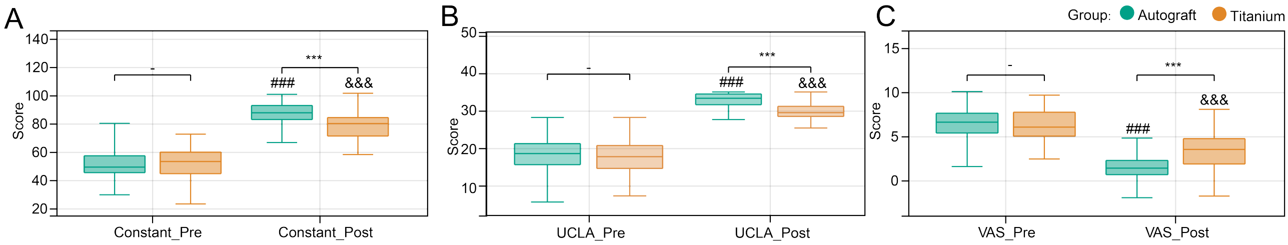

Fig. 3. Functional outcomes following surgery. (A) Change in Constant-Murley score. (B) Change in University of California at Los Angeles (UCLA) score. (C) Change in visual analogue scale (VAS) pain score. Group comparisons: $^{***}p < 0.001$; "–" indicates no significant difference. Within-group comparisons: Autograft group, pre- vs. post-surgery: $^{\#\#\#}p < 0.001$; Titanium group, pre- vs. post-surgery: $^{\&\&\&}p < 0.001$.

