Original papers

# The distance between the anterior and posterior edges of the fibula at a lateral internal rotation of 15° is associated with postoperative malreduction in patients with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury

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None declared

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## Abstract

**Background.** Malreduction remains a problem in patients with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury. Current methods of malreduction evaluation have many limitations, and novel techniques are required.

**Objectives.** The aim of the study was to investigate the association between the distance between the anterior and posterior edges of the fibula at a 15° lateral internal rotation and postoperative malreduction in patients with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury.

**Materials and methods.** This prospective observational cohort study enrolled 187 patients diagnosed with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury between January 2020 and January 2022. The patients were divided into 2 groups according to their postoperative malreduction condition: the malreduction group and the non-malreduction group. After tibiofibular syndesmosis reduction, a computed tomography (CT) scan was used to measure the distance between the anterior and posterior edges of the fibula at a standard lateral position and a position with a lateral internal rotation of 15°. Demographic data and basic clinical characteristics were recorded for all patients.

**Results.** The mean distance between the anterior and posterior edges of the fibula was longer in malreduction patients than non-malreduction patients at the standard lateral and 15° lateral internal rotation positions. At a lateral internal rotation of 15°, the distance between the anterior and posterior edges correlated negatively with the postoperative Mazur and American Orthopaedic Foot and Ankle Society (AOFAS) scores, and correlated positively with the length of hospitalization and fracture healing time. Receiver operating characteristic (ROC) curves revealed the potential postoperative malreduction diagnostic value of fibular anterior–posterior edge distance using an internal rotation of 15°. Postoperative AOFAS score, length of hospitalization, fracture healing time, and the distance between the anterior and posterior edges of the fibula at a lateral internal rotation of 15° were independent risk factors of malreduction.

**Conclusions.** The fibular anterior–posterior edge distance at an internal rotation of 15° is associated with postoperative ankle joint function and the occurrence of malreduction.

**Key words:** fibular anterior–posterior edge distance, malreduction, tibiofibular syndesmosis reduction, ankle joint fracture

# Background

The lower tibiofibular syndesmosis is vital for ankle joint structural stability and is a site of frequent damage, accounting for 1–11% of all orthopedic ankle joint injuries.[1,2] Despite the development of surgical strategies, malreduction remains a problem in patients with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury.[3,4] The occurrence of malreduction is related to many factors. A recent study reported that malreduction was influenced by incisura morphology, with more shallow syndesmoses likely causing a higher malreduction rate.[5] However, even without considering these factors, it is widely accepted that achieving anatomic reduction remains a significant clinical challenge, even for experienced surgeons.[6]

Current standard malreduction evaluation methods involve measuring the tibiofibular clear space and tibiofibular overlap.[7] However, the fibula is located at the posterolateral side of the tibia; thus, there are few non-overlapping parts of the tibia and fibula in standard ankle joint lateral imaging.[8] When evaluated during surgery, fractures with posterior malleolus and internal fixation can affect the measurement of the lateral fibula position relative to the tibia, affecting the judgment of whether the fibula has a malreduction in the sagittal position.[9,10]

The malreduction rate after the reduction of tibiofibular syndesmosis injury can be as high as 50%, indicating limitations of the current evaluation methods.[11–13] In recent years, many novel potential methods for evaluating malreduction after lower tibiofibular syndesmosis injury have been developed.[3,14] However, most of the studies on the subject were cadaver-based investigations.

# Objectives

The present study aimed to investigate the clinical significance of the distance between the anterior and posterior edge of the fibula at a standard lateral internal rotation of 15° in patients with postoperative malreduction after lower tibiofibular syndesmosis injury. The findings may provide a novel method to predict and reduce malreduction in tibiofibular syndesmosis injury.

