Am J Transl Res 2026;18(8):7236-7258
www.ajtr.org /ISSN:1943-8141/AJTR0170977

Original Article

Effect of fibular rotation and sagittal shift on postoperative function in ankle fractures with syndesmotic injury

Jianliang Li[1], Xingzhang Yao[1], Jia Wang[2], Jiwei Zhang[1], Hui Yao[1], Chun Yang[3], Bingyang Fan[3], Yanlong Jia[3]

[1]Repair and Reconstruction Department of Orthopedics, Gansu Province Hospital OF TCM, No. 418, Guazhou Road, Qilihe District, Lanzhou 730050, Gansu, China; [2]Thi Third Department of Spinal Orthopedic, Gansu Province Hospital OF TCM, No. 418, Guazhou Road, Qilihe District, Lanzhou 730050, Gansu, China; [3]Department of Sports Medicine, Yanan City Traditional Chinese Medicine Hospital, No. 26, Xuanyuan Avenue, New District, Baota District, Yan'an 716000, Shaanxi, China

Received December 23, 2025; Accepted March 10, 2026; Epub August 15, 2026; Published August 30, 2026

Abstract: Objectives: To evaluate whether postoperative radiographic and functional outcomes in ankle fractures with syndesmotic injury are associated with a CT-based grading system based on fibular rotation (FR) and sagittal shift distance (SSD), and to assess the influence of surgical timing and patient-related factors on prognosis. Methods: This retrospective cohort study included 370 patients with ankle fractures and syndesmotic injury treated with open reduction and internal fixation between June 2021 and September 2024. Based on preoperative CT measurements, patients were classified into three groups: Group A (FR < 5° and SSD < 2 mm), Group B (5° ≤ FR ≤ 10° or 2 mm ≤ SSD ≤ 5 mm), and Group C (FR > 10° or SSD > 5 mm). Radiographic reduction quality, loss of reduction at 6 months, functional outcomes (SF-36, AOFAS, VAS, ankle range of motion), complications, and reoperations were compared. Inverse probability of treatment weighting and propensity score matching were applied. Multivariate logistic regression was used to identify independent predictors of poor prognosis (final AOFAS < 80), and interaction analyses were performed. Results: Patients with high-grade syndesmotic malalignment (Group C) had significantly poorer radiographic reduction, higher rates of loss of reduction, complications, and reoperation, and inferior functional outcomes compared to Groups A and B (all P < 0.001). Multivariate analysis identified older age, surgical delay, diabetes, higher body mass index, Weber C fracture, posterior malleolar fracture, and loss of reduction at 6 months as independent risk factors for poor prognosis. A significant interaction was observed between syndesmotic injury grade and surgical delay. Conclusions: CT-based FR/SSD grading is useful for identifying high-risk syndesmotic malalignment in ankle fracture. Postoperative outcomes are primarily influenced by patient characteristics, fracture pattern, surgical timing, and maintenance of reduction, underscoring the importance of timely surgery and stable syndesmotic reduction, particularly for more severe injuries.

Keywords: Syndesmotic injury, ankle fracture, fibular rotation, sagittal shift distance, surgical delay, prognosis

Introduction

Syndesmotic injury is one of the most important complicating factors in ankle fractures and plays a critical role in maintaining ankle mortise alignment, load transmission, and normal joint range of motion [1]. Once the distal tibiofibular syndesmosis becomes unstable or is inadequately reduced, joint contact stress increases markedly, which may subsequently lead to persistent pain and post-traumatic ankle arthritis, as highlighted in a review by Chi et al. [2]. Recent prospective studies have reported that approximately 18% of ankle sprains and 23% of ankle fractures are associated with distal tibiofibular syndesmotic instability, suggesting that the incidence of syndesmotic injury in ankle trauma is substantially higher than traditionally appreciated [3]. Systematic reviews further indicate that syndesmotic involvement occurs in approximately 10%-20% of ankle fractures, and that failure to recognize or adequately reduce such injuries is associated with significantly impaired long-term functional outcomes [4].

https://doi.org/10.62347/VQHK9706

In current clinical practice, radiographic grading and intraoperative assessment remain the primary methods for evaluating the extent and stability of syndesmotic injury. Previous studies have demonstrated that syndesmotic widening, fibular rotational malalignment, or sagittal plane displacement - even after internal fixation - are frequently associated with limping, restricted weight bearing, and early development of post-traumatic osteoarthritis [5]. Vohra et al. [6] emphasized that subtle malalignment is often underestimated on conventional radiographs, whereas computed tomography (CT) or three-dimensional imaging allows more sensitive detection of rotational and sagittal abnormalities, which have been shown to correlate closely with deterioration in functional outcome measures such as the American Orthopaedic Foot and Ankle Society (AOFAS) score [7]. However, the quantitative relationship between different grades of syndesmotic injury and postoperative prognosis remains incompletely understood. Most existing studies dichotomize patients based on the presence or absence of syndesmotic injury or rely on simple imaging thresholds, which may fail to capture the combined severity of rotational and sagittal displacement.

Beyond injury characteristics, patient-specific factors and perioperative management also exert a substantial influence on postoperative outcome. Increasing age is associated with osteoporosis and reduced soft-tissue healing capacity, and has been linked to poorer functional recovery and a higher risk of joint stiffness following ankle fracture surgery [8]. Naumann et al. [9] reported that surgical delay was associated with prolonged hospitalization, increased complication rates, and lower functional scores at mid- to long-term follow-up, suggesting a potential time-dependent effect of surgical timing on prognosis. In patients with diabetes, meta-analytic evidence indicates that the overall complication rate after ankle fracture is approximately twice that of non-diabetic patients, with significantly higher risks of infection, nonunion, and even amputation [10]. These findings suggest that metabolic comorbidities may amplify the adverse prognostic effect of injury severity by impairing microcirculation and bone healing. Clinically, considerable heterogeneity is often observed among patients with similar syndesmotic injuries treated with comparable fixation methods, particularly with respect to pain relief, restoration of ankle motion, and time to return to work, indicating that prognosis cannot be adequately explained by a single risk factor or a simplistic grading system.

Based on these considerations, the present study proposes a three-tier (A/B/C) syndesmotic injury grading system based on fibular rotation (FR) and sagittal shift distance (SSD). We aimed to compare systematically the radiographic reduction quality and mid-term functional outcomes across different injury grades, and to explore interaction and potential mediation effects involving age, surgical delay, and diabetes. Through this approach, we sought to provide more refined evidence to support individualized surgical timing decisions and prognostic assessment in patients with ankle fracture complicated by syndesmotic injury.

Materials and methods

Study design and sample size estimation

This was a single-center retrospective cohort study. A total of 370 patients with ankle fractures and syndesmotic injury who received internal fixation at our institution between June 2021 and September 2024 were enrolled. Sample size estimation was based on previous research on unstable syndesmotic injury associated with ankle fractures. Lee et al. [11] reported in a prospective study that unstable syndesmotic injury occurred in approximately 28.6% (20/70) of ankle fracture patients. Using an expected incidence of P = 0.29, a two-sided significance level of $\alpha = 0.05$, a critical value of $Z_{0.975} = 1.96$, and a margin of error E = 0.05, the formula $N = Z^2 \times [P \times (1-P)]/E^2$ yielded a minimum required sample size of approximately 314 cases. The final enrollment of 370 patients met this requirement. In accordance with the Declaration of Helsinki [12], the Gansu Province Hospital OF TCM ethics committee approved the study protocol. Due to the retrospective nature of the study, informed consent was waived or simplified.

Inclusion and exclusion criteria

Inclusion criteria were: (1) age of 18 years or above; (2) first instance of traumatic ankle fracture with demonstrated syndesmotic injury on imaging; (3) received open reduction and internal fixation (ORIF) with preoperative ankle CT; and (4) postoperative follow-up duration of 6 months or longer along with complete clinical and radiographic data.

Exclusion criteria were: (1) pathological fractures or Gustilo type III open fractures; (2) previous ankle surgery or severe pre-existing ankle deformity or arthritis; (3) severe polytrauma requiring staged surgery or systemic conditions precluding standard rehabilitation; and (4) incomplete imaging data or CT image quality insufficient for precise measurement.

Diagnosis of distal tibiofibular syndesmotic injury

In this study, distal tibiofibular syndesmotic injury was diagnosed based on a comprehensive assessment combining preoperative imaging findings and intraoperative evaluation when applicable. All enrolled patients underwent preoperative ankle computed tomography (CT), which was systematically reviewed for evidence of syndesmotic disruption, including abnormal fibular rotation, sagittal displacement of the fibula relative to the tibia, or widening of the distal tibiofibular relationship compared with established reference values or the contralateral side. Patients demonstrating such imaging features were considered to have syndesmotic injury and were eligible for inclusion.

In cases where imaging findings were equivocal, intraoperative assessment of syndesmotic stability (such as hook testing or external rotation stress testing) was performed at the discretion of the operating surgeon to confirm instability. Final diagnosis was established by consensus between two experienced orthopaedic surgeons based on the overall clinical, radiographic, and intraoperative findings.

Grouping method

All enrolled patients underwent preoperative ankle CT. Based on the measured FR and sagittal shift distance (SSD), patients were classified as follows: Group A (low-grade displacement): FR < 5° and SSD < 2 mm (n = 142); Group B (moderate displacement): 5° ≤ FR ≤ 10° or 2 mm ≤ SSD ≤ 5 mm (n = 153); Group C (high-grade displacement): FR > 10° or SSD > 5 mm (n = 75). The degree of syndesmotic displacement was determined based on two key CT-derived parameters: FR and SSD, which reflect rotational and anteroposterior malalignment of the distal fibula relative to the tibia. These two components represent the principal planes of syndesmotic malreduction and have been shown to influence ankle mortise congruency and functional outcome.

The threshold values used for grouping were selected according to previously reported imaging-based criteria and commonly accepted clinical reference ranges. Minor FR (< 5°) and minimal sagittal displacement (< 2 mm) are generally considered to fall within physiological variation or acceptable reduction error, whereas rotational deformity exceeding 10° or sagittal displacement greater than 5 mm has been associated with clinically relevant syndesmotic malalignment and impaired ankle function. Intermediate values were therefore classified as moderate displacement to capture a transitional severity range. This pragmatic classification was designed to integrate both rotational and sagittal components of syndesmotic injury and to facilitate clinically meaningful stratification of injury severity.

Clinical and radiographic data collection

The following data were extracted from the electronic medical record system and picture archiving and communication system (PACS): general information including sex, age, body mass index (BMI), smoking history, diabetes, and other comorbidities; injury-related data including injured side, time from injury to surgery (days), and mechanism of injury (twisting, traffic accident, fall from height, sports injury, etc.); fracture characteristics including Weber classification (C = 1, B = 0), presence of posterior malleolar fracture, medial structure injury, and posterior tibial marginal fracture; surgical and follow-up data including surgical procedure, syndesmotic screw fixation status, postoperative complications (such as wound complications, implant-related complications, deep vein thrombosis), syndesmotic screw loosening, and loss of reduction at 6 months postoperatively; and radiographic parameters including preoperative and postoperative tibiofibular clear space (TFCS), tibiofibular overlap (TFO), restoration of normal FR (yes = 1, no = 0), and syndesmotic injury grade (Group A, B, or C).