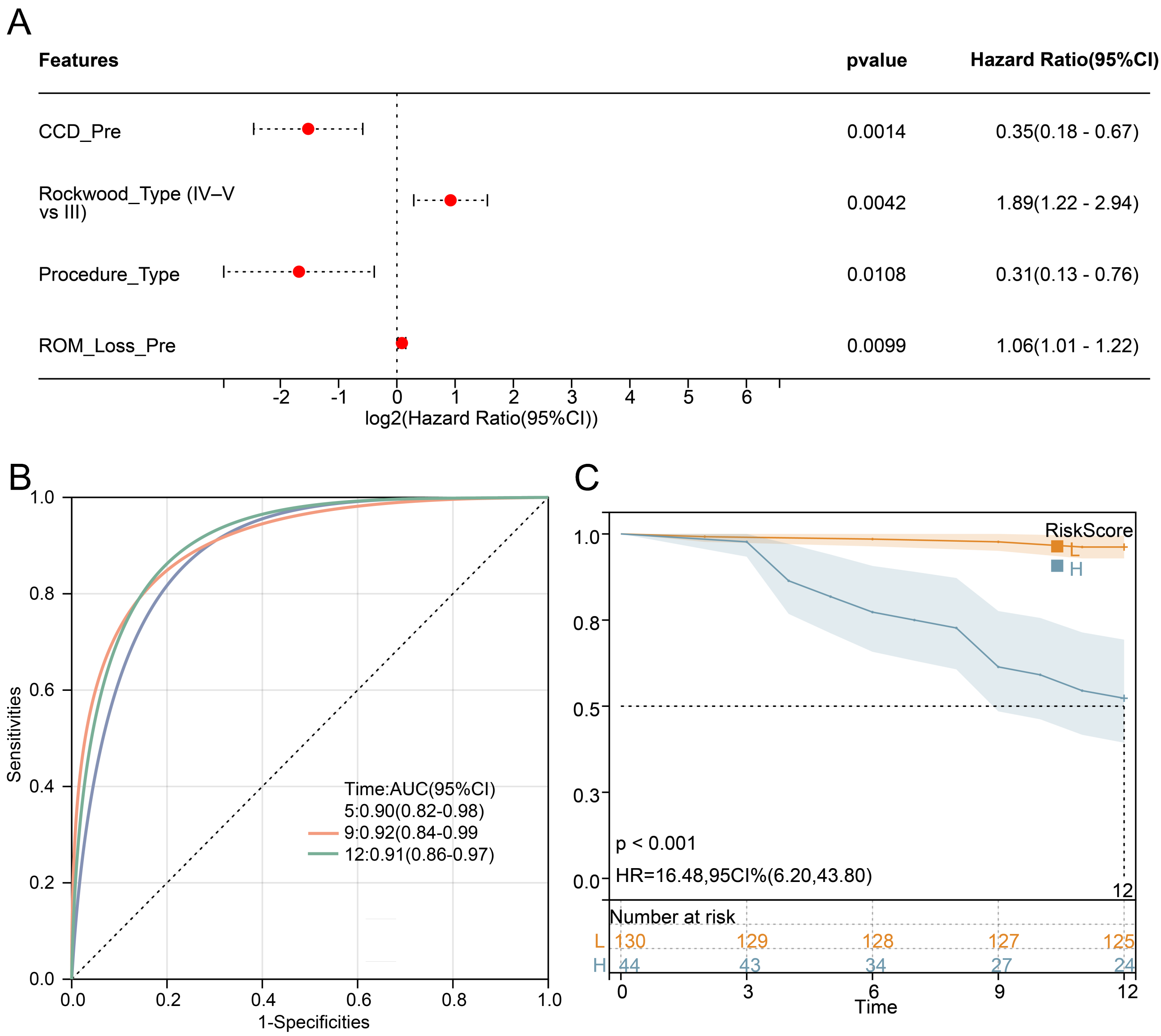

Fig. 4. Predictive performance of the multivariable Cox model for redislocation risk. (A) Forest plot of hazard ratios from the multivariable Cox regression. (B) Time-dependent receiver operating characteristic (ROC) curves at 5, 9, and 12 months postoperatively. (C) Kaplan–Meier curves stratified by predicted risk scores (L = low-risk group; H = high-risk group). AUC, area under the curve; HR, hazard ratio.

Table 3. Univariate logistic regression analysis (matched cohort, n = 174).

Variables	β	S.E	Z	p-value	OR (95% CI)
Procedure type					
Autograft					1.00 (reference)
Titanium	1.02	0.45	2.27	0.023	2.77 (1.15–6.67)
Injury mechanism					
Fall					1.00 (reference)
Sports	0.61	0.31	1.97	0.049	1.84 (1.00–3.40)
Traffic	0.17	0.38	0.45	0.655	1.19 (0.57–2.52)
Rockwood type					
III					1.00 (reference)
IV	0.25	0.47	0.53	0.596	1.29 (0.51–3.25)
V	0.73	0.35	2.09	0.037	2.08 (1.05–4.13)
Age	0.04	0.02	2.08	0.037	1.04 (1.00–1.08)
BMI	–0.07	0.04	–1.65	0.099	0.93 (0.85–1.01)
HMD pre	–0.14	0.20	–0.70	0.485	0.87 (0.59–1.27)
ROM loss pre	0.02	0.01	1.71	0.088	1.02 (0.99–1.04)
ACD pre	0.11	0.05	2.21	0.027	1.12 (1.01–1.24)
CCD pre	–0.01	0.16	–0.06	0.952	0.99 (0.73–1.35)
Axial stability pre	–0.08	0.20	–0.40	0.691	0.92 (0.62–1.36)
Tendon signal intensity pre	–0.89	0.45	–1.98	0.048	0.41 (0.17–0.98)
Bone remodeling pre	–0.72	0.34	–2.12	0.034	0.49 (0.25–0.94)
Constant pre	–0.03	0.02	–1.50	0.134	0.97 (0.93–1.01)
UCLA pre	0.01	0.05	0.20	0.841	1.01 (0.92–1.11)
VAS pre	–0.11	0.13	–0.85	0.396	0.90 (0.69–1.18)

Notes: β, regression coefficient; Z, Wald statistic. OR, odds ratio.

Table 4. Multivariable logistic regression analysis (matched cohort, n = 174).

Variables	β	S.E.	Z	p-value	OR (95% CI)
Procedure type					
Titanium vs. autograft	0.86	0.42	2.05	0.040	2.36 (1.04–5.34)
Rockwood type V vs. III	0.65	0.31	2.10	0.036	1.91 (1.04–3.53)
ACD pre	0.09	0.04	2.10	0.036	1.10 (1.01–1.20)
Bone remodeling pre	–0.59	0.28	–2.11	0.035	0.55 (0.32–0.95)

Notes: β, regression coefficient; Z, Wald statistic.

significant risk factor for complications (odds ratio (OR) = 2.36, 95% CI: 1.04–5.34, p = 0.040). Additional independent predictors included Rockwood type V injuries (OR = 1.91, 95% CI: 1.04–3.53, p = 0.036) and greater postoperative ACD (OR = 1.10, 95% CI: 1.01–1.20, p = 0.036). In contrast, higher preoperative bone remodeling capacity was identified as a protective factor (OR = 0.55, 95% CI: 0.32–0.95, p = 0.035).