# Materials and methods

## Study design and participants

This prospective observational cohort study enrolled 187 patients diagnosed with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury between January 2020 and January 2022. The diagnosis was confirmed in all cases with imaging evidence, such as computed tomography (CT) scan, X-ray and magnetic resonance imaging (MRI). The inclusion criteria were as follows: 1) adults with their first diagnosis of an ankle joint fracture combined with a lower tibiofibular syndesmosis injury; 2) tibiofibular separation requiring reduction of tibiofibular syndesmosis; 3) no ankle joint injury before the study; 4) closed fracture. The following patients were excluded: 1) those with ankle joint injury before the study or previous lower tibiofibular syndesmosis injury; 2) open fracture patients; 3) patients with a surgical contraindication, such as severe cardiovascular, renal or liver dysfunctions. Written informed consent was obtained from all participants. The ethical committee of Zhuzhou Hospital, affiliated to Xiangya School of Medicine (Central South University, Changsha, China) approved the study (approval No. 201905029).

All patients received routine surgeries, with the tibiofibular syndesmosis reduction conducted using either tibiofibular screw or button fixation, as reported elsewhere.[15,16] Follow-up occurred 6 months after surgery, during which patients were divided into malreduction and non-malreduction groups based on postoperative malreduction condition.

## Sample size calculation

For sample size calculation, we used the distance between the anterior and posterior edges of the fibula at a standard lateral internal rotation of 15° as the primary observational factor. The formula to calculate sample size of cohort study, $(Z_{1-\alpha/2\times\sigma}/\delta)^2$, was used, in which $Z_{1-\alpha/2}$ represents standardized value for the corresponding level of confidence, σ represents predicted standard error, and δ represents allowable error. In this study, the value of $Z_{1-\alpha/2} = 1.96$ (at 95% CI), σ = 8.31 according to our previous experience, and δ = 1.19. Thus $n = (1.96\times8.31/1.19)^2 = 187$.

## Measurement of the distance between the anterior and posterior edges of the fibula during surgery

Since the fibula has a posterior arch at the lower end, we rotated the ankle joint 15° inward on the standard lateral position to obtain an overlapping image of the distal posterior edge of the fibula and the posterior edge of the tibia. Then, we measured the distance between the anterior and posterior edges of the most prominent tibia of the ankle joint and the anterior and posterior edges of the fibula on the image obtained at that position.

After the tibiofibular syndesmosis reduction, a CT scan measured the distance between the anterior and posterior edges of the fibula at 2 positions, the standard lateral position and a lateral internal rotation of 15°. The CT scans were obtained with the use of an SCT-7000TS CT scanner (Shimadzu Corp., Kyoto, Japan). Figure 1 depicts typical examples of the images captured.