Radiographic measurement methods

All patients underwent ankle radiography and CT both preoperatively and postoperatively. CT scanning was performed using a 64-slice spiral CT scanner (GE LightSpeed VCT, GE Healthcare, USA). Patients were positioned supine with the ankle in neutral position. Scanning parameters included tube voltage of 120 kV, tube current of 200-250 mA (automodulated), slice thickness of 0.625 mm, slice interval of 0.625 mm, rotation time of 0.5 s, matrix of 512 × 512, and field of view of 180-220 mm. Bone window reconstruction and multiplanar reconstruction (MPR) were applied.

FR was measured on the axial plane approximately 10 mm proximal to the tibial articular surface. The precise level was determined using MPR. A tibial axis was drawn connecting the anterior and posterior margins of the tibia, and a fibular axis was drawn similarly. The angle between these two axes defined the FR, which was compared with the contralateral side to assess fibular internal or external rotation. SSD was measured on sagittal reconstructed images using the anterior tibial margin as a reference line to determine the anteroposterior displacement of the fibula relative to the tibia. TFCS and TFO were measured at the level of the ankle mortise on anteroposterior radiographs or corresponding CT slices using standard methods and compared with the contralateral side.

To minimize measurement bias, all radiographic measurements were performed independently by two trained orthopaedic surgeons under blinded conditions. When discrepancies exceeded 10%, a third senior surgeon reviewed the images and determined the final values.

Functional scoring and ankle range of motion assessment

At the final follow-up, health-related quality of life was assessed using the Short Form-36 Health Survey (SF-36), a validated generic questionnaire consisting of 36 items covering eight domains of physical and mental health. The total SF-36 score ranges from 0 to 100, with higher scores indicating better overall health status and functional well-being. Pain intensity was evaluated using the visual analogue scale (VAS), which ranges from 0 to 10, where 0 represents no pain and 10 represents the worst pain imaginable. For both instruments, assessments were completed by patients at follow-up visits under standardized conditions. Ankle range of motion was assessed by measuring dorsiflexion and plantarflexion angles using a standard handheld goniometer. Measurements were performed with the patient in the supine position, with the knee in a neutral or slightly flexed position to minimize the influence of the gastrocnemius muscle. The axis of the goniometer was aligned with the lateral malleolus, the stationary arm aligned with the fibular shaft, and the moving arm aligned with the lateral border of the foot. Patients were instructed to actively perform maximal dorsiflexion and plantarflexion, and each measurement was repeated three times. The mean value was used for final analysis (Figure S1).

Outcome measures

Primary outcomes included: (1) postoperative and follow-up syndesmotic radiographic alignment, including postoperative TFCS and TFO values and their differences from the contralateral side, and whether FR was restored to normal; (2) occurrence of loss of reduction at 6 months postoperatively; and (3) classification of patients into good prognosis and poor prognosis groups based on whether the final American Orthopaedic Foot and Ankle Society (AOFAS) score (at ≥ 6 months) was ≥ 80 or < 80, to identify independent risk factors for poor outcome [13].

Secondary outcomes included: (1) SF-36 total score and VAS pain score at final follow-up; (2) ankle dorsiflexion and plantarflexion range of motion; and (3) overall complication rates, including wound complications, implant-related complications, deep vein thrombosis, and other recorded complications.

Statistical analysis

Statistical analyses were performed using R software version 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria) and SPSS version 27.0 (IBM Corp., Armonk, NY, USA). First, continuous variables were tested for normality. Normally distributed data were expressed as mean ± standard deviation (mean ± SD), with intergroup comparisons using one-way analysis of variance or t-tests. Non-normally distributed data were expressed as median (interquartile range), with intergroup comparisons using Kruskal-Wallis or Mann-Whitney U tests. Categorical variables were expressed as counts and percentages, with intergroup comparisons using chi-square tests or Fisher's exact tests.

To reduce the influence of baseline confounders on outcome comparisons among the FR/SSD groups, a multinomial logistic regression model was constructed in R to calculate propensity scores. Inverse probability of treatment weighting (IPTW) was then applied, and the balance of baseline covariates before and after weighting was assessed across the three groups. Based on the weighted data, univariate and multivariate logistic regression models were used to analyze independent associations between clinical and radiographic variables and outcome events. Odds ratios (OR) and 95% confidence intervals (CI) were calculated. All statistical tests were two-sided, with $P < 0.05$ considered significant.

Results

Baseline characteristics

No significant differences were observed among the three groups in age, sex, BMI, smoking history, alcohol consumption, diabetes, hypertension, or injured side (all $P > 0.05$) (**Table 1**). With respect to fracture-related variables, there was a difference in Weber classification ($P < 0.001$) with a higher distribution of Weber C fracture in case of high-grade displacement. Injury mechanism also differed significantly ($P < 0.001$); high-energy injuries and sports injuries were more common in Group C. With respect to medial structure involvement, medial malleolar fracture ($P = 0.008$), posterior malleolar fracture ($P < 0.001$), medial structure injury ($P < 0.001$), and posterior tibial marginal fracture ($P < 0.001$) all showed significant differences, with higher incidences in the high-grade group. Time from injury to surgery also differed significantly among the three groups ($P < 0.001$), with greater surgical delay observed in Group C (**Table 1**).

Intraoperative and postoperative radiographic reduction

Significant differences were found in immediate postoperative satisfactory reduction rates among the three groups ($P < 0.001$), with a notably higher proportion of unsatisfactory reduction in Group C. The rate of normal FR restoration also differed significantly ($P < 0.001$), with the highest incidence of rotational abnormality in the high-grade group. Sagittal plane reduction showed significant intergroup differences ($P < 0.001$), with sagittal malalignment more common in Group C. At 6-month follow-up, the proportion of loss of reduction differed significantly ($P < 0.001$), with markedly elevated risk in the high-grade group. The incidence of syndesmotic screw or fixation loosening also differed significantly ($P < 0.001$), being substantially higher in Group C. The proportion of abnormal syndesmotic interval at final follow-up also showed significant differences ($P < 0.001$). For radiographic measurements, postoperative TFCS and TFO both differed significantly among groups (both $P < 0.001$), with more pronounced syndesmotic malalignment in the high-grade group (**Table 2**).

SF-36 score comparison

No significant difference was observed in preoperative SF-36 total scores among the three groups ($P > 0.05$), indicating similar baseline functional status. Postoperative total scores in SF-36 were significantly different ($P < 0.001$) among groups with Group C demonstrating inadequate functional improvement. The overall improvement in SF-36 scores was significantly different among the groups ($P = 0.012$) with smallest improvement in the high-grade group. The comparison of the groups A and B was significant with each other. Within-group comparisons showed Group A and group B was significant. Group C significantly improved ($P = 0.006$) but it was a small effect (**Table 3**).

Functional outcomes at final follow-up

Significant differences in AOFAS scores were observed at final follow-up ($P < 0.001$), with notably lower scores in Group C. The rate of excellent or good AOFAS outcomes also differed significantly ($P < 0.001$), with a marked decline in the high-grade group. VAS pain scores at final follow-up differed significantly ($P < 0.001$), with higher pain levels in Group C. Regarding joint mobility, both dorsiflexion ($P < 0.001$) and plantarflexion ($P < 0.001$) angles showed significant intergroup differences, with more pronounced limitation in the high-grade group. Time to return to work also differed sig-

Table 1. Comparison of baseline characteristics among three groups

Variable	Total	Group A (n = 142)	Group B (n = 153)	Group C (n = 75)	Statistic	*P* value
Age (years)	48.91±13.06	48.51±13.15	49.19±12.95	49.07±13.28	0.105	0.9
Sex					0.747	0.688
Male	198 (53.51%)	72 (50.70%)	85 (55.56%)	41 (54.67%)		
Female	172 (46.49%)	70 (49.30%)	68 (44.44%)	34 (45.33%)		
BMI					5.749	0.056
≥ 25	118 (31.89%)	38 (26.76%)	48 (31.37%)	32 (42.67%)		
< 25	252 (68.11%)	104 (73.24%)	105 (68.63%)	43 (57.33%)		
Smoking history					1.884	0.39
Yes	87 (23.51%)	28 (19.72%)	39 (25.49%)	20 (26.67%)		
No	283 (76.49%)	114 (80.28%)	114 (74.51%)	55 (73.33%)		
Alcohol consumption					1.998	0.368
Yes	92 (24.86%)	30 (21.13%)	40 (26.14%)	22 (29.33%)		
No	278 (75.14%)	112 (78.87%)	113 (73.86%)	53 (70.67%)		
Diabetes					1.416	0.493
Yes	48 (12.97%)	15 (10.56%)	21 (13.73%)	12 (16.00%)		
No	322 (87.03%)	127 (89.44%)	132 (86.27%)	63 (84.00%)		
Hypertension					0.485	0.785
Yes	76 (20.54%)	28 (19.72%)	34 (22.22%)	14 (18.67%)		
No	294 (79.46%)	114 (80.28%)	119 (77.78%)	61 (81.33%)		
Weber classification					57.19	< 0.001
B	189 (51.08%)	105 (73.94%)	67 (43.79%)	17 (22.67%)		
C	181 (48.92%)	37 (26.06%)	86 (56.21%)	58 (77.33%)		
Injury mechanism					25.019	< 0.001
Twisting	211 (57.03%)	102 (71.83%)	80 (52.29%)	29 (38.67%)		
High-energy	104 (28.11%)	25 (17.61%)	50 (32.68%)	29 (38.67%)		
Sports	55 (14.86%)	15 (10.56%)	23 (15.03%)	17 (22.67%)		
Injured side					0.152	0.927
Left	192 (51.89%)	72 (50.70%)	80 (52.29%)	40 (53.33%)		
Right	178 (48.11%)	70 (49.30%)	73 (47.71%)	35 (46.67%)		
Medial malleolar fracture					9.754	0.008
Yes	178 (48.11%)	55 (38.73%)	78 (50.98%)	45 (60.00%)		
No	192 (51.89%)	87 (61.27%)	75 (49.02%)	30 (40.00%)		
Posterior malleolar fracture					49.632	< 0.001
Yes	105 (28.38%)	19 (13.38%)	42 (27.45%)	44 (58.67%)		
No	265 (71.62%)	123 (86.62%)	111 (72.55%)	31 (41.33%)		
Medial structure injury					34.432	< 0.001
Yes	150 (40.54%)	35 (24.65%)	66 (43.14%)	49 (65.33%)		
No	220 (59.46%)	107 (75.35%)	87 (56.86%)	26 (34.67%)		
Posterior tibial marginal fracture					67.597	< 0.001
Yes	113 (30.54%)	18 (12.68%)	45 (29.41%)	50 (66.67%)		
No	257 (69.46%)	124 (87.32%)	108 (70.59%)	25 (33.33%)		
Time from injury to surgery (days)	4.00 [3.00, 6.00]	4.00 [3.00, 5.00]	4.00 [3.00, 6.00]	7.00 [5.00, 8.00]	52.593	< 0.001

Note: BMI, body mass index; SSD, sagittal shift distance; FR, fibular rotation.

nificantly (P < 0.001), with substantially longer recovery time in Group C (**Table 4**).