Based on the multivariate findings, a risk-scoring model was developed and validated in both the training and internal validation cohorts (Fig. 5). The model demonstrated strong discriminative performance, with an area under the receiver operating characteristic curve of 0.81 in the training set and 0.78 in the validation set (Fig. 5A–C). Calibration analysis showed good agreement, with Hosmer-Lemeshow test p-values of 0.430 and 0.342 in the training and validation cohorts, respectively, indicating good model calibration. Minor deviations from the ideal calibration line in certain probability ranges (Fig. 5E) indicated slight over- or underestimation, offering a more nuanced assessment of the model performance (Fig. 5D,E). Decision curve analysis (DCA) further confirmed that the model yielded greater net clinical benefit compared to "treat-all" or "treat-none" strategies across a broad range of threshold probabilities (Fig. 5F,G), supporting its potential utility in clinical decision-making.

Model performance metrics are summarized in Table 5. In the training cohort, predictive accuracy reached 70%, with a sensitivity of 65% and specificity of 89%. In the validation cohort, accuracy improved to 76%, with a sensitivity of 72% and specificity of 86%. Positive predictive value (PPV) was high in both cohorts (95% in training, 94% in validation), while negative predictive value (NPV) was relatively lower (41% and 52%, respectively). The cut-off value for both groups is 0.17.

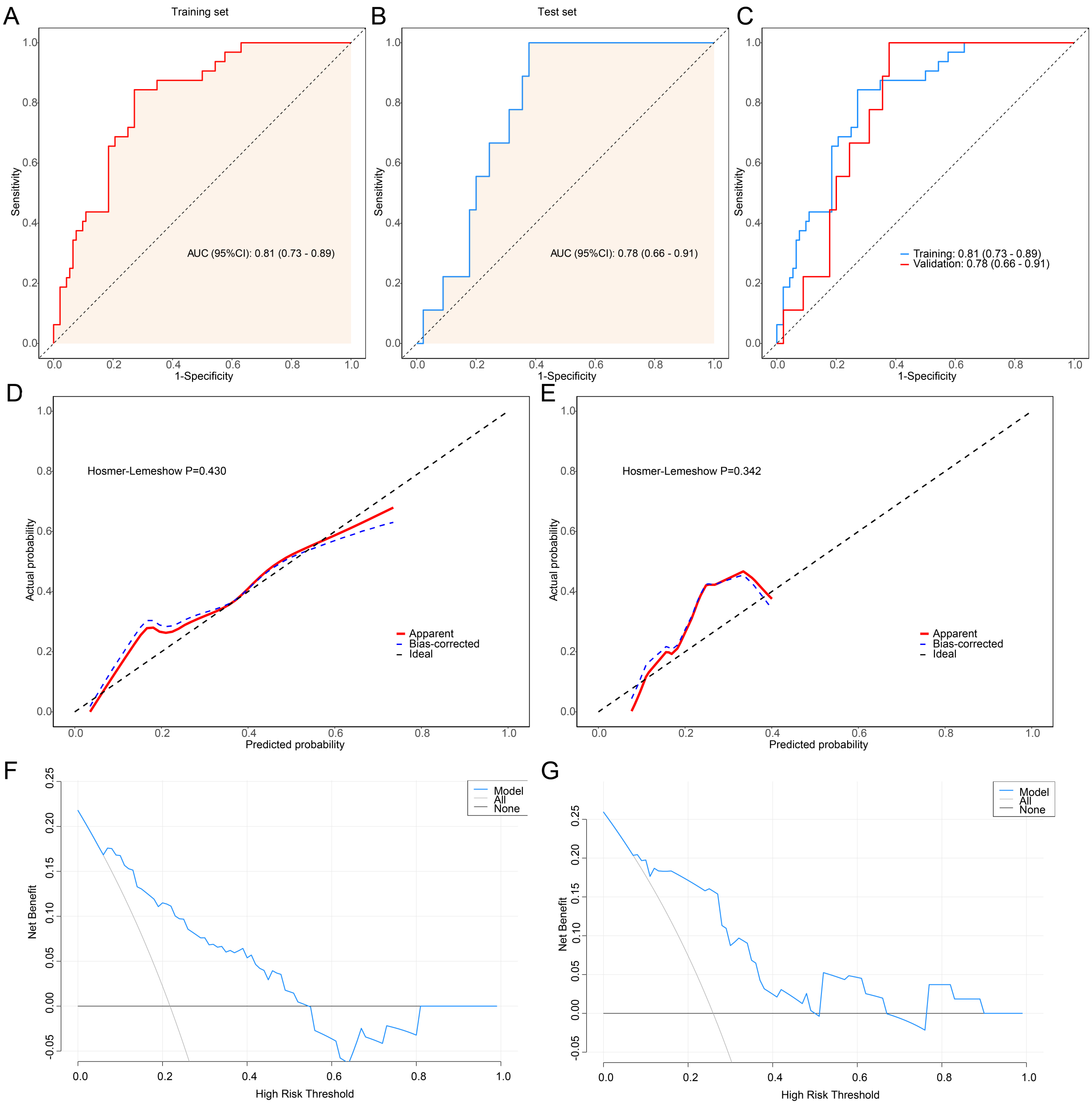

Fig. 5. Performance and validation of the complication prediction model. (A–C) ROC curves and AUC values for training and test cohorts. (D,E) Calibration curves and Hosmer–Lemeshow goodness-of-fit tests. The red line represents apparent predictions, the blue line shows bias-corrected predictions, and the black dashed line indicates the ideal reference. (F,G) Decision curve analysis showing net clinical benefit across varying risk thresholds.