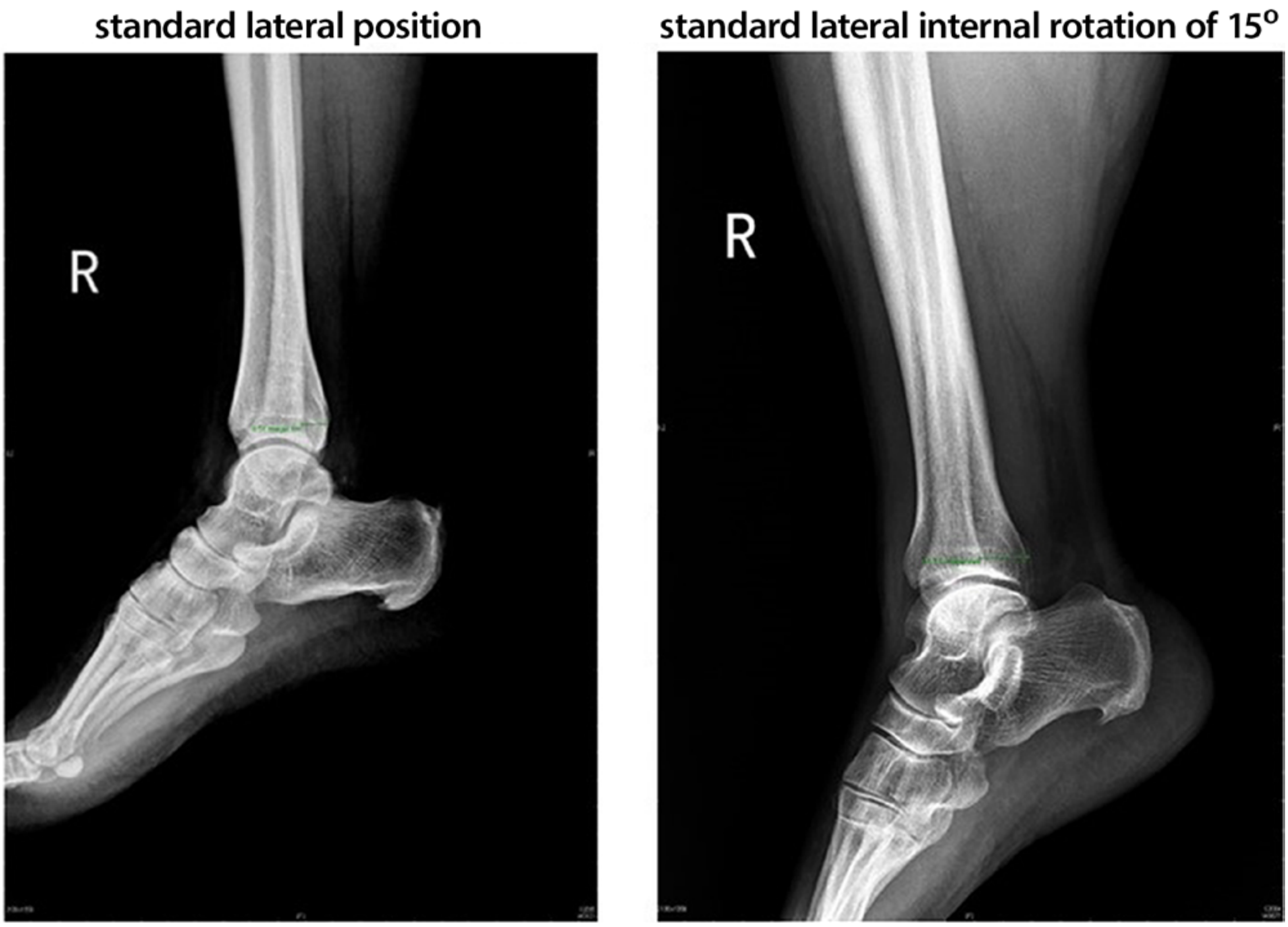


Fig. 1. Typical examples of images showing the distance between the anterior and posterior edges of the fibula at the standard lateral position (a 32-year-old female, on the left) and with a lateral internal rotation of 15° (a 53-year-old female, on the right)

## Measurement of postoperative recovery

Demographic data and basic clinical characteristics were recorded for all patients, including age, sex, body mass index (BMI), cause of fracture, Lauge–Hansen type, and reduction methods. The modified Mazur score and American Orthopaedic Foot and Ankle Society (AOFAS) score evaluated the ankle function before and 6 months after the surgery. The duration of hospitalization and fracture healing time were also recorded. Postoperative complications during the follow-up were noted, and a CT scan confirmed the malreduction after surgery.

## Statistical analyses

Normally distributed data were expressed as mean ± standard deviation (M ±SD), and non-normally distributed data were presented as median (range and interquartile range (IQR)). The Kolmogorov–Smirnov method was used to analyze data distribution. Intergroup comparisons were performed with Student's t-test or Mann–Whitney U test for normally or non-normally distributed data, respectively. The t-test employing Levene's method was used to assess the homogeneity of variance. The $\chi^2$ test was utilized to compare rates, while the relationship between variables was evaluated with Spearman's correlation analysis. A receiver operating characteristic (ROC) curve allowed for assessing the diagnostic value, and the logistic regression analysis was used to evaluate the malreduction risk factor. The Box–Tidwell test was employed to measure continuous data linear relationships, with the variance inflation factor (VIF) assessing multicollinearity. Detailed statistical data are listed in the Supplementary materials. Statistical significance was indicated by $p < 0.05$. All calculations employed IBM Statistical Package for Social Sciences (SPSS) v. 22.0 (IBM Corp., Armonk, USA) and GraphPad Prism v. 6.0 (GraphPad Software Inc., San Diego, USA).