Complications and reoperation

Significant differences existed in overall complication rates (P < 0.001), with markedly higher rates in the high-grade group. Loss of reduction (P < 0.001), refractory pain (P < 0.001), and post-traumatic osteoarthritis (P < 0.001) all showed significant intergroup differences, with substantially higher risk in Group C. Wound infection did not differ significantly among groups (P > 0.05). Reoperation rates differed

Table 2. Comparison of postoperative radiographic reduction and follow-up outcomes among the three groups

Variable	Total	Group A (n = 142)	Group B (n = 153)	Group C (n = 75)	Statistic	*P* value
Satisfactory immediate postoperative reduction					36.099	< 0.001
Yes	302 (81.62%)	130 (91.55%)	128 (83.66%)	44 (58.67%)		
No	68 (18.38%)	12 (8.45%)	25 (16.34%)	31 (41.33%)		
Normal fibular rotation restoration					46.257	< 0.001
Yes	276 (74.59%)	128 (90.14%)	112 (73.20%)	36 (48.00%)		
No	94 (25.41%)	14 (9.86%)	41 (26.80%)	39 (52.00%)		
Normal sagittal reduction (SSD < 2 mm)					30.623	< 0.001
Yes	291 (78.65%)	129 (90.85%)	118 (77.12%)	44 (58.67%)		
No	79 (21.35%)	13 (9.15%)	35 (22.88%)	31 (41.33%)		
Loss of reduction at 6 months					41.232	< 0.001
Yes	61 (16.49%)	9 (6.34%)	22 (14.38%)	30 (40.00%)		
No	309 (83.51%)	133 (93.66%)	131 (85.62%)	45 (60.00%)		
Syndesmotic screw/fixation loosening					35.674	< 0.001
Yes	48 (12.97%)	8 (5.63%)	15 (9.80%)	25 (33.33%)		
No	322 (87.03%)	134 (94.37%)	138 (90.20%)	50 (66.67%)		
Abnormal syndesmotic interval at final follow-up					49.713	< 0.001
Yes	72 (19.46%)	10 (7.04%)	27 (17.65%)	35 (46.67%)		
No	298 (80.54%)	132 (92.96%)	126 (82.35%)	40 (53.33%)		
Postoperative TFCS (mm)	3.27±0.86	2.86±0.59	3.22±0.77	4.15±0.85	77.938	< 0.001
Postoperative TFO (mm)	5.03±1.26	5.73±1.09	4.91±1.04	3.95±1.14	67.024	< 0.001

Note: TFCS, tibiofibular clear space; TFO, tibiofibular overlap; SSD, sagittal shift distance; FR, fibular rotation.

significantly (P < 0.001), with a notably higher proportion in the high-grade group. Analysis of reoperation causes showed significant differences in reoperation for loss of reduction (P < 0.001) and for post-traumatic osteoarthritis (P = 0.012). Reoperation for refractory pain did not differ significantly (P > 0.05) (**Table 5**).

Propensity score matching analysis

Given the significant baseline differences in certain variables among the three groups, propensity score matching (PSM) was performed to reduce confounding. At a caliper width of 0.20, the matched sample size was too small for subsequent analysis. After stepwise adjustment within the 0.20-0.30 caliper range, a caliper width of 0.24 yielded both a relatively large matched sample and elimination of all significant baseline differences among groups, representing optimal matching quality. The propensity score distribution showed marked intergroup differences before matching, while after matching the distributions overlapped substantially and baseline differences were greatly reduced (**Figure 1**).

Baseline characteristics after propensity score matching

Following PSM at a caliper width of 0.24, no significant differences remained among the three groups in any demographic variable (age, sex, BMI, smoking history, alcohol consumption, diabetes, hypertension), injury characteristics (mechanism, side), fracture-related parameters (Weber classification, medial malleolar fracture, posterior malleolar fracture, medial structure injury, posterior tibial marginal fracture), or time from injury to surgery (all P > 0.05). Balance was well achieved (**Table 6**).

Postoperative radiographic reduction after matching

After matching, significant differences persisted in immediate postoperative satisfactory reduction rates (P = 0.022), with a higher proportion of unsatisfactory reduction in the high-grade group. The incidence of abnormal syndesmotic interval at final follow-up also differed significantly (P = 0.030), suggesting poorer restoration of syndesmotic alignment in Group C.

Table 3. Comparison of preoperative and postoperative SF-36 scores among the three groups

Variable	Total (n = 370)	Group A (n = 142)	Group B (n = 153)	Group C (n = 75)	Statistic	*P* value
Preoperative SF-36 total score	56.12±13.96	56.87±12.25	56.22±15.07	54.48±14.69	0.727	0.484
Postoperative SF-36 total score	69.50 [59.00, 79.00]	77.00 [67.50, 84.00]	67.00 [60.00, 75.00]	58.00 [55.00, 64.50]	89.034	< 0.001
SF-36 improvement	17.00 [8.00, 27.00]	20.00 [10.25, 29.75]	16.00 [8.00, 27.00]	14.00 [7.00, 22.50]	8.890	0.012
Within-group comparison (statistic)		14.955	7.646	2.829		
Within-group comparison (*P* value)		< 0.001	< 0.001	0.006		

Note: SF-36, Short Form-36 Health Survey.

Table 4. Comparison of functional outcomes at final follow-up among the three groups

Variable	Total (n = 370)	Group A (n = 142)	Group B (n = 153)	Group C (n = 75)	Statistic	*P* value
AOFAS at final follow-up	86.00 [81.00, 90.00]	87.00 [82.25, 91.00]	86.00 [81.00, 90.00]	80.00 [70.00, 88.00]	23.216	< 0.001
Excellent/good AOFAS (≥ 80)					43.300	< 0.001
Yes	285 (77.03%)	128 (90.14%)	119 (77.78%)	38 (50.67%)		
No	85 (22.97%)	14 (9.86%)	34 (22.22%)	37 (49.33%)		
VAS pain score at final follow-up	3.00 [2.00, 3.00]	2.00 [1.25, 3.00]	3.00 [2.00, 4.00]	4.00 [3.00, 5.00]	98.196	< 0.001
Ankle dorsiflexion (°)	15.89±5.42	19.11±4.59	14.99±4.76	11.65±4.49	68.442	< 0.001
Ankle plantarflexion (°)	38.62±7.49	42.15±6.63	38.50±6.43	32.16±6.69	56.928	< 0.001
Time to return to work (weeks)	11.00 [9.00, 14.00]	10.00 [7.25, 11.00]	12.00 [9.00, 14.00]	15.00 [13.50, 18.00]	103.029	< 0.001

Note: AOFAS, American Orthopaedic Foot and Ankle Society score; VAS, visual analogue scale.

Table 5. Comparison of complications and reoperation among the three groups

Variable	Total (n = 370)	Group A (n = 142)	Group B (n = 153)	Group C (n = 75)	Statistic	*P* value
Any complication					30.466	< 0.001
Yes	92 (24.86%)	20 (14.08%)	36 (23.53%)	36 (48.00%)		
No	278 (75.14%)	122 (85.92%)	117 (76.47%)	39 (52.00%)		
Loss of reduction					40.203	< 0.001
Yes	55 (14.86%)	8 (5.63%)	19 (12.42%)	28 (37.33%)		
No	315 (85.14%)	134 (94.37%)	134 (87.58%)	47 (62.67%)		
Refractory pain					15.835	< 0.001
Yes	42 (11.35%)	9 (6.34%)	15 (9.80%)	18 (24.00%)		
No	328 (88.65%)	133 (93.66%)	138 (90.20%)	57 (76.00%)		
Post-traumatic osteoarthritis					18.643	< 0.001
Yes	33 (8.92%)	6 (4.23%)	11 (7.19%)	16 (21.33%)		
No	337 (91.08%)	136 (95.77%)	142 (92.81%)	59 (78.67%)		
Wound infection					3.572	0.168
Yes	12 (3.24%)	3 (2.11%)	4 (2.61%)	5 (6.67%)		
No	358 (96.76%)	139 (97.89%)	149 (97.39%)	70 (93.33%)		
Reoperation					38.58	< 0.001
Yes	36 (9.73%)	5 (3.52%)	12 (7.84%)	21 (25.92%)		
No	334 (90.27%)	137 (96.48%)	141 (92.16%)	54 (74.67%)		
Reoperation for loss of reduction		3 (2.11%)	7 (4.6%)	14 (18.67%)	23.743	< 0.001
Reoperation for refractory pain		2 (1.41%)	3 (2.0%)	5 (6.7%)	5.703	0.058
Reoperation for osteoarthritis		0 (0.00%)	2 (1.3%)	4 (5.3%)	8.912	0.012

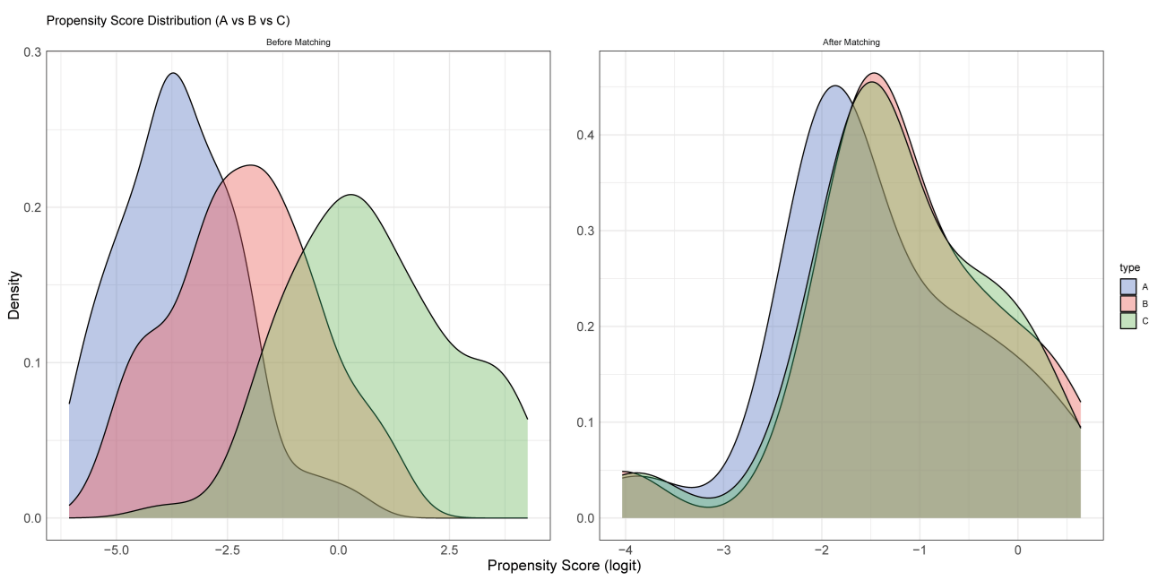

Figure 1. Density distribution of propensity scores among three groups (A, B, C) before and after matching. Note: PSM, propensity score matching; SMD, standardized mean difference.

Normal FR restoration, normal sagittal reduction, 6-month loss of reduction, and syndesmotic screw/fixation loosening did not differ significantly among groups (all P > 0.05). For radiographic measurements, postoperative TFCS and TFO both showed significant differences (P < 0.001 for both), with more pronounced deviation from normal in the high-grade group (**Table 7**).