Table 5. Confusion matrix and model performance in training and validation sets.

Data	AUC (95% CI)	Accuracy (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Cut-off
Training	0.81 (0.73–0.89)	0.70 (0.61–0.78)	0.65 (0.55–0.74)	0.89 (0.77–1.00)	0.95 (0.90–1.00)	0.41 (0.29–0.54)	0.17
Validation	0.78 (0.66–0.91)	0.76 (0.62–0.87)	0.72 (0.59–0.86)	0.86 (0.67–1.00)	0.94 (0.85–1.00)	0.52 (0.32–0.73)	0.17

Notes: PPV, positive predictive value; NPV, negative predictive value.

Machine Learning-Based Prediction of Functional Recovery at 12 Months

To enhance individualized prediction of long-term functional outcomes, an XGBoost-based machine learning model was developed to estimate Constant–Murley scores at 12 months postoperatively. The model achieved an AUC of 0.83 in the training cohort and 0.78 in the validation cohort, indicating strong fit and generalizability (Fig. 6A). SHAP analysis identified surgical technique as the most influential predictor, followed by preoperative bone remod-

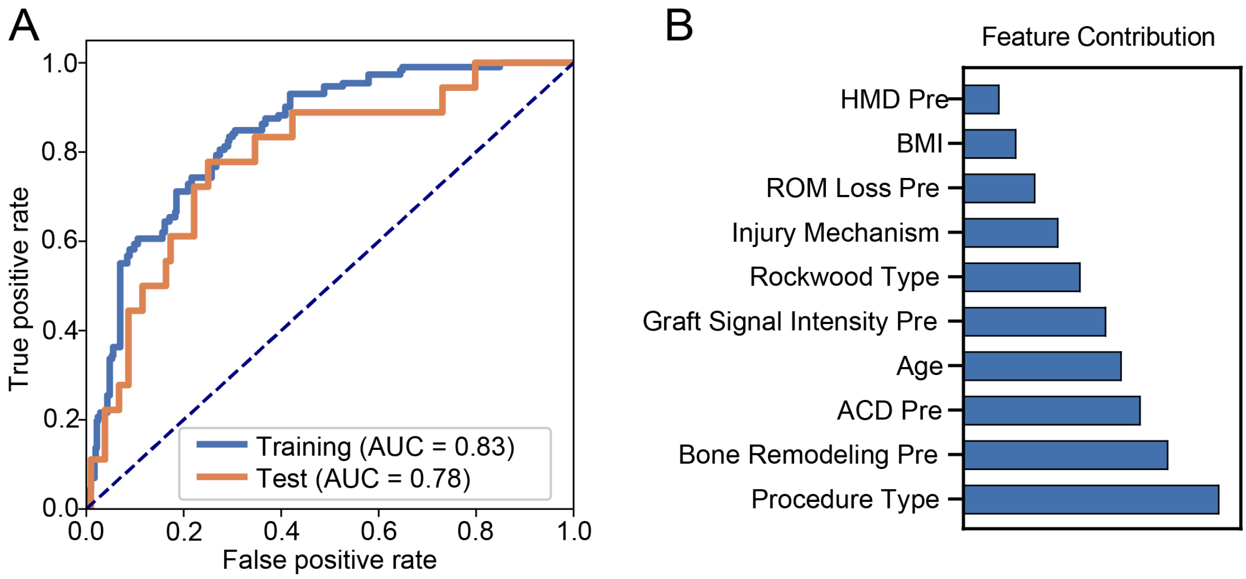

Fig. 6. Machine learning-based model for predicting 12-month functional recovery. (A) ROC curves for training and validation datasets. (B) Feature importance rankings showing relative contributions of predictive variables.

eling score, preoperative ACD, patient age, and tendon signal intensity (Fig. 6B). Moderately important predictors included Rockwood classification, mechanism of injury, and preoperative range-of-motion limitation. By contrast, BMI and preoperative HMD contributed minimally to the predictive model.