# Results

## Comparison of clinical characteristics between malreduction and non-malreduction patients

Table 1 lists the clinical outcomes for all patients and the comparisons between malreduction and non-malreduction patients. Malreduction was found in 68 cases

Table 1. Basic clinical characteristics between malreduction and non-malreduction patients

| Variables | | All patients (n = 187) | Malreduction (n = 68) | Non-malreduction (n = 119) | t/Z/$\chi^2$ | p-value* |
|---|---|---|---|---|---|---|
| Age [years] | | 40.36 ±12.00 | 41.63 ±11.28 | 39.64 ±12.38 | 1.094 | 0.275 |
| Female sex, n (%) | | 80 (42.78) | 29 (42.65) | 51 (42.86) | 0.001 | 0.976 |
| BMI [kg/m$^2$] | | 26.37 (18.05–34.97, 8.41) | 27.53 (18.11–34.36, 7.60) | 26.16 (18.05–34.97, 8.82) | −0.667 | 0.505 |
| Cause of fracture, n (%) | traffic accident | 118 (63.10) | 45 (66.18) | 73 (61.34) | 0.507 | 0.476 |
| | full | 69 (36.90) | 23 (33.82) | 46 (38.66) | | |
| Lauge–Hansen type, n (%) | supination external rotation | 62 (33.16) | 23 (33.82) | 39 (32.77) | 0.434 | 0.933 |
| | supination adduction | 33 (17.65) | 12 (17.65) | 21 (17.65) | | |
| | pronation external rotation | 52 (27.81) | 20 (29.41) | 32 (26.89) | | |
| | pronation abduction | 40 (21.39) | 13 (19.12) | 27 (22.69) | | |
| Reduction methods, n (%) | tibiofibular screw | 102 (54.55) | 39 (57.35) | 63 (52.94) | 0.393 | 0.531 |
| | button fixation | 85 (45.45) | 29 (42.65) | 56 (47.06) | | |
| Mazur score | before surgery | 46.00 (30.00–60.00, 15.00) | 48.50 (31.00–60.00, 14.75) | 45.00 (30.00–60.00, 15.00) | −1.636 | 0.102 |
| | 6 months after surgery | 79.00 (61.00–98.00, 15.00) | 74.50 (61.00–88.00, 11.75) | 84.00 (70.00–98.00, 16.00) | −6.174 | <0.001 |
| AOFAS score | before surgery | 42.00 (25.00–59.00, 17.00) | 42.50 (26.00–59.00, 16.50) | 42.00 (25.00–59.00, 18.00) | −0.429 | 0.668 |
| | 6 months after surgery | 82.00 (65.00–97.00, 11.00) | 75.00 (65.00–88.00, 10.75) | 86.00 (75.00–97.00, 10.00) | −7.906 | <0.001 |
| | hospitalization [days] | 11.00 (7.00–15.00, 3.00) | 13.00 (10.00–15.00, 2.00) | 9.00 (7.00–12.00, 3.00) | −9.851 | <0.001 |
| | fracture healing [days] | 57.00 (50.00–70.00, 6.00) | 60.00 (50.00–70.00, 9.00) | 56.00 (50.00–60.00, 5.00) | −5.347 | <0.001 |
| Postoperative complications, n (%) | infection | 17 (9.09) | 7 (10.29) | 10 (8.40) | 0.438 | 0.803 |
| | pain | 8 (4.28) | 3 (4.41) | 5 (4.20) | | |
| | exclusive granuloma | 4 (2.14) | 1 (1.47) | 3 (2.52) | | |

*p-values were calculated for comparison between malreduction and non-malreduction patients. Normally distributed data (only age) were compared using the Student's t-test. Non-normally distributed data were analyzed using the Mann–Whitney U test. Rates were compared using the $\chi^2$ test.
The measurement data were expressed as mean ± standard deviation (M ±SD) for normally distributed data or median (interquartile range (IQR), distance) for non-normally distributed data. AOFAS – American Orthopaedic Foot and Ankle Society; BMI – body mass index.