SF-36 scores after matching

After matching, preoperative SF-36 total scores did not differ significantly (P > 0.05), indicating

Table 6. Comparison of baseline characteristics among the three groups after propensity score matching

Variable	Total (n = 57)	Group A (n = 19)	Group B (n = 19)	Group C (n = 19)	Statistic	*P* value
Age (years)	48.53±13.34	44.79±15.67	50.53±10.92	50.26±12.90	1.126	0.332
Sex					1.895	0.388
Male	34 (59.65%)	9 (47.37%)	12 (63.16%)	13 (68.42%)		
Female	23 (40.35%)	10 (52.63%)	7 (36.84%)	6 (31.58%)		
BMI					2.813	0.245
≥ 25	22 (38.60%)	5 (26.32%)	10 (52.63%)	7 (36.84%)		
< 25	35 (61.40%)	14 (73.68%)	9 (47.37%)	12 (63.16%)		
Smoking history					0.543	0.762
Yes	15 (26.32%)	5 (26.32%)	6 (31.58%)	4 (21.05%)		
No	42 (73.68%)	14 (73.68%)	13 (68.42%)	15 (78.95%)		
Alcohol consumption					1.326	0.515
Yes	14 (24.56%)	3 (15.79%)	6 (31.58%)	5 (26.32%)		
No	43 (75.44%)	16 (84.21%)	13 (68.42%)	14 (73.68%)		
Diabetes					3.069	0.216
Yes	5 (8.77%)	0 (0.00%)	3 (15.79%)	2 (10.53%)		
No	52 (91.23%)	19 (100.00%)	16 (84.21%)	17 (89.47%)		
Hypertension					3.353	0.187
Yes	6 (10.53%)	0 (0.00%)	3 (15.79%)	3 (15.79%)		
No	51 (89.47%)	19 (100.00%)	16 (84.21%)	16 (84.21%)		
Weber classification					1.825	0.401
B	28 (49.12%)	11 (57.89%)	10 (52.63%)	7 (36.84%)		
C	29 (50.88%)	8 (42.11%)	9 (47.37%)	12 (63.16%)		
Injury mechanism					2.628	0.622
Twisting	37 (64.91%)	12 (63.16%)	14 (73.68%)	11 (57.89%)		
High-energy	12 (21.05%)	4 (21.05%)	2 (10.53%)	6 (31.58%)		
Sports	8 (14.04%)	3 (15.79%)	3 (15.79%)	2 (10.53%)		
Injured side					1.825	0.401
Left	29 (50.88%)	8 (42.11%)	12 (63.16%)	9 (47.37%)		
Right	28 (49.12%)	11 (57.89%)	7 (36.84%)	10 (52.63%)		
Medial malleolar fracture					3.410	0.182
Yes	18 (31.58%)	5 (26.32%)	4 (21.05%)	9 (47.37%)		
No	39 (68.42%)	14 (73.68%)	15 (78.95%)	10 (52.63%)		
Posterior malleolar fracture					1.853	0.396
Yes	25 (43.86%)	6 (31.58%)	9 (47.37%)	10 (52.63%)		
No	32 (56.14%)	13 (68.42%)	10 (52.63%)	9 (47.37%)		
Medial structure injury					1.825	0.401
Yes	28 (49.12%)	11 (57.89%)	7 (36.84%)	10 (52.63%)		
No	29 (50.88%)	8 (42.11%)	12 (63.16%)	9 (47.37%)		
Posterior tibial marginal fracture					0.000	1.000
Yes	24 (42.11%)	8 (42.11%)	8 (42.11%)	8 (42.11%)		
No	33 (57.89%)	11 (57.89%)	11 (57.89%)	11 (57.89%)		
Time from injury to surgery (days)	5.00 [4.00, 7.00]	6.00 [4.00, 7.00]	5.00 [4.50, 7.00]	4.00 [3.00, 6.50]	3.337	0.189

Note: BMI, body mass index; PSM, propensity score matching.

balanced baseline functional status. Postoperative SF-36 total scores differed significantly (P = 0.002), with poorer functional recovery in Group C. The improvement in SF-36 scores also differed significantly (P = 0.031), with the smallest improvement in the high-grade group. For within-group comparisons, Groups A and B showed significant postopera-

Table 7. Comparison of postoperative radiographic reduction and follow-up outcomes among the three groups after propensity score matching

Variable	Total (n = 57)	Group A (n = 19)	Group B (n = 19)	Group C (n = 19)	Statistic	*P* value
Satisfactory immediate postoperative reduction					7.600	0.022
Yes	45 (78.95%)	17 (89.47%)	17 (89.47%)	11 (57.89%)		
No	12 (21.05%)	2 (10.53%)	2 (10.53%)	8 (42.11%)		
Normal fibular rotation restoration					3.167	0.205
Yes	48 (84.21%)	18 (94.74%)	16 (84.21%)	14 (73.68%)		
No	9 (15.79%)	1 (5.26%)	3 (15.79%)	5 (26.32%)		
Normal sagittal reduction (SSD < 2 mm)					3.410	0.182
Yes	39 (68.42%)	16 (84.21%)	12 (63.16%)	11 (57.89%)		
No	18 (31.58%)	3 (15.79%)	7 (36.84%)	8 (42.11%)		
Loss of reduction at 6 months					3.189	0.203
Yes	13 (22.81%)	3 (15.79%)	3 (15.79%)	7 (36.84%)		
No	44 (77.19%)	16 (84.21%)	16 (84.21%)	12 (63.16%)		
Syndesmotic screw/fixation loosening					4.609	0.100
Yes	10 (17.54%)	1 (5.26%)	3 (15.79%)	6 (31.58%)		
No	47 (82.46%)	18 (94.74%)	16 (84.21%)	13 (68.42%)		
Abnormal syndesmotic interval at final follow-up					7.007	0.030
Yes	14 (24.56%)	1 (5.26%)	5 (26.32%)	8 (42.11%)		
No	43 (75.44%)	18 (94.74%)	14 (73.68%)	11 (57.89%)		
Postoperative TFCS (mm)	3.51±0.97	2.67±0.72	3.54±0.69	4.31±0.72	25.085	< 0.001
Postoperative TFO (mm)	4.64±1.21	5.43±0.98	4.48±0.97	4.01±1.22	8.758	< 0.001

Note: TFCS, tibiofibular clear space; TFO, tibiofibular overlap; SSD, sagittal shift distance; FR, fibular rotation.

tive improvements (P < 0.001 and P = 0.019, respectively), while Group C showed no significant pre-to-post improvement (P > 0.05) (**Table 8**).

Functional outcomes at final follow-up after matching

After matching, significant differences in AOFAS scores remained at final follow-up (P = 0.037), with notably lower scores in the high-grade group. The rate of excellent or good outcomes also differed significantly (P = 0.002), with a marked decline in Group C. VAS pain scores differed significantly (P < 0.001), with higher pain levels in the high-grade group. Both dorsiflexion and plantarflexion angles showed significant differences (both P < 0.001), with more pronounced limitation in Group C. Time to return to work also differed significantly (P < 0.001), with substantially longer recovery time in the high-grade group (**Table 9**).

Complications and reoperation after matching

After matching, overall complication rates differed significantly (P = 0.014), with higher rates in the high-grade group. Loss of reduction (P = 0.046) and refractory pain (P = 0.020) also showed significant differences, with higher proportions in Group C. Post-traumatic osteoarthritis and wound infection did not differ significantly (both P > 0.05). Reoperation rates differed significantly (P = 0.009), with a notably higher proportion in the high-grade group. Reoperation for loss of reduction showed significant differences (P = 0.020), while reoperation for refractory pain did not (P > 0.05). No reoperations for post-traumatic osteoarthritis were observed after matching (**Table 10**).

Comparison between good and poor prognosis groups

Patients were classified into two groups based on their final follow-up AOFAS scores: those with a good prognosis (AOFAS ≥ 80) and those with a poor prognosis (AOFAS < 80). A comparative analysis was conducted on baseline characteristics, radiographic reductions, and functional outcome. There was a significant difference in the grade of syndesmotic injury between the two groups (P = 0.002), with a notably higher proportion of high-grade injuries observed in the poor prognosis group. Additionally, medial structure injuries exhibited a significant difference (P = 0.044). Regarding

Table 8. Comparison of preoperative and postoperative SF-36 scores among the three groups after propensity score matching

Variable	Total (n = 57)	Group A (n = 19)	Group B (n = 19)	Group C (n = 19)	Statistic	*P* value
Preoperative SF-36 total score	55.30±15.61	50.84±14.20	56.74±16.44	58.32±15.92	1.219	0.303
Postoperative SF-36 total score	68.00 [59.00, 81.00]	77.00 [71.00, 86.50]	68.00 [65.00, 79.50]	59.00 [55.00, 67.50]	12.061	0.002
SF-36 improvement	22.00 [7.00, 31.00]	28.00 [19.50, 37.50]	21.00 [6.50, 32.50]	8.00 [5.00, 24.00]	6.921	0.031
Within-group comparison (statistic)		6.57	2.585	0.878		
Within-group comparison (*P* value)		< 0.001	0.019	0.392		

Note: SF-36, Short Form-36 Health Survey.

Table 9. Comparison of functional outcomes at final follow-up among the three groups after propensity score matching

Variable	Total (n = 57)	Group A (n = 19)	Group B (n = 19)	Group C (n = 19)	Statistic	*P* value
AOFAS at final follow-up	88.00 [81.00, 91.00]	89.00 [85.50, 91.50]	89.00 [85.00, 92.00]	80.00 [70.00, 89.00]	6.589	0.037
Excellent/good AOFAS (≥ 80)					12.033	0.002
Yes	45 (78.95%)	18 (94.74%)	17 (89.47%)	10 (52.63%)		
No	12 (21.05%)	1 (5.26%)	2 (10.53%)	9 (47.37%)		
VAS pain score at final follow-up	3.00 [2.00, 4.00]	2.00 [2.00, 2.50]	3.00 [2.00, 3.50]	4.00 [3.00, 5.00]	19.16	< 0.001
Ankle dorsiflexion (°)	15.38±5.23	18.68±4.01	15.69±4.92	11.77±4.40	11.454	< 0.001
Ankle plantarflexion (°)	37.28±7.45	41.73±6.70	37.93±5.17	32.17±7.22	10.678	< 0.001
Time to return to work (weeks)	11.42±3.65	8.79±2.84	11.16±1.95	14.32±3.65	17.38	< 0.001

Note: AOFAS, American Orthopaedic Foot and Ankle Society score; VAS, visual analogue scale.

Table 10. Comparison of complications and reoperation among the three groups after propensity score matching

Variable	Total (n = 57)	Group A (n = 19)	Group B (n = 19)	Group C (n = 19)	Statistic	*P* value
Any complication					8.515	0.014
Yes	16 (28.07%)	3 (15.79%)	3 (15.79%)	10 (52.63%)		
No	41 (71.93%)	16 (84.21%)	16 (84.21%)	9 (47.37%)		
Loss of reduction					6.178	0.046
Yes	13 (22.81%)	3 (15.79%)	2 (10.53%)	8 (42.11%)		
No	44 (77.19%)	16 (84.21%)	17 (89.47%)	11 (57.89%)		
Refractory pain					7.824	0.02
Yes	6 (10.53%)	0 (0.00%)	1 (5.26%)	5 (26.32%)		
No	51 (89.47%)	19 (100.00%)	18 (94.74%)	14 (73.68%)		
Post-traumatic osteoarthritis					4.471	0.107
Yes	6 (10.53%)	0 (0.00%)	2 (10.53%)	4 (21.05%)		
No	51 (89.47%)	19 (100.00%)	17 (89.47%)	15 (78.95%)		
Wound infection					1.036	0.596
Yes	2 (3.51%)	1 (5.26%)	0 (0.00%)	1 (5.26%)		
No	55 (96.49%)	18 (94.74%)	19 (100.00%)	18 (94.74%)		
Reoperation					9.500	0.009
Yes	9 (15.79%)	1 (5.26%)	1 (5.26%)	7 (36.84%)		
No	48 (84.21%)	18 (94.74%)	18 (94.74%)	12 (63.16%)		
Reoperation for loss of reduction		0 (0.00%)	1 (5.26%)	5 (26.31%)	7.824	0.02
Reoperation for refractory pain		0 (0.00%)	0 (0.00%)	2 (10.53%)	4.145	0.126
Reoperation for osteoarthritis		0 (0.00%)	0 (0.00%)	0 (0.00%)	-	-

radiographic parameters, postoperative tibiofibular clear space (TFCS) (P = 0.017) and tibiofibular overlap (TFO) (P = 0.022) were significantly different, indicating more pronounced syndesmotic malalignment in the poor prognosis group. The angles of dorsiflexion (P = 0.005) and plantarflexion (P < 0.001) also showed significant differences, with greater limitations noted in the poor prognosis group. Furthermore, the rate of reduction loss at the 6-month follow-up was significantly different (P = 0.004), with a higher proportion of patients in the poor prognosis group experiencing this issue. Other demographic variables, including sex, BMI, smoking history, alcohol consumption, diabetes, hypertension, and age, as well as injury characteristics (mechanism, side), fracture-related parameters (Weber classification, presence of medial malleolar fracture, posterior malleolar fracture, posterior tibial marginal fracture), postoperative reduction parameters (normal fracture restoration, normal sagittal reduction, screw loosening), and general complications did not show significant differences (all P > 0.05) (**Table 11**).