Discussion

This study systematically compared the clinical outcomes, biomechanical performance, and long-term prognosis of autograft tendon reconstruction versus conventional titanium fixation in patients with Rockwood type III–V AC joint dislocations. Based on propensity score-matched analyses, the autologous tendon group demonstrated superior outcomes in anatomical restoration, joint stability, functional recovery, and complication control compared with the titanium fixation group. By integrating conventional statistical approaches with machine learning techniques, we developed a recurrence risk prediction model using Cox regression and a postoperative complication prediction model using logistic regression combined with XGBoost algorithms. Surgical approach, preoperative structural parameters, and injury severity were identified as key predictive variables. Both models exhibited robust discrimination and calibration performance in validation cohorts.

AC joint stability is maintained by a complex ligamentous network, primarily comprising the AC ligaments and the CC ligaments, which include the conoid and trapezoid components. Biomechanical evidence indicates that anatomical reconstruction with tendon grafts more accurately replicates the native mechanical properties of the ligament [21]. In our study, postoperative radiographic and biomechanical assessments supported this, as the autologous tendon group demonstrated significantly better ACD restoration and axial stability scores. Although the titanium group achieved satisfactory initial reduction, minor displacement was observed in some patients during long-term follow-up. These findings align with a laboratory study showing that anatomical reconstruction restores near-normal anteroposterior and rotational stability [22].

Tauber *et al*. [23] previously reported that anatomical reconstruction using tendon grafts results in superior clinical and radiological outcomes compared with non-anatomical techniques. Biomechanical *in vitro* studies further confirm this, demonstrating that reconstructions with semitendinosus or gracilis autografts possess tensile strength comparable to native CC ligaments and exhibit higher initial stiffness than traditional fixation methods. Failures typically occur within the graft substance rather than at fixation sites, indicating favorable structural durability [24]. In contrast, titanium screw fixation (or double-loop techniques), though less invasive and technically straightforward, relies solely on mechanical constraint. This may result in overtightening or subtle micromotion, thereby disrupting physiological load transfer within the scapular girdle. Such alterations may underlie residual pain or functional limitations observed in a subset of patients [25]. Therefore, autograft reconstruction may provide superior long-term outcomes in individuals with high functional demands, whereas titanium fixation remains a viable option for achieving immediate stability and minimizing early complications.

In terms of functional recovery, the autologous tendon group achieved significantly better outcomes than the titanium fixation group, demonstrated by higher Constant–Murley and UCLA scores and lower VAS pain scores. These findings underscore the superiority of tendon reconstruction in pain control, range of motion recovery, and restoration of muscle strength. Ulusoy *et al*. [26] reported that reconstruction of the coracoclavicular ligaments with tendon grafts resulted in satisfactory UCLA scores, marked pain reduction, and no major complications. Similarly, a comparative study of allograft tendon reconstruction versus hook plate fixation showed that, at six months postoperatively, the graft group achieved higher Constant–Murley scores, greater shoulder mobility, and significantly reduced early postoperative pain ($p < 0.001$) [27]. Unlike titanium fixation, which provides only passive mechanical stability, autologous tendon grafts offer dynamic, active stabilization. They restore anatomical integrity while promoting proprioceptive feedback and neuromuscular coordination of the acromioclavicular complex. Notably, the autologous tendon group exhibited superior control of HMD and reduced ROM loss, suggesting enhanced resistance to torsional and tensile stresses during functional loading.

Although both techniques demonstrated acceptable safety profiles, their complication patterns differed. In the titanium group, hardware-related complications were prevalent, including screw loosening, soft tissue irritation, and, in some cases, the need for hardware removal, consistent with previous reports [28]. Residual discomfort and mechanical irritation were likely related to limited implant biocompatibility and altered bone-loading dynamics. In contrast, the autologous tendon group avoided implant-related complications but involved risks associated with graft harvesting, including donor site pain, graft fatigue, or elongation [29]. In our cohort, graft failure and hematoma were rare, possibly due to gradual biological integration and remodeling of the autograft. However, transosseous drilling of the clavicle and coracoid introduces a theoretical risk of iatrogenic fracture [30], although no such events were observed, highlighting the importance of surgical expertise. In summary, titanium fixation is primarily associated with hardware-related complications, while tendon reconstruction carries risks related to graft harvesting and tunnel preparation. Each method presents a distinct risk-benefit profile, and surgical decision-making should be individualized based on patient anatomy, functional requirements, and surgeon proficiency.