(36.36%). No significant differences were found for demographic data and basic clinical characteristics, including age, sex, BMI, cause of fracture, Lauge–Hansen type, and reduction methods, as well as Mazur and AOFAS scores before the surgery. However, both Mazur and AOFAS scores significantly increased in non-malreduction patients compared with the malreduction patients 6 months after surgery ($p < 0.001$). In addition, hospitalization length and fracture healing time were substantially longer in malreduction patients than in non-malreduction patients ($p < 0.001$). No significant difference was found for other postoperative complications.

## Comparison of the distance between the anterior and posterior edges of the fibula between malreduction and non-malreduction patients

Investigations focused on comparing the distance between the anterior and posterior edges of the fibula between malreduction and non-malreduction patients. As shown in Fig. 2A,B, the mean distance between the anterior and posterior edges of the fibula was significantly longer in malreduction patients than in non-malreduction patients at the standard lateral position and at a lateral internal rotation of 15° ($p < 0.05$).

## The relationship between postoperative recovery and the distance between the anterior and posterior edges

To further investigate the clinical significance of the distance between the anterior and posterior edges, Spearman's correlation analysis evaluated the relationship between anterior and posterior edge distance and postoperative recovery indices. Findings demonstrated that the distance between the anterior and posterior edges correlated negatively with the postoperative Mazur and AOFAS scores when using a lateral internal rotation of 15°, and correlated positively with hospitalization and fracture healing