Multicollinearity testing and logistic regression analysis

Before multivariate logistic regression, variance inflation factor (VIF) testing was performed for all candidate variables. All VIF values were low (< 2), indicating no multicollinearity and permitting inclusion in the regression model (**Table 12**).

By univariate logistic regression, age, time from injury to surgery, postoperative TFCS, postoperative TFO, postoperative SF-36 total score, VAS pain score, ankle range of motion (dorsiflexion and plantarflexion), syndesmotic injury grade, BMI, diabetes, Weber classification, posterior malleolar fracture, medial structure injury, posterior tibial marginal fracture, FR restoration, 6-month loss of reduction, syndesmotic screw/fixation loosening, and any complication were all associated with outcome (all P < 0.05).

By multivariate logistic regression, age (P < 0.001), time from injury to surgery (P < 0.001), BMI (P = 0.050), diabetes (P = 0.004), Weber

Table 11. Comparison of baseline characteristics among three groups

Variable	Total	Poor prognosis (n = 85)	Good prognosis (n = 285)	Statistic	*P* value
Syndesmotic injury grade				12.033	0.002
A	19 (33.33%)	1 (8.33%)	18 (40.00%)		
B	19 (33.33%)	2 (16.67%)	17 (37.78%)		
C	19 (33.33%)	9 (75.00%)	10 (22.22%)		
Sex				0.790	0.374
Male	34 (59.65%)	9 (75.00%)	25 (55.56%)		
Female	23 (40.35%)	3 (25.00%)	20 (44.44%)		
BMI				0.000	1.000
≥ 25	22 (38.60%)	5 (41.67%)	17 (37.78%)		
< 25	35 (61.40%)	7 (58.33%)	28 (62.22%)		
Smoking history				0.236	0.627
Yes	15 (26.32%)	2 (16.67%)	13 (28.89%)		
No	42 (73.68%)	10 (83.33%)	32 (71.11%)		
Alcohol consumption				0.000	1.000
Yes	14 (24.56%)	3 (25.00%)	11 (24.44%)		
No	43 (75.44%)	9 (75.00%)	34 (75.56%)		
Diabetes				0.264	0.607
Yes	5 (8.77%)	2 (16.67%)	3 (6.67%)		
No	52 (91.23%)	10 (83.33%)	42 (93.33%)		
Hypertension				0.000	1.000
Yes	6 (10.53%)	1 (8.33%)	5 (11.11%)		
No	51 (89.47%)	11 (91.67%)	40 (88.89%)		
Weber classification				0.338	0.561
B	28 (49.12%)	5 (41.67%)	23 (51.11%)		
C	29 (50.88%)	7 (58.33%)	22 (48.89%)		
Injury mechanism				2.484	0.289
Twisting	37 (64.91%)	9 (75.00%)	28 (62.22%)		
High-energy	12 (21.05%)	3 (25.00%)	9 (20.00%)		
Sports	8 (14.04%)	0 (0.00%)	8 (17.78%)		
Injured side				0.005	0.945
Left	29 (50.88%)	6 (50.00%)	23 (51.11%)		
Right	28 (49.12%)	6 (50.00%)	22 (48.89%)		
Medial malleolar fracture				0.247	0.619
Yes	18 (31.58%)	5 (41.67%)	13 (28.89%)		
No	39 (68.42%)	7 (58.33%)	32 (71.11%)		
Posterior malleolar fracture				3.211	0.073
Yes	25 (43.86%)	8 (66.67%)	17 (37.78%)		
No	32 (56.14%)	4 (33.33%)	28 (62.22%)		
Medial structure injury				4.073	0.044
Yes	28 (49.12%)	9 (75.00%)	19 (42.22%)		
No	29 (50.88%)	3 (25.00%)	26 (57.78%)		
Posterior tibial marginal fracture				1.824	0.177
Yes	24 (42.11%)	3 (25.00%)	21 (46.67%)		
No	33 (57.89%)	9 (75.00%)	24 (53.33%)		
Normal fibular rotation restoration				0.000	1.000
Yes	48 (84.21%)	10 (83.33%)	38 (84.44%)		
No	9 (15.79%)	2 (16.67%)	7 (15.56%)		
Normal sagittal reduction (SSD < 2 mm)				0.041	0.840
Yes	39 (68.42%)	9 (75.00%)	30 (66.67%)		
No	18 (31.58%)	3 (25.00%)	15 (33.33%)		

Loss of reduction at 6 months				8.491	0.004
Yes	13 (22.81%)	7 (58.33%)	6 (13.33%)		
No	44 (77.19%)	5 (41.67%)	39 (86.67%)		
Syndesmotic screw/fixation loosening				1.419	0.233
Yes	10 (17.54%)	4 (33.33%)	6 (13.33%)		
No	47 (82.46%)	8 (66.67%)	39 (86.67%)		
Abnormal syndesmotic interval at final follow-up				0.174	0.677
Yes	14 (24.56%)	4 (33.33%)	10 (22.22%)		
No	43 (75.44%)	8 (66.67%)	35 (77.78%)		
Any complication				2.375	0.123
Yes	16 (28.07%)	6 (50.00%)	10 (22.22%)		
No	41 (71.93%)	6 (50.00%)	35 (77.78%)		
Age (years)	48.53±13.34	45.08±12.04	49.44±13.64	1.007	0.319
Time from injury to surgery (days)	5.00 [4.00, 7.00]	5.50 [3.00, 7.00]	5.00 [4.00, 7.00]	0.189	0.850
Postoperative TFCS (mm)	3.51±0.97	4.09±0.97	3.35±0.92	-2.464	0.017
Postoperative TFO (mm)	4.64±1.21	3.94±1.00	4.83±1.20	2.349	0.022
Postoperative SF-36 total score	70.16±13.35	67.25±13.06	70.93±13.46	0.847	0.401
VAS pain score at final follow-up	3.00 [2.00, 4.00]	3.00 [2.75, 4.25]	3.00 [2.00, 4.00]	1.684	0.092
Ankle dorsiflexion (°)	15.38±5.23	11.72±5.03	16.36±4.88	2.903	0.005
Ankle plantarflexion (°)	37.28±7.45	28.81±6.92	39.54±5.82	5.450	< 0.001

Note: AOFAS, American Orthopaedic Foot and Ankle Society score; TFCS, tibiofibular clear space; TFO, tibiofibular overlap.

Table 12. Variance inflation factor (VIF) analysis for multicollinearity assessment

Variable	VIF	Interpretation
Age	1.269	Low multicollinearity
Time from injury to surgery	1.344	Low multicollinearity
Postoperative TFCS (mm)	1.711	Low multicollinearity
Postoperative TFO (mm)	1.38	Low multicollinearity
Postoperative SF-36 total score	1.272	Low multicollinearity
VAS pain score	1.506	Low multicollinearity
Ankle dorsiflexion (°)	1.381	Low multicollinearity
Ankle plantarflexion (°)	1.363	Low multicollinearity
Syndesmotic injury grade	1.855	Low multicollinearity
BMI	1.083	Low multicollinearity
Diabetes	1.129	Low multicollinearity
Weber classification	1.214	Low multicollinearity
Injury mechanism	1.097	Low multicollinearity
Posterior malleolar fracture	1.282	Low multicollinearity
Medial structure injury	1.156	Low multicollinearity
Posterior tibial marginal fracture	1.191	Low multicollinearity
Normal fibular rotation restoration	1.294	Low multicollinearity
Loss of reduction at 6 months	1.2	Low multicollinearity
Syndesmotic screw/fixation loosening	1.144	Low multicollinearity
Any complication	1.114	Low multicollinearity

Note: TFCS, tibiofibular clear space; TFO, tibiofibular overlap; SF-36, Short Form-36 Health Survey; VAS, visual analogue scale; BMI, body mass index; FR, fibular rotation.

classification (P = 0.017), posterior malleolar fracture (P = 0.008), and 6-month loss of reduction (P = 0.032) were confirmed as independent risk factors for poor prognosis. Postoperative TFCS, TFO, SF-36 score, VAS score, ankle range of motion, FR restoration, and complications were not significant in multivariate analysis (P > 0.05). Univariate and multivariate logistic regression results are presented as a forest plot (**Figure 2**).

It should be noted that because of the small number of patients with poor prognosis in the PSM-matched sample, the "events per variable ≥ 10" rule for logistic regression was not satisfied. Preliminary analysis also showed substantial bias. Therefore, risk factor analysis was not performed on the PSM-matched sample.

Interaction analysis

Interaction effects between syndesmotic injury grade and age, surgical delay, and diabetes were analyzed. **Figure 3** displays the interaction patterns between injury grade (Group A

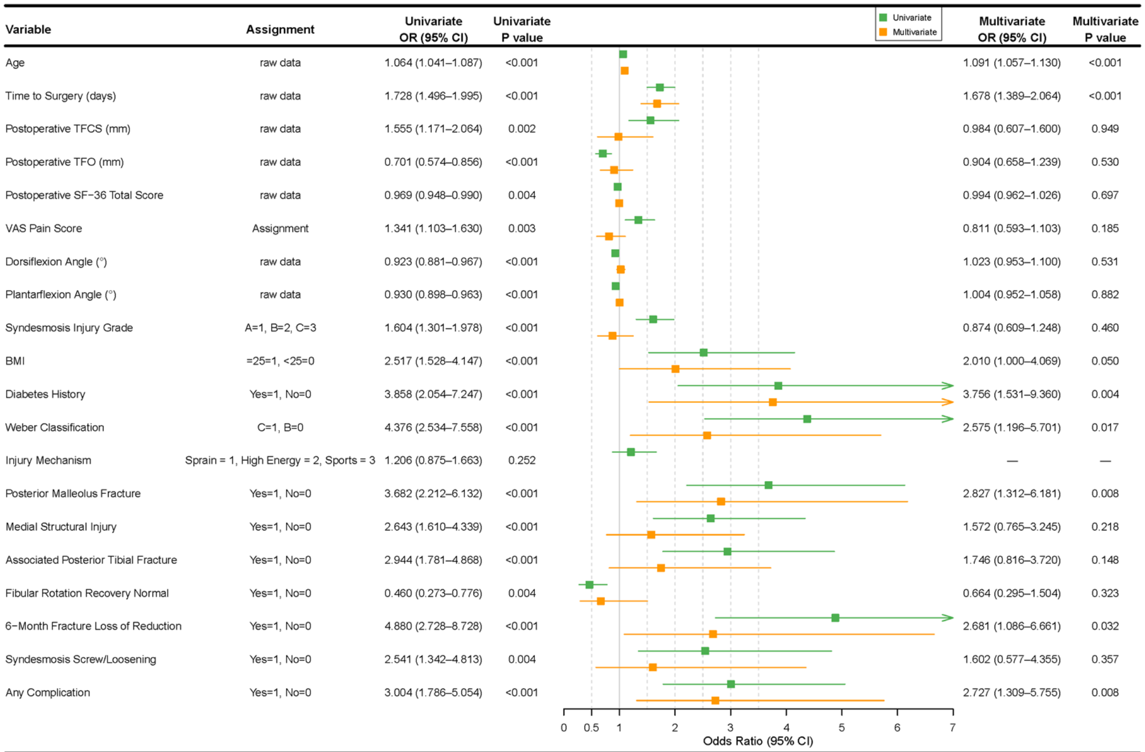

Figure 2. Forest plot of univariate and multivariate logistic regression analyses for factors affecting postoperative prognosis. Note: Green lines and squares represent univariate logistic regression analysis; yellow lines and squares represent multivariate logistic regression analysis. TFCS, tibiofibular clear space; TFO, tibiofibular overlap; SF-36, Short Form-36 Health Survey; VAS, visual analogue scale; BMI, body mass index; FR, fibular rotation.

