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RESEARCH ARTICLE

Optimizing Syndesmotic Injury Management: Radiological Indicators and Screw Trajectory Techniques

M. Ponmalai[1], Srinivasan S[1], Anbarasan A[1], Sankara Narayanan G[1], Sameen Taj[1], Subramanian A[2] and Yuvaraj M[1]

[1]Department of Anatomy, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences, Chennai 602105, Tamil Nadu, India.

[2]Department of Orthopaedics, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences, Chennai 602105, Tamil Nadu, India.

*Corresponding Author
Subramanian A

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Abstract: Syndesmotic injuries frequently occur alongside ankle fractures and require precise management to avoid malreduction. This study explores the use of radiological indicators to assess intraoperative reduction adequacy without specialized equipment. Using 3D models reconstructed from CT scans of 150 patients, we analyzed the morphology of the syndesmotic joint and identified consistent landmarks for optimal screw placement. Key findings include the reliability of proximal fibula overlap as a landmark for determining internal rotation and screw trajectory. The proposed technique proved superior to traditional tibial tubercle methods, offering greater consistency and practicality under standard fluoroscopic imaging. Additionally, the study highlighted significant frequencies of syndesmotic joint asymmetry (29.4%) and side differences (19.6%), emphasizing the need for careful evaluation of the contralateral joint. Although limitations such as increased fluoroscopy exposure and variability in anatomical conditions exist, these findings provide actionable insights for enhancing surgical outcomes. Future clinical studies are recommended to validate and refine these methods.

Keywords: Syndesmotic Injury, Proximal Fibula Overlap, Tibial Torsion Angle, Screw Trajectory Optimization, Radiological Indicators.

INTRODUCTION

Syndesmotic injury or instability frequently accompanies ankle fractures and has traditionally been treated with a trans-syndesmotic screw. However, the dynamic suture-button technique has recently gained popularity due to its potential benefits over the conventional screw fixation method. Regardless of the fixation approach, achieving the optimal trajectory for implant placement is critical to avoiding iatrogenic malreduction. [1]

To manage syndesmotic instability, surgeons typically rely on intraoperative assessments of reduction adequacy using conventional radiography, which includes plain and fluoroscopic imaging. These methods do not require specialized equipment. [2] Radiographic evaluation of the syndesmotic joint is traditionally performed using anteroposterior (AP), lateral, and mortise views. In the mortise view, the medial clear space between the talar dome and the distal tibia should measure no more than 2 mm. To obtain this view, the leg is internally rotated 15°–20°, aligning the intermalleolar line parallel to the detector. This position often places the fifth toe in line with the center of the calcaneum.

However, AP and mortise radiographs are known to lack precision in assessing syndesmotic reduction. Postoperative computed tomography (CT) is a more accurate modality for evaluating the syndesmosis. It is common for intraoperative fluoroscopic images to suggest adequate fibular positioning, only for postoperative CT scans to reveal slight anterior or posterior displacement of the fibula within the tibial incisura. [3] Additionally, tibial torsion—a variable anatomical parameter—can complicate the accurate determination of the injured ankle's rotational alignment. Preoperative measurements of the contralateral, uninjured leg are recommended to account for individual variability.

Recent studies have proposed using the tibial tubercle (TT) as a consistent intraoperative landmark for assessing syndesmotic reduction and guiding the trajectory of fixation screws. Despite this, some orthopedic surgeons have questioned the clinical relevance of this landmark due to anatomical variations in the tibial tubercle, as raised in academic discussions and professional congresses focused on foot and ankle surgery. [4]

Building on these findings, the authors explored an alternative, reliable landmark: the degree of overlap between the proximal fibula and the lateral tibial margin. This overlap has been utilized in clinical practice as a consistent indicator for determining the leg's internal rotation. This cadaveric study aimed to validate the clinical significance of this overlap, examine the morphology of the syndesmotic joint, evaluate the implications for optimal fixation, and compare the practical utility of the tibial tubercle versus the fibula-tibia overlap. The investigation involved analyzing three-dimensional (3D) models and simulating the virtual implantation of a syndesmotic screw to identify the most effective approach. [5]