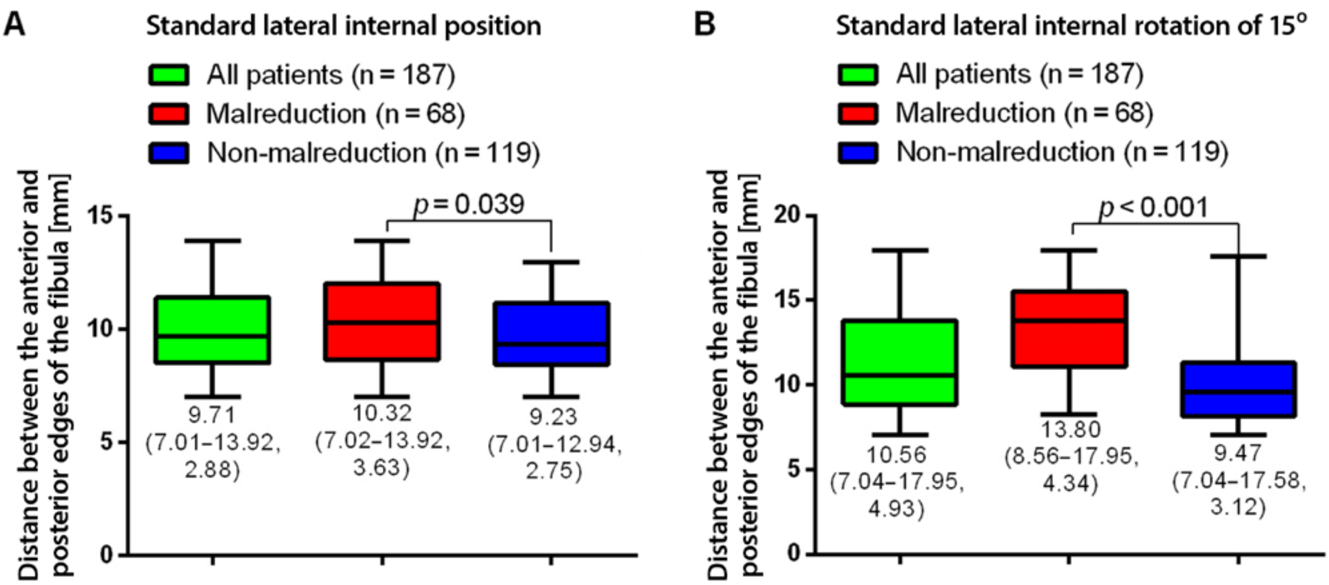


Fig. 2. The distance between the anterior and posterior edges of the fibula between malreduction and non-malreduction patients at the standard lateral position (A) and with a lateral internal rotation of 15° (B). Comparison between the malreduction and non-malreduction groups was evaluated using the Mann–Whitney U test. Data are depicted as median with interquartile range (IQR) and distance

Table 2. Spearman's analysis for correlation between postoperative recovery and distance between the anterior and posterior edges

| Variables | | Spearman's correlation | p-value |
|---|---|---|---|
| Standard lateral position | postoperative Mazur score | −0.104 | 0.158 |
| | postoperative AOFAS score | −0.170 | 0.020 |
| | hospitalization | 0.139 | 0.057 |
| | fracture healing | 0.018 | 0.806 |
| Standard lateral internal rotation of 15° | postoperative Mazur score | −0.208 | 0.004 |
| | postoperative AOFAS score | −0.277 | <0.001 |
| | hospitalization | 0.378 | <0.001 |
| | fracture healing | 0.238 | 0.001 |

AOFAS – American Orthopaedic Foot and Ankle Society.

duration (Table 2). However, a negative correlation was found between the anterior and posterior edge distances and postoperative AOFAS score for the standard lateral position. These results indicated that more extensive anterior and posterior edge distances were associated with poor postoperative recovery, especially for the 15° lateral internal rotation position.

## The diagnostic potential of the distance between the anterior and posterior edge for postoperative malreduction

The ROC curves explored the diagnostic value of the distance between the anterior and posterior edges for postoperative malreduction. As shown in Fig. 3, the area under the curve (AUC) at the standard lateral position was 0.581, with a sensitivity of 60.50% (51.13–69.34%), specificity of 53.62% (41.20–65.72%), and cutoff value >10.06 mm. When using a 15° lateral internal rotation, the AUC was 0.822, with a sensitivity of 75.36% (63.51–84.94%), specificity of 73.95% (65.11–81.56%), and cutoff value >11.18 mm. These results suggested that the distance between the anterior and posterior edges showed potential diagnostic value for postoperative malreduction, particularly for the 15° lateral internal rotation images.

## Logistic regression for risk factors of postoperative malreduction

The risk factors of postoperative malreduction were investigated using univariate and multivariate logistic regression analyses. The postoperative Mazur score, postoperative AOFAS score, length of hospitalization, fracture healing duration, and the distance between the anterior and posterior edges of the fibula at the standard lateral and 15° internal rotation positions were risk factors in the univariate model. In the multivariate regression model, preoperative factors (age, sex, BMI, cause of fracture, Lauge–Hansen type, restoration methods,