Both Cox regression and machine learning analyses confirmed the critical influence of surgical strategy on long-term outcomes. Surgical technique, preoperative CCD, Rockwood classification, and preoperative ROM limitation emerged as independent predictors of postoperative redislocation. An increased CCD reflects a significant disruption of the coracoclavicular complex, compromising the ability to sustain postoperative reduction. Similarly, higher-grade Rockwood types (IV–V) reflect more severe injury patterns, consistent with previously reported gradients of redislocation risk [27]. Logistic regression analysis further identified surgical technique, Rockwood classification, and widened ACD as significant predictors of postoperative complications. Conversely, the potential for bone remodeling was associated with reduced complication rates, likely due to modulation of local inflammation mediated by autografts. As the composite endpoint encompassed a broader spectrum of postoperative events, variable selection was based on univariate analysis for each endpoint. Consequently, some variables significant in the Cox model were excluded from the complication analysis, reflecting differences in predictor relevance across distinct outcomes.

We further explored the utility of an XGBoost model for predicting 12-month postoperative functional outcomes. The model demonstrated robust performance, with area under the curve values of 0.83 in the training set and 0.78 in the validation set, indicating acceptable generalizability. Notably, the principal predictive variables identified by the XGBoost model were consistent with those highlighted in Cox and logistic regression analyses, underscoring the effectiveness of the model in feature extraction and its potential to uncover underlying clinical mechanisms. To strengthen its clinical utility, future research should incorporate larger, multicenter datasets and examine a broader range of reconstruction techniques and graft types (e.g., allografts, synthetic ligaments) to validate and refine the external stability and clinical applicability.

This study has several limitations. First, as a single-center retrospective analysis, although PSM was applied to adjust for certain confounders, key prognostic covariates such as injury mechanism and BMI were not included in the matching process. This may have resulted in an incomplete balance at the PSM level and residual confounding. Future investigations should prospectively collect and incorporate a broader range of prognostic variables at the study design stage, and apply more advanced matching techniques (e.g., multivariable propensity scores, weighting methods) to further minimize residual bias. Second, variability in surgeon expertise and patient-specific factors may have influenced clinical outcomes. Third, although follow-up emphasized shoulder function and procedure-related complications, donor site outcomes, such as pain, muscle weakness, or local discomfort following hamstring tendon harvest, were not systematically evaluated. The lack of donor site surveillance may underestimate the overall morbidity associated with autograft reconstruction. Future research should incorporate long-term functional evaluation of donor sites to more accurately characterize the complete risk-benefit profile. Moreover, both radiographic and functional assessments were limited to a 12-month timeframe, limiting evaluation of long-term structural integrity and joint function at 2 or 5 years. Biomechanical assessments were based on imaging-derived parameters and lacked *in vitro* validation or dynamic motion analysis. Incorporating finite element modeling or real-time kinematic tracking in future studies may yield deeper insights into AC joint mechanics across reconstruction techniques. Finally, to enhance the assessment of patient-centered outcomes, future prospective studies should include standardized patient-reported outcome measures (PROMs), such as the SF-36, and systematically collect representative imaging from typical surgical cases and major complications. These additions would provide a more comprehensive understanding of surgical efficacy and patient experience, thereby improving the translational value of the findings.

Conclusions

Based on 12-month follow-up data, this study demonstrates that autologous tendon graft reconstruction offers superior anatomical reduction, biomechanical stability, and functional recovery compared to conventional titanium fixation in high-grade acromioclavicular joint dislocations. These benefits are particularly evident in younger patients with favorable tissue quality and higher functional demands. Since this study primarily reflects short-term postoperative outcomes, the long-term integrity and complication profiles remain to be validated. Nevertheless, the present findings support broader clinical adoption of tendon graft techniques and highlight the potential value of integrating individualized predictive tools into preoperative decision-making.

Availability of Data and Materials

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contributions

DXZ and YJY were responsible for study design, data curation, statistical analysis, and drafting the manuscript. RX and SLH participated in data collection and quality control. YHL and TJM contributed to the literature review and preliminary data analysis. HRCZ and HZ were involved in study design, clinical data interpretation, and figure preparation. ZJJ and YTY contributed to the study design, provided technical support, and helped revise the manuscript. HXS contributed to study conception, methodological supervision, and critical revision of the manuscript. FY conceived and designed the entire study, supervised all stages of the work, and reviewed all drafts. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Tongliao People's Hospital (Approval No. TLPH-EC-2025-68). As this was a retrospective study based on anonymized clinical data, the requirement for informed consent was waived. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki.

Acknowledgment

Not applicable.

Funding

Not applicable.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Cañete San Pastor P, Prosper Ramos I, Lopez Valenciano J, Copete I. Arthroscopic Treatment of Chronic Acromioclavicular Dislocation With Semitendinosus Autograft and Coracoclavicular Suspension Fixation. Arthroscopy Techniques. 2022; 11: e1779–e1785. https://doi.org/10.1016/j.eats.2022.06.014.