MATERIALSANDMETHODS

Digital data of the human body were collected with proper consent and utilized for this study, conducted at Saveetha Medical College and Hospital, affiliated to SIMATS, Chennai, India. in 2022. CT images were obtained from 150 patients who underwent continuous 1.0 mm slice CT scans in the supine position. Patients with joint or tibiofibular bone abnormalities were excluded based on a review of their medical records. The final cohort included 150 individuals (80 males and 70 females) with an average age of 52.4 years (range: 21–60 years; SD: 9.12) and an average height of 160.58 cm (range: 146–176 cm; SD: 7.23).

CT data in Digital Imaging and Communications in Medicine (DICOM) format were imported into specialized software to reconstruct 3D models of the tibia, fibula, and talus. After generating these 3D models, the CT scanning planes were reoriented to produce anatomical axial and coronal images parallel to the tibial plafond in a neutral rotation. [6]

A life-sized 3D cylinder model (diameter: 3.5 mm; length: 100 mm) was designed using 3D CAD software to simulate syndesmotic screw fixation in the distal tibiofibular joint. Following the creation of 3D bone and implant reconstructions, virtual implantation of syndesmotic screws (represented as syndesmotic cylinders) was performed using synchronized views in axial, coronal, sagittal, and 3D biplanar images. In the true coronal plane, a provisional line (1 mm in diameter) was marked at the proximal end of the incisura fibularis to establish the screw height. [7] In the axial plane, this line was adjusted to bisect the fibula and incisura fibularis, defining the ideal trajectory for the syndesmotic cylinder. The placement was refined and verified multiple times by experienced surgeons involved in the study.

To account for tibial torsion and its variability, a proximal tibial cylinder (diameter: 3.5 mm; length: 150 mm) tangent to the posterior tibial condyles was traced. The angle between the proximal cylinder and the syndesmotic screw was measured for individual comparisons. [8]

Using the software's capability for free 360° rotation and magnification in any plane, the morphology of the syndesmotic joint was analyzed. [9-13] The 3D models were rotated until the syndesmotic cylinder was parallel to the ground without tilt, defining the syndesmotic anteroposterior (AP) projection. In this projection, the degree of overlap between the proximal fibula and the lateral border of the tibia was assessed as a practical and consistent landmark. [14, 15] Additional indicators, such as the relationship between adjacent bones, a regular Shenton's line, and Weber's indices, were evaluated and compared with conventional ankle mortise projections.

Measurements were reported as means with ranges or binary variables, including the overlap point, tibial torsion, and others. Statistical analyses were conducted using a standard statistical software package. P-values below 0.05 were considered statistically significant.

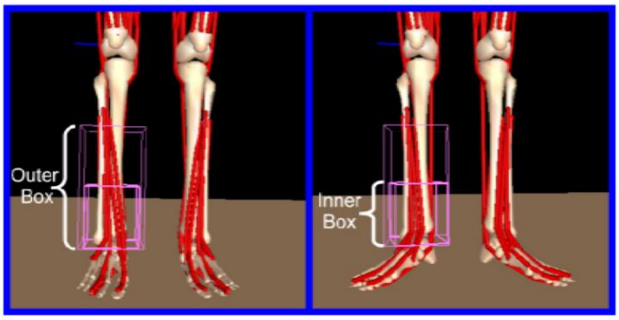

Figure 1: Tibiofibular Joint Morphology and Tibial Torsion: 3D Perspective on Syndesmotic Screw Placement

RESULTS

The analysis of syndesmotic joint characteristics in a cohort of 150 patients revealed significant findings. The average Tibial Torsion Angle (TTA) was measured at 36.7° (range: 17.2°–54.4°, SD: 8.78). A statistically significant difference was observed between men (38.6° ± 8.66°) and women (35.0° ± 8.60°, $p = 0.038$).