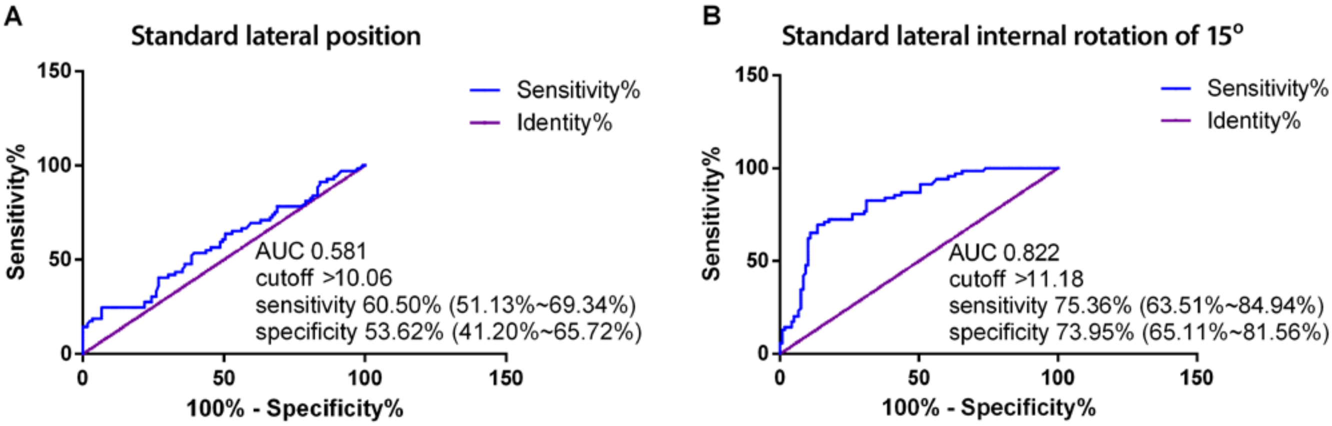


Fig. 3. Receiver operating characteristic (ROC) curves of the distance between the anterior and posterior edges of the fibula for diagnosis of postoperative malreduction using a standard lateral position (A) and a 15° lateral internal rotation (B)

AUC – area under the curve.

Table 3. Binary logistic regression analysis for risk factors of postoperative malreduction

| Variables | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | OR | 95% CI | $R^2$ | p-value | OR | 95% CI | $R^2$ | p-value |
| Age | 0.986 | 0.962–1.011 | 0.009 | 0.274 | 0.989 | 0.961–1.011 | 0.037 | 0.269 |
| Sex | 0.991 | 0.543–1.811 | <0.001 | 0.978 | 1.036 | 0.554–1.936 | | 0.913 |
| BMI | 0.980 | 0.922–1.041 | 0.003 | 0.509 | 0.979 | 0.920–1.042 | | 0.512 |
| Cause of fracture | 1.233 | 0.661–2.299 | 0.003 | 0.510 | 1.255 | 0.663–2.374 | | 0.486 |
| Lauge–Hansen type | 1.044 | 0.806–1.352 | 0.001 | 0.746 | 1.084 | 0.831–1.413 | | 0.552 |
| Restoration methods | 1.195 | 0.656–2.179 | 0.002 | 0.560 | 1.152 | 0.617–2.151 | | 0.657 |
| Preoperative Mazur score | 0.972 | 0.939–1.006 | 0.019 | 0.106 | 0.974 | 0.940–1.009 | | 0.141 |
| Preoperative AOFAS score | 0.994 | 0.964–1.024 | 0.001 | 0.685 | 0.996 | 0.966–1.028 | | 0.818 |
| Postoperative Mazur score | 1.142 | 1.092–1.195 | 0.301 | <0.001 | 1.138 | 0.971–1.333 | 0.926 | 0.110 |
| Postoperative AOFAS score | 1.270 | 1.183–1.363 | 0.479 | <0.001 | 1.345 | 1.109–1.633 | | 0.003 |
| Hospitalization | 0.276 | 0.189–0.403 | 0.691 | <0.001 | 0.236 | 0.114–0.490 | | <0.001 |
| Fracture healing | 0.790 | 0.726–0.858 | 0.284 | <0.001 | 0.718 | 0.548–0.942 | | 0.017 |
| Postoperative complications | 1.022 | 0.635–1.644 | <0.001 | 0.930 | 0.685 | 0.201–2.338 | | 0.546 |
| Anterior and posterior edge distance 1* | 0.831 | 0.706–0.977 | 0.037 | 0.025 | 1.235 | 0.707–2.156 | | 0.458 |
| Anterior and posterior edge distance 2# | 0.634 | 0.554–0.726 | 0.388 | <0.001 | 0.465 | 0.297–0.729 | | 0.001 |

*standard lateral position; #standard lateral internal rotation of 15°; BMI – body mass index; AOFAS – American Orthopaedic Foot and Ankle Society; OR – odds ratio; 95% CI – 95% confidence interval.

preoperative Mazur score, preoperative AOFAS score) and postoperative factors (postoperative Mazur score, postoperative AOFAS score, length of hospitalization, fracture healing duration, postoperative complications, and the distance between the anterior and posterior edges of the fibula for the diagnosis of postoperative malreduction at the standard lateral and 15° lateral internal rotation positions) were analyzed using 2 different models. Postoperative AOFAS score, length of hospitalization, fracture healing time, and the distance between the anterior and posterior edges of the fibula at the 15° internal lateral rotation position were independent risk factors of postoperative malreduction, according to the multivariate analysis (Table 3).