[2] Borbas P, Angelella D, Laux CJ, Bachmann E, Ernstbrunner L, Bouaicha S, *et al*. Acromioclavicular joint stabilization with a double cow-hitch technique compared to a double tight-rope: a biomechanical study. Archives of Orthopaedic and Trauma Surgery. 2022; 142: 1309–1315. https://doi.org/10.1007/s00402-021-03774-7.

[3] Dursun M, Altun G, Ozsahin M. SURGICAL TREATMENT OF ACROMIOCLAVICULAR DISLOCATION: HOOK PLATE VERSUS SUTURE BUTTON. Acta Ortopedica Brasileira. 2023; 31: e252916. https://doi.org/10.1590/1413-785220233101e252916.

[4] Velasquez Garcia A, Abdo G. Reliability of the ISAKOS Modification to Subclassify Rockwood Type III Acromioclavicular Joint Injuries. Orthopaedic Journal of Sports Medicine. 2022; 10: 23259671221133379. https://doi.org/10.1177/23259671221133379.

[5] Choi JH, Chun YM, Yoon TH. Effect of cigarette smoking on the maintenance of reduction after treatment of acute acromioclavicular joint dislocation with hook plate fixation. Clinics in Shoulder and Elbow. 2023; 26: 373–379. https://doi.org/10.5397/cise.2023.00738.

[6] Dündar A, İpek D. Comparison of the Hook Plate versus TightRope System in the Treatment of Acute Type III Acromioclavicular Dislocation. Advances in Orthopedics. 2022; 2022: 8706638. https://doi.org/10.1155/2022/8706638.

[7] Gao R, Zhang W, Yang Y, Zhang Y, Hu Y, Wu H, *et al*. Evaluation of the coracoid bone tunnel placement on Dog Bone™ button fixation for acromioclavicular joint dislocation: a cadaver study combined with finite element analysis. BMC Musculoskeletal Disorders. 2023; 24: 18. https://doi.org/10.1186/s12891-022-06119-6.

[8] Patel MS, Hill BW, Casey P, Abboud JA. Modified Weaver-Dunn Technique Using Transosseous Bone Tunnels and Coracoid Suture Augmentation. The Journal of the American Academy of Orthopaedic Surgeons. 2022; 30: 111–118. https://doi.org/10.5435/JAAOS-D-21-00732.

[9] Focsa LC, Plomion M, Vignes J, Rousseau MA, Boyer P. Quality and stability of reduction of operated acromioclavicular dislocation using dual acromioclavicular and coracoclavicular stabilization. Orthopaedics & Traumatology, Surgery & Research: OTSR. 2024; 110: 103789. https://doi.org/10.1016/j.otsr.2023.103789.

[10] Ye G, Peng CA, Sun HB, Xiao J, Zhu K. Treatment of Rockwood type III acromioclavicular joint dislocation using autogenous semitendinosus tendon graft and endobutton technique. Therapeutics and Clinical Risk Management. 2016; 12: 47–51. https://doi.org/10.2147/TCRM.S81829.

[11] Ranne JO, Sarimo JJ, Rawlins MI, Heinonen OJ, Orava SY. All-arthroscopic double-bundle coracoclavicular ligament reconstruction using autogenous semitendinosus graft: a new technique.

Arthroscopy Techniques. 2012; 1: e11–4. https://doi.org/10.1016/j.eats.2011.12.006.

[12] Maia Dias C, Leite MJ, Ribeiro da Silva M, Granate P, Manuel Teixeira J. Arthroscopic Anatomical Acromioclavicular Joint Reconstruction using a Button Device and a Semitendinosus Graft. Orthopaedic Surgery. 2022; 14: 605–612. https://doi.org/10.1111/os.13202.

[13] Chen YT, Wu KT, Jhan SW, Hsu SL, Liu HC, Wang CJ, *et al*. Is coracoclavicular reconstruction necessary in hook plate fixation for acute unstable acromioclavicular dislocation? BMC Musculoskeletal Disorders. 2021; 22: 127. https://doi.org/10.1186/s12891-021-03978-3.

[14] Ge Y, Li H, Tao H, Hua Y, Chen J, Chen S. Comparison of tendon-bone healing between autografts and allografts after anterior cruciate ligament reconstruction using magnetic resonance imaging. Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA. 2015; 23: 954–960. https://doi.org/10.1007/s00167-013-2755-x.