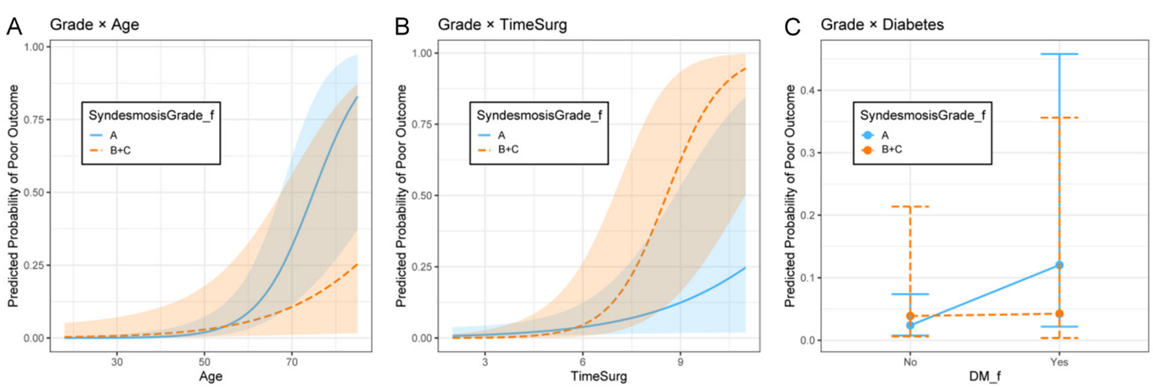

Figure 3. Interaction analysis between syndesmotic injury grade and age, surgical delay, and diabetes. A. Interaction between grade and age. B. Interaction between grade and time to surgery. C. Interaction between grade and diabetes.

vs. Groups B+C) and three key clinical variables in predicting poor prognosis.

For the age interaction (**Figure 3A**), the interaction term between injury grade and age approached statistical significance (Estimate = -0.0617, P = 0.078). As age increased, the risk of poor prognosis rose in both groups, but more steeply in Groups B+C. Age as an independent factor significantly increased poor prognosis risk (OR = 1.120, 95% CI 1.066-1.177).

For surgical delay (**Figure 3B**), a significant interaction was observed (Estimate = 0.535, P

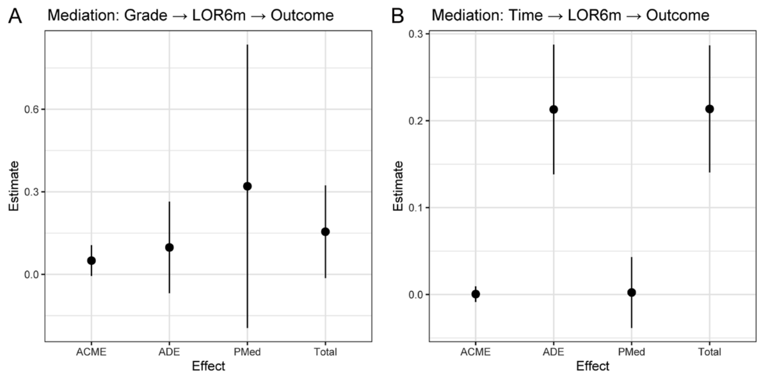

Figure 4. Mediation analysis of syndesmotic injury grade and surgical delay on poor prognosis through loss of reduction at 6 months (LOR6m). A. Mediation pathway: Grade → LOR6m → Outcome. B. Mediation pathway: Time to surgery → LOR6m → Outcome. Note: LOR6m, loss of reduction at 6 months; TimeSurg, time to surgery; ACME, average causal mediation effect; ADE, average direct effect; PMed, proportion mediated.

= 0.028). As surgical delay increased, the probability of poor prognosis rose more markedly in the B+C group. Within the 3-7 day delay range, the risk difference between groups widened rapidly. Surgical delay itself also significantly increased poor prognosis risk (OR = 2.223, 95% CI 1.563-3.161).

For the diabetes interaction (**Figure 3C**), the interaction term did not reach statistical significance (Estimate = -1.155, P = 0.197). Although predicted probabilities differed between diabetic patients across injury grades, confidence intervals were wide and the interaction was unstable. This suggests that sample size distribution may have limited detection power.

Mediation analysis

Figure 4 illustrates the results from two mediation pathways. The first pathway assessed the indirect effect of syndesmotic injury grade on poor prognosis through loss of reduction at 6 months (LOR6m). The second pathway evaluated the potential mediating role of LOR6m in the relationship between surgical delay and poor prognosis. For Pathway A (injury grade → LOR6m → poor prognosis), the average causal mediation effect (ACME) was 0.050 (95% CI -0.006 to 0.106), while the average direct effect (ADE) was 0.098 (95% CI -0.068 to 0.264), resulting in a total effect of 0.155 (95% CI -0.013 to 0.323). Although the proportion mediated (PMed) reached 0.320, the confidence interval was wide (-0.194 to 0.835), indicating a limited trend toward mediation through LOR6m, with the mediation effect being unstable. More complex mechanisms may be involved, such as the severity of soft tissue injury, altered joint contact pressure, and occult rotational abnormalities. For Pathway B (surgical delay → LOR6m → poor prognosis), the ACME was negligible (0.001, 95% CI -0.008 to 0.009), indicating no significant indirect effect. However, both the direct effect of surgical delay and the total effect (0.214, 95% CI 0.141 to 0.287) were significant. The fraction mediated was very small (0.002, 95% CI -0.038 to 0.043). The relationship between surgical delay and poor prognosis occurs primarily through direct pathways, rather than through LOR6m. The two pathways differ significantly, with structural factors (injury grade) influencing prognosis through one route, while temporal factors (surgical delay) influence through the other.

Discussion

This study included 370 patients with ankle fractures and syndesmotic injury. Utilizing FR and SSD, we developed a three-tier injury grading system and systematically compared postoperative radiographic reduction quality, functional outcomes, and complication rates across groups. We further employed IPTW, PSM, multivariate regression, interaction analysis, and mediation analysis to evaluate the independent prognostic effect of the grading system and its underlying mechanistic pathways. Overall, the results demonstrated that patients with high-grade (Group C) injuries exhibited inferior postoperative reduction quality, higher complication and reoperation rates, and significantly worse functional recovery. However, by multivariate analysis, injury grade itself did not emerge as an independent predictor. Instead, clinical factors including age, surgical delay, diabetes, obesity, Weber C classification, and posterior malleolar fracture superseded its prognostic effect.

These results suggest that this grading system, as a structural-radiographic characterization, represents the injury's "composite severity". The factors that accompany a high-grade injury are the ones that alter mortise stability and affect maintenance of the reduction - such as posterior malleolar fracture, Weber C classification, and medial structure injury. Once these factors are included in the model, the grading system's "composite injury indicator" is superseded by more direct causal variables, with the result that its independent effect is eliminated. Injury grade alone must not determine prognosis; instead, all factors that contribute to discrimination must be considered.

Surgical delay represents one of the major factors affecting prognosis. Delayed treatment can result in hematoma organization and scar formation within the syndesmotic space, rendering anatomical fibular rotation reduction more difficult and increasing the risk of postoperative malalignment. Postponed surgical intervention is also associated with substantial soft tissue swelling, altered tissue tension, and limited surgical access, all of which can compromise reduction quality and internal fixation stability. Yang et al. [14] demonstrated that untreated small posterior malleolar fragments combined with early removal of syndesmotic screws (6-8 weeks) were associated with recurrent syndesmotic instability, further underscoring the importance of surgical timing and adequate duration of fixation maintenance. Our multivariate analysis confirmed that surgical delay significantly increased the risk of poor prognosis ($P < 0.001$). Furthermore, a significant interaction between surgical delay and injury grade was identified in this study ($P = 0.028$). In patients with moderate-to-high-grade injuries, the probability of poor prognosis increased markedly with surgical delay, in contrast to those with low-grade injuries. This finding suggests that high-grade injuries exhibit a "time-dependent" characteristic: as rotational or translational displacement becomes more severe, the soft tissue milieu deteriorates more rapidly over time. This interaction effect implies that patients with moderate-to-high-grade syndesmotic injuries should undergo surgery promptly - ideally within 72 hours - to prevent irreversible soft tissue changes and syndesmotic interval deterioration. This interaction represents one of the most clinically actionable findings of our study. The differential sensitivity to surgical timing between injury grades provides a framework for triage decision-making. For patients presenting with low-grade displacement, a brief delay to optimize soft tissue conditions or manage comorbidities may be acceptable without substantially compromising outcomes. However, for patients with moderate-to-high-grade injuries, such delay carries a meaningful prognostic penalty. We therefore advocate for a severity-stratified approach to surgical scheduling, wherein high-grade injuries receive priority in operative sequencing.

The independent effects of age, diabetes, and BMI on prognosis warrant careful consideration. Older patients demonstrated more pronounced declines in functional scores, which may be attributable to diminished ligamentous repair and elasticity restoration capacity, delayed muscle strength recovery, and reduced tolerance of rehabilitation protocols [15]. Patients with diabetes experience impaired microcirculation, sensory abnormalities, and compromised tissue regeneration capacity, rendering them more susceptible to chronic pain, delayed soft tissue healing, and alignment instability. Obesity increases mechanical loading on the ankle joint and may elevate internal fixation stress, thereby increasing the risk of reduction loss and poor functional outcome [16]. These patient-specific factors highlight the importance of individualized treatment planning that extends beyond the operative intervention itself. In our practice, we have implemented enhanced perioperative glycemic control protocols for diabetic patients, extended immobilization periods for elderly patients with osteoporotic bone, and weight-based activity restrictions for obese individuals. Future prospective studies should investigate whether optimized management of modifiable risk factors can improve outcomes in these vulnerable populations.