# Discussion

In ankle joint fracture, lower tibiofibular syndesmosis injury is a common complication that, if not appropriately treated, affects ankle joint function.[14] Despite many therapeutic options available for lower tibiofibular syndesmosis, postoperative complications such as infection and malreduction limit their application.[17] Furthermore, traditional methods for evaluating malreduction are insufficient.[18] In the present study, we proposed a novel method for evaluating malreduction by measuring the distance between the anterior and posterior edges of the fibula using a lateral internal rotation of 15°. The distance was longer in patients with postoperative malreduction, which is associated with patient recovery of ankle joint function, and the method has a potential to predict postoperative malreduction.

Postoperative malreduction is a common complication after surgery of lower tibiofibular syndesmosis injury, with malreduction rates reportedly ranging from 15% to 50%. There is no specific effective method to reduce malreduction.[14] In a randomized controlled trial, the authors reported a malreduction rate of 39% for screw fixation and 15% using TightRope fixation for reducing tibiofibular syndesmosis.[19] In addition, a meta-analysis found that malreduction occurred in 12.6% of patients treated with a syndesmotic screw for distal tibiofibular syndesmosis injury.[20] In the present study, malreduction occurred in 36.36% (68/187) of patients.

Currently, the evaluation of postoperative malreduction relies on measuring the tibiofibular clear space and tibiofibular overlap.[21] However, traditional methods have failed to reduce the malreduction rate to an acceptable level. In recent years, some new methods have reported reduced malreduction rates. Futamura et al. demonstrated that using intraoperative perspective mortise views, based on Weber's 3 indexes, could avoid the malreduction of syndesmosis, with an AUC of 0.857 in the diagnosis potential.[22] Another study reported using the Leporjärvi clear space for lateral translation, the Nault anterior tibiofibular distance for posterior translation, and the Nault talar dome angle for external rotation of the fibula as potential measuring methods for detecting isolated malreduction in distal tibiofibular syndesmosis injury.[23] In a recent study, Bai et al. found that when the syndesmosis was fixed at an internal rotation of 20°, the tibiofibular clear space and the anteroposterior ratio could achieve a diagnostic value of 92.3% and a sensitivity of 100% for syndesmosis malreduction.[24]

The current research proposed a novel method for measuring the distance between the anterior and posterior edges of the fibula using a lateral internal rotation of 15°. We found that the distance between the anterior and posterior edges of the fibula was associated with postoperative ankle joint function and malreduction occurrence, in which a longer distance predicted a higher rate of malreduction and worse ankle joint function.

## Limitations

The present study was limited by being a single-center trial with a small sample size that only analyzed short-term efficacy after surgery. As such, the relationship between the fibular anterior and posterior edge distance and long-term surgical efficacy is unclear. These issues require further study to provide adequate evidence.

# Conclusions

In summary, the distance between the anterior and posterior edges of the fibula was associated with postoperative ankle joint function and malreduction occurrence when using a lateral internal rotation of 15°. These findings may prove a novel method for evaluating postoperative malreduction after reduction surgery in patients with an ankle joint fracture combined with a lower tibiofibular syndesmosis injury.

## Supplementary data

The supplementary materials are available at https://doi.org/10.5281/zenodo.8087392. The package contains the following files:

Supplementary Table 1. Information on t-test from Table 1.

Supplementary Table 2. Assumptions for logistic regression from Table 3.

Supplementary Fig. 1. Normality test for continuous data.

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