[15] Ihara H, Miwa M, Deya K, Torisu K. MRI of anterior cruciate ligament healing. Journal of Computer Assisted Tomography. 1996; 20: 317–321. https://doi.org/10.1097/00004728-199603000-00029.

[16] Razmjou H, Bean A, Macdermid JC, van Osnabrugge V, Travers N, Holtby R. Convergent validity of the constant-murley outcome measure in patients with rotator cuff disease. Physiotherapy Canada. Physiotherapie Canada. 2008; 60: 72–79. https://doi.org/10.3138/physio/60/1/72.

[17] Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clinical Orthopaedics and Related Research. 1987; 160–164.

[18] Ellman H, Kay SP. Arthroscopic subacromial decompression for chronic impingement. Two- to five-year results. The Journal of Bone and Joint Surgery British Volume. 1991; 73: 395–398. https://doi.org/10.1302/0301-620X.73B3.1670435.

[19] Amstutz HC, Sew Hoy AL, Clarke IC. UCLA anatomic total shoulder arthroplasty. Clinical Orthopaedics and Related Research. 1981; 7–20.

[20] Roach KE, Budiman-Mak E, Songsiridej N, Lertratanakul Y. Development of a shoulder pain and disability index. Arthritis Care and Research: the Official Journal of the Arthritis Health Professions Association. 1991; 4: 143–149.

[21] Jari R, Costic RS, Rodosky MW, Debski RE. Biomechanical function of surgical procedures for acromioclavicular joint dislocations. Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association. 2004; 20: 237–245. https://doi.org/10.1016/j.arthro.2004.01.011.

[22] Hislop P, Sakata K, Ackland DC, Gotmaker R, Evans MC. Acromioclavicular Joint Stabilization: A Biomechanical Study of Bidirectional Stability and Strength. Orthopaedic Journal of Sports Medicine. 2019; 7: 2325967119836751. https://doi.org/10.1177/2325967119836751.

[23] Tauber M, Gordon K, Koller H, Fox M, Resch H. Semitendinosus tendon graft versus a modified Weaver-Dunn procedure for acromioclavicular joint reconstruction in chronic cases: a prospective comparative study. The American Journal of Sports Medicine. 2009; 37: 181–190. https://doi.org/10.1177/0363546508323255.

[24] Lee SJ, Nicholas SJ, Akizuki KH, McHugh MP, Kremenic IJ, Ben-Avi S. Reconstruction of the coracoclavicular ligaments with tendon grafts: a comparative biomechanical study. The American Journal of Sports Medicine. 2003; 31: 648–655. https://doi.org/10.1177/03635465030310050301.

[25] Lee CY, Chen PC, Liu YC, Tsai YC, Chou PH, Fu YC, *et al*. Does coracoclavicular augmentation additional to hook plate fixation provide benefits in acute unstable acromioclavicular dislocation? A meta-analysis. BMC Musculoskeletal Disorders. 2022; 23: 205. https://doi.org/10.1186/s12891-022-05142-x.

[26] Ulusoy A, Turgut N, Cilli F, Unal AM. Reconstruction of Coracoclavicular Ligaments with Semitendinosus Autograft and Temporary Kirschner Wires is a good option for Chronic Acromioclavicular Joint Instability. Malaysian Orthopaedic Journal. 2024; 18: 99–105. https://doi.org/10.5704/MOJ.2403.013.

[27] Du B, Xu Y, Li Z, Ji S, Ren C, Li M, *et al*. Efficacy of allogeneic tendon material coracoclavicular ligament reconstruction combined with Kirschner wire and titanium alloy hook plate material fixation in the treatment of acromioclavicular joint dislocation. Frontiers in Bioengineering and Biotechnology. 2024; 12: 1388905. https://doi.org/10.3389/fbioe.2024.1388905.

[28] Kim SH, Koh KH. Treatment of Rockwood Type III Acromioclavicular Joint Dislocation. Clinics in Shoulder and Elbow. 2018; 21: 48–55. https://doi.org/10.5397/cise.2018.21.1.48.

[29] Lee BK, Jamgochian GC, Syed UAM, Getz CL, Dodson CC, Namdari S, *et al*. Reconstruction of Acute Acromioclavicular (AC) Joint Dislocations with or without Tendon Graft: a Retrospective Comparative Study. The Archives of Bone and Joint Surgery. 2019; 7: 239–245.

[30] Martetschläger F, Saier T, Weigert A, Herbst E, Winkler M, Henschel J, *et al*. Effect of Coracoid Drilling for Acromioclavicular Joint Reconstruction Techniques on Coracoid Fracture Risk: A Biomechanical Study. Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association. 2016; 32: 982–987. https://doi.org/10.1016/j.arthro.2015.11.049.