The presence of posterior malleolar fracture, Weber C classification, and postoperative loss of reduction were also identified as independent predictors of poor outcome. According to the review by Pollard et al. [17], posterior malleolar fractures contribute substantially to ankle stability, and their role in syndesmotic rotational stability is often underestimated. Inadequate reduction of the posterior malleolus during surgery may obscure control of anteroposterior or rotational alignment of the fibula, thereby compromising syndesmotic stability. Weber C fractures represent high-energy injuries with more extensive interosseous membrane damage [18]. The fibula frequently migrates proximally by a significant distance, making intraoperative reduction and restoration of length technically demanding. Postoperative loss of reduction reflects failure to maintain alignment and constitutes one of the strongest predictors of functional impairment and post-traumatic arthritis. In this study, loss of reduction demonstrated a significant prognostic effect (P = 0.032). Li et al. [19] reported in a prospective study that dynamic changes in syndesmotic reduction occurred during the first postoperative year. After screw removal, reduction may initially improve but can subsequently deteriorate with weight bearing. For ankles with gaps of 2 mm or greater, complete reduction was associated with optimal outcomes. These findings align with and support our mediation analysis results. Our experience reinforces the critical importance of meticulous posterior malleolar evaluation and treatment. We advocate for routine computed tomography assessment of the posterior malleolus in all syndesmotic injuries, as conventional radiographs frequently underestimate fragment size and displacement. For fragments involving greater than 25% of the articular surface or those with significant step-off, we recommend direct reduction and fixation rather than relying on indirect ligamentotaxis.

Xu et al. [20] conducted a meta-analysis comparing fixation methods for syndesmotic injury and reported that the suture-button group achieved significantly higher AOFAS scores at 3-month and 2-year follow-up. The suture-button group also demonstrated significantly better outcomes in terms of malreduction rates, implant failure, implant removal, and local irritation. Published data [21] similarly indicate that screw fixation and dynamic fixation (TightRope) did not differ significantly in AOFAS, OMAS, or FADI scores at one year; however, the dynamic fixation group showed greater improvement in postoperative pain and earlier weight bearing. Chen et al. [22] demonstrated that the Rigidloop elastic fixation system maintains syndesmotic stability comparable to screw fixation while offering faster recovery with fewer complications and early functional benefits. Further evidence indicates that the suture-button group experienced lower rates of implant-related problems and reoperations, more rapid return to weight bearing, and better radiographic stability.

Weng et al. [24] developed a novel syndesmotic plate that achieved fixation strength comparable to standard syndesmotic screws. Meekaew et al. [25] performed finite element analysis and cadaveric validation comparing screw fixation against Endobutton fixation, demonstrating that coiling and fixation offer improved stability in various aspects compared to normal syndesmosis. Although the screw model demonstrated superior translational and compressive stability compared to the Endobutton model, rotational stability was equivalent between the two. These studies indicate that while dynamic fixation devices may offer advantages in functional recovery and complication rates, fixation method selection in highly unstable injuries should be individualized according to specific injury characteristics.

In a study by Bae et al. [26], it was found that anterior inferior tibiofibular ligament (AITFL) avulsion fractures occur in rotational ankle fractures, and that anatomic reduction and fixation may obviate the need for syndesmotic screw fixation in 83.3% of cases, with good stability and functional outcomes. Direct reduction and fixation of avulsion fractures may be beneficial in the treatment of AITFL injuries. A literature review [27] confirmed that accurate diagnosis and repair of syndesmotic injury is essential for ankle fracture patients, with ongoing exploration of more accurate and simplified injury identification methods, improved reduction success rates, and reduced surgical complications. The systematic investigation by Murphy et al. [4] found no statistically significant difference in functional outcome at final follow-up between dynamic fixation and screw fixation; nonetheless, the dynamic fixation group experienced lower rates of postoperative complications and reoperations. Saraglis et al. [28] reported that radiographic assessment revealed no statistical differences in imaging parameters between the two techniques; however, the screw group had a higher rate of radiographic malreduction, while the TightRope system demonstrated a lower rate. Evidence further indicates [29] that suture-button fixation demonstrates efficacy comparable to traditional syndesmotic screws while offering the advantages of early weight-bearing and no need for routine removal.

For the management of chronic syndesmotic injuries, Stake et al. [30] reported outcomes using a suture button combined with a quadricortical screw for revision fixation. After a mean follow-up of 45 months, the AOFAS score was recorded at 87. Although most patients exhibited radiographic progression of osteoarthritis, functional outcomes remained favorable and comparable to other studies. This suggests that even in the presence of secondary arthritic changes, active surgical treatment can enhance functionality in patients with chronic injuries. Oliveira et al. [31] conducted a retrospective study involving 49 patients and found that suture button fixation of the syndesmosis resulted in a mean postoperative AOFAS score of 97.06 and a VAS score of 0.16, with no instances of postoperative instability. Only two cases exhibited suture button-related changes, and no patients reported dissatisfaction. Similarly, Yawar et al. [23] discovered that 9% of patients in the TightRope group required reoperation for any reason, in contrast to 21% in the syndesmotic screw group. All four reoperations in the TightRope group were due to implant failure or symptoms, with only one patient (3%) undergoing removal due to persistent pain. Published data [32] indicate that the TightRope group achieved weight-bearing significantly earlier (6.19±0.9 weeks vs. 7.13±0.95 weeks) and demonstrated better functional outcomes at six months (87.5% vs. 37.5% achieving excellent AOFAS scores).

Jlidi et al. [33] conducted a prospective study comparing modified dynamic suture-button fixation with static screw fixation. The dynamic fixation group returned to work faster and achieved better AOFAS scores and ankle range of motion. Although early skin complication rates were higher, late complications did not differ significantly. Güngör et al. [21] similarly confirmed in their cohort study that dynamic fixation was functionally comparable to screw fixation, with early full weight-bearing and improved pain control being advantages of dynamic over screw fixation. Based on our synthesis of the existing literature and our own clinical experience, we advocate for a nuanced approach to fixation method selection. For patients with isolated syndesmotic injury or those with high functional demands (such as athletes or young laborers), dynamic fixation devices may offer meaningful advantages in terms of earlier rehabilitation and return to activity. However, for patients with severe comminution, significant posterior malleolar involvement, or highly unstable injury patterns, we continue to favor screw fixation - potentially combined with plate stabilization - to ensure adequate initial stability during the critical healing phase. The key principle is that the fixation method should be tailored to both injury characteristics and patient-specific factors, rather than applying a one-size-fits-all approach.

Synthesizing the above evidence, our findings are consistent with previous research. Prognosis of syndesmotic injury is influenced by multiple factors, and injury grade itself does not serve as an independent predictor. Surgical timing, age, comorbidities, and fracture type are the key determinants. Regarding fixation method selection, dynamic fixation devices such as suture-button, TightRope, and Rigidloop may offer advantages in functional recovery, early weight-bearing, complication rates, and reoperation rates. However, for highly unstable injuries, fixation method selection should still be individualized.

Mediation analysis results further elucidated the mechanisms by which injury grade and surgical delay affect prognosis. For the pathway from injury grade through loss of reduction at 6 months (LOR6m) to poor prognosis, the average causal mediation effect (ACME) was 0.050 (95% CI -0.006 to 0.106), the average direct effect (ADE) was 0.098 (95% CI -0.068 to 0.264), and the total effect was 0.155 (95% CI -0.013 to 0.323). The proportion mediated was 0.320, but the confidence interval was wide (-0.194 to 0.835). The mediation through LOR6m suggests a marginal trend that is not statistically robust. More complex mechanisms - such as soft tissue injury severity, joint contact pressure alterations, and occult rotational abnormalities - may underlie this pathway.

For the pathway from surgical delay through LOR6m to poor prognosis, the ACME was nearly zero (0.001, 95% CI -0.008 to 0.009), indicating no significant indirect effect. Nonetheless, surgical delay demonstrated a significant direct effect (ADE = 0.213, 95% CI 0.138 to 0.288) and total effect (0.214, 95% CI 0.141 to 0.287). The proportion mediated was negligible (0.002, 95% CI -0.038 to 0.043). This finding indicates that surgical delay exerts its adverse prognostic influence through direct pathways rather than through LOR6m. The two pathways differ fundamentally: structural factors (injury grade) and temporal factors (surgical delay) influence prognosis through distinct mechanistic routes. The mediation analysis results provide mechanistic insights that refine our understanding of prognosis in syndesmotic injury. The fact that surgical delay affects outcome primarily through direct pathways - rather than through loss of reduction - suggests that the adverse effects of delay extend beyond purely mechanical considerations. We hypothesize that delayed surgery may lead to persistent articular cartilage stress, subchondral bone changes, and synovial inflammatory alterations that are not fully captured by radiographic assessment of reduction quality. These multifactorial influences likely explain why surgical delay remains prognostically significant even when adequate radiographic reduction is achieved.

From a clinical standpoint, these results suggest that special attention should be directed toward the following considerations: First, patients presenting with moderate-to-high-grade syndesmotic injuries should undergo surgery or stabilization within 72 hours whenever feasible, to prevent soft tissue degradation. Second, posterior malleolar fractures should be carefully evaluated, and when indicated, anatomically reduced and stably fixed. Third, perioperative metabolic status should be optimized in diabetic and obese patients. Fourth, intraoperative assessment should meticulously evaluate fibular rotation, sagittal alignment, and tibiofibular relationship. Fifth, the first three postoperative months warrant vigilant monitoring for any signs of reduction loss. Sixth, fixation method selection should be individualized; in patients requiring early functional recovery, dynamic fixation devices may be preferred. We wish to emphasize that our findings should not be interpreted as diminishing the importance of achieving excellent reduction or selecting optimal fixation. Rather, our results highlight that technical excellence in the operating room must be complemented by attention to the broader clinical context. This holistic perspective should inform shared decision-making discussions with patients and their families, helping to set realistic expectations and optimize modifiable risk factors.

This study possesses several methodological strengths. It is the first to construct a clinically practical three-tier classification based on FR and SSD and perform large-sample analysis. It combines IPTW and PSM dual techniques to address baseline imbalance and enhance causal inference. It introduces interaction and mediation models to reveal underlying mechanisms. However, several limitations warrant acknowledgment. This was a single-center retrospective study with potential selection and information bias. The high-grade injury group had a relatively small sample size, resulting in wide confidence intervals for some models. Functional follow-up was limited to 6 months or longer and cannot fully assess long-term post-traumatic arthritis development. Future multicenter, prospective studies with longer follow-up are needed to further validate these findings. The role of AI-assisted imaging grading or biomarkers in prediction also deserves exploration.

Conclusion

The key for patients with moderate-to-high-grade syndesmotic injuries lies not in the severity of the injury itself, but rather in the feasibility of early surgical intervention, the ability to maintain reduction, and the management of any underlying conditions. Although the grading system proposed in this study did not serve as an independent predictor, its interaction with surgical timing offers significant guidance for clinical decision-making. These findings can facilitate the optimization of individualized treatment strategies for ankle fractures accompanied by syndesmotic injuries.

Disclosure of conflict of interest

None.

Address correspondence to: Yanlong Jia, Department of Sports Medicine, Yanan City Traditional Chinese Medicine Hospital, No. 26, Xuanyuan Avenue, New District, Baota District, Yan'an 716000, Shaanxi, China. E-mail: Jiayanlong1923@163.com

References

[1] Liu J, Valentine D and Ebraheim NA. Management of syndesmosis injury: a narrative review. Orthop Res Rev 2022; 14: 471-475.

[2] Yuen CP and Lui TH. Distal tibiofibular syndesmosis: anatomy, biomechanics, injury and management. Open Orthop J 2017; 11: 670-677.

[3] Sun S, Tang T, Shi P, Yang C, Wang W, Chen L and Wei M. Standing on single foot-binding test yields satisfactory results as a novel method for the diagnosis of distal tibiofibular syndesmosis instability: a prospective, cross-sectional diagnostic-accuracy study. BMC Musculoskelet Disord 2024; 25: 53.

[4] Murphy SC, Murphy B and O'Loughlin P. Syndesmotic injury with ankle fracture: a systematic review of screw vs dynamic fixation. Ir J Med Sci 2024; 193: 1323-1330.

[5] Pogliacomi F, De Filippo M, Casalini D, Longhi A, Tacci F, Perotta R, Pagnini F, Tocco S and Ceccarelli F. Acute syndesmotic injuries in ankle fractures: from diagnosis to treatment and current concepts. World J Orthop 2021; 12: 270-291.

[6] Vohra R, Singh A, Thorat B and Patel D. Instability of the distal tibiofibular syndesmosis. J Orthop Surg (Hong Kong) 2023; 31: 10225536231182349.

[7] Kaftandziev I, Bakota B, Trpeski S, Arsovski O, Spasov M and Cretnik A. The effect of the ankle syndesmosis reduction quality on the short-term functional outcome following ankle fractures. Injury 2021; 52 Suppl 5: S70-S74.

[8] Julian TH, Broadbent RH and Ward AE. Surgical vs non-surgical management of Weber B fractures: a systematic review. Foot Ankle Surg 2020; 26: 494-502.

[9] Burchard R, Hamidy K, Pahlkötter A, Soost C, Palm M, Graw JA and Bouillon B. Influence of time to surgery in ankle fractures on the rate of complications and length of stay - a multivariate analysis. Z Orthop Unfall 2019; 157: 183-187.

[10] Lopez-Capdevila L, Rios-Ruh JM, Fortuño J, Costa AE, Santamaria-Fumas A, Dominguez-Sevilla A and Sales-Perez M. Diabetic ankle fracture complications: a meta-analysis. Foot Ankle Surg 2021; 27: 832-837.

[11] Lee SW, Lee KJ, Park CH, Kwon HJ and Kim BS. The valid diagnostic parameters in bilateral CT scan to predict unstable syndesmotic injury with ankle fracture. Diagnostics (Basel) 2020; 10: 812.

[12] Shrestha B and Dunn L. The declaration of Helsinki on medical research involving human subjects: a review of seventh revision. J Nepal Health Res Counc 2020; 17: 548-552.

[13] Barber HF, Randall ZD, Strok MJ, Goldfarb JH, Yaeger L and Berkes MB. Functional outcomes after ankle fracture-dislocation: a systematic review. Arch Orthop Trauma Surg 2025; 145: 117.

[14] Yang TC, Tzeng YH, Wang CS, Lin CC, Chang MC and Chiang CC. Untreated small posterior fragment of ankle fracture with early removal of syndesmotic screw is associated with recurrent syndesmotic instability. Injury 2021; 52: 638-643.

[15] Chen X and Chen Y. Correlation between postoperative serum bone metabolism levels and fracture healing in elderly osteoporotic fracture patients. Endocrine 2025; 90: 303-312.

[16] Wang Z, Wang H, Zhuang C, Chen W, Hoang TM, Li J and Lin H. The effect of type 2 diabetes mellitus on the prognosis of osteoporotic vertebral compression fracture with osteoporotic fracture classification after vertebroplasty. J Orthop Surg Res 2023; 18: 342.

[17] Pollard JD and Krcal CE Jr. Considerations with fractures of the posterior malleolus in ankle fractures. Clin Podiatr Med Surg 2024; 41: 103-117.

[18] Lim B, Shaalan M, O'hEireamhoin S and Lyons F. Syndesmotic fixation in Weber B ankle fractures: a systematic review. PLoS One 2024; 19: e0304148.

[19] Li X, Liu P, Duan R, Wang X, Zhu Q, Ni S and Wang X. Ankle fracture with syndesmotic injury treated by screw fixation: a prospective study on clinical and radiographic outcomes. Front Surg 2025; 12: 1689228.

[20] Xu K, Zhang J, Zhang P, Liang Y, Hu JL, Wang X and Wang J. Comparison of suture-button versus syndesmotic screw in the treatment of distal tibiofibular syndesmosis injury: a meta-analysis. J Foot Ankle Surg 2021; 60: 555-566.

[21] Güngör E, Ercan N, Ovalı SA, Ayduğan MY and Çetin H. Comparison of screw fixation and dynamic fixation in the treatment of ankle fractures with syndesmotic ruptures. Ulus Travma Acil Cerrahi Derg 2024; 30: 900-906.

[22] Chen K, Zhu Q, Huo W, Zhang J and Wang S. Comparison of elastic fixation and rigid fixation in the treatment of distal tibiofibular syndesmosis injury. J Foot Ankle Surg 2026; 65: 28.e1-28.e7.

[23] Yawar B, Hanratty B, Asim A, Niazi AK and Khan AM. Suture-button versus syndesmotic screw fixation of ankle fractures: a comparative retrospective review over one year. Cureus 2021; 13: e17826.

[24] Weng Q, Lin C, Liu Y, Dai G, Lutchooman V and Hong J. Biomechanical analysis of a novel syndesmotic plate compared with traditional screw and suture button fixation. J Foot Ankle Surg 2020; 59: 522-528.

[25] Meekaew P, Paholpak P, Wisanuyotin T, Sirichativapee W, Sirichativapee W, Kosuwon W and Kasai Y. Biomechanics comparison between endobutton fixation and syndesmotic screw fixation for syndesmotic injury ankle fracture; a finite element analysis and cadaveric validation study. J Orthop 2022; 34: 207-214.

[26] Bae KJ, Kang SB, Kim J, Lee J and Go TW. Reduction and fixation of anterior inferior tibiofibular ligament avulsion fracture without syndesmotic screw fixation in rotational ankle fracture. J Int Med Res 2020; 48: 300060519882550.

[27] Spindler FT, Böcker W, Polzer H and Baumbach SF. A systematic review of studies on the diagnostics and classification system used in surgically treated, acute, isolated, unstable syndesmotic injury: a plea for uniform definition of syndesmotic injuries. EFORT Open Rev 2024; 9: 16-24.

[28] Saraglis G, Khan A, Chaudhari H, Pyakurel S, Elahi Rabbani SF and Arafa M. Radiographic evaluation of syndesmosis stabilisation using the TightRope system versus syndesmotic screw fixation for the management of ankle fractures with a syndesmotic injury. Cureus 2023; 15: e45910.

[29] Xu Y, Kang R, Li M, Li Z, Ma T, Ren C, Wang Q, Lu Y and Zhang K. The clinical efficacy of suture-button fixation and trans-syndesmotic screw fixation in the treatment of ankle fracture combined with distal tibiofibular syndesmosis injury: a retrospective study. J Foot Ankle Surg 2022; 61: 143-148.

[30] Stake IK, Andersen MR and Husebye EE. Chronic syndesmotic injury: revision and fixation with a suture button and a quadricortical screw. Foot Ankle Spec 2021; 14: 334-343.

[31] Oliveira Junior AS, Pigossi BD, Saito GH, Nishikawa DRC, Mendes AAM and Prado MP. Treatment of distal tibiofibular syndesmosis injury associated with ankle fractures with suture button. Rev Bras Ortop (Sao Paulo) 2022; 57: 496-501.

[32] Shevate I, Salunkhe R, Pervez F and Pawar P. A prospective study on fixation of syndesmotic ankle injury: tight rope versus screw fixation. Cureus 2024; 16: e67172.

[33] Jlidi M, Bouaicha W, Sbaihi S, Gharbi H, Lamouchi M, Mallek K, Jaziri S and Daas S. Comparative study for surgical treatment of acute distal tibiofibular syndesmotic lesions using the modified suture-button fixation versus static syndesmotic screw fixation. Foot Ankle Spec 2024; 19386400241256440.

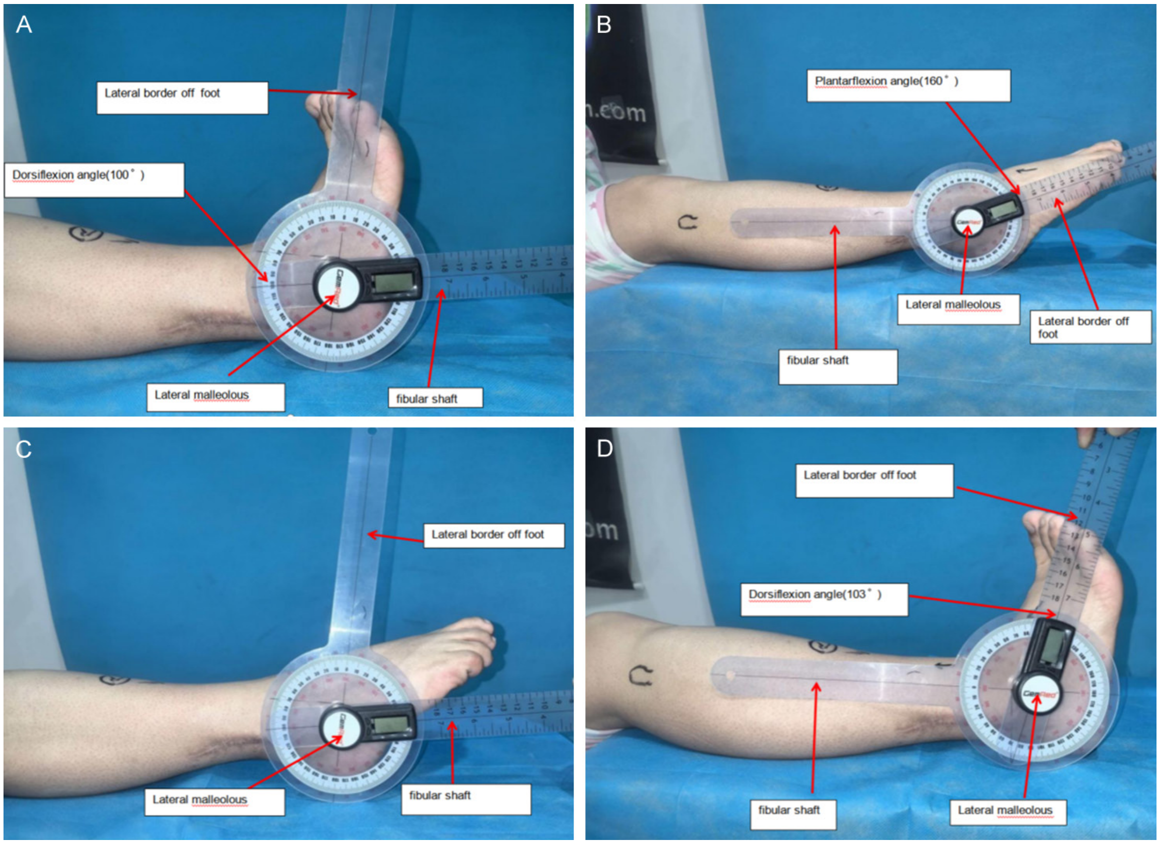

Figure S1. Measurement of ankle dorsiflexion and plantarflexion range of motion. A. Measurement of ankle dorsiflexion. The subject was positioned supine with the knee in a neutral or slightly flexed position. The axis of the goniometer was aligned with the lateral malleolus, the stationary arm with the fibular shaft, and the moving arm with the lateral border of the foot. B. Measurement of ankle plantarflexion using the same subject positioning and anatomical landmarks as in dorsiflexion measurement. C. Representative image demonstrating the neutral ankle position and the alignment of the goniometer with the lateral malleolus (axis), fibular shaft (stationary arm), and lateral border of the foot (moving arm). D. Additional example of ankle dorsiflexion measurement illustrating consistent subject positioning and goniometer alignment. Note: ROM, range of motion.