Regarding proximal fibula overlap in the AP projection, the overlap was found to be nonlinear or linear across all cases. The syndesmotic joint types were classified into two categories: flat joints (66 cases) and crescent joints (84 cases).

The position of the distal fibula in the incisura was symmetric in 107 cases, while 43 cases (28.7%) showed asymmetry. Side differences in the distal fibula position were noted in 30 cases (20.0%). These differences were found to be significantly influenced by joint symmetry, with an odds ratio of 3.50 (95% CI: 1.235–9.936, $p = 0.018$), indicating that symmetric syndesmosis increased the risk of side differences. [16]

The height of the incisura fibularis averaged 26.6 mm (range: 21.1–32.7 mm, SD: 2.51), with no statistically significant differences between men (26.2 ± 2.76 mm) and women (27.07 ± 2.21 mm, $p = 0.067$).
Similarly, the cadaver height showed no significant association with joint type: 161.1 ± 7.56 cm for flat joints and 160.2 ± 7.00 cm for crescent joints ($p = 0.560$).

In summary, significant differences in tibial torsion and syndesmotic joint symmetry were identified, with symmetry impacting the likelihood of side differences. The data further underscore the variability of syndesmotic joint morphology and its implications for clinical assessment and treatment.

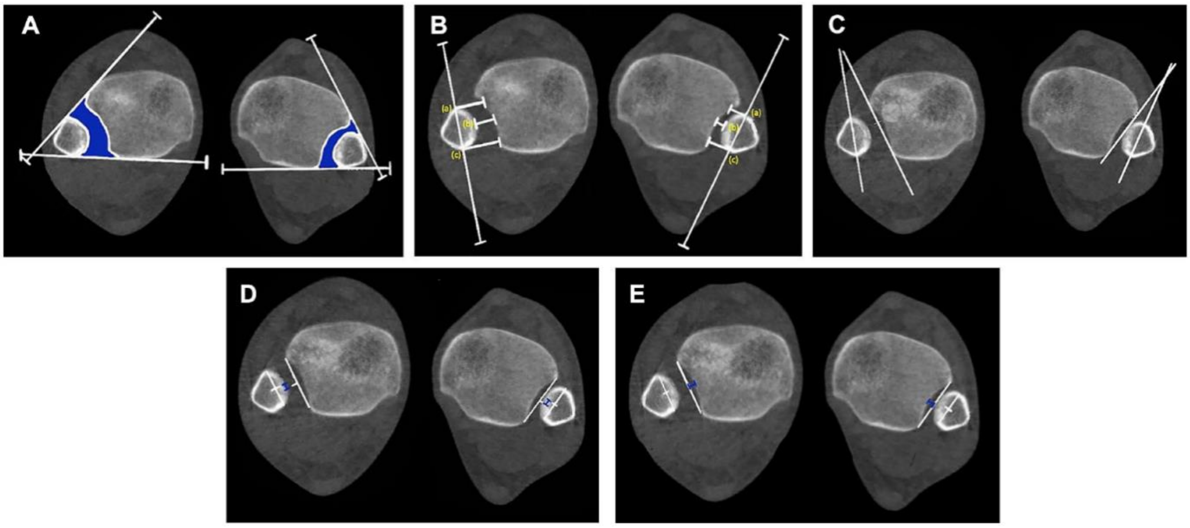

Figure 2: Tibial Torsion Angle Variations and Syndesmotic Joint Types in Clinical Assessment

Table 1: Analysis of Syndesmotic Joint Characteristics in a Study of 150 Patients

Parameter	**Value**	**Statistical Significance (p-value)**
Tibial Torsion Angle (TTA)	36.7° (Range: 17.2°–54.4°, SD: 8.78)	-
TTA in Men	38.6° ± 8.66°	-
TTA in Women	35.0° ± 8.60°	0.038
Proximal Fibula Overlap in AP Projection	Nonlinear or linear overlap	-
Syndesmotic Joint Type - Flat	66 cases	-
Syndesmotic Joint Type - Crescent	84 cases	-
Distal Fibula Position - Symmetric	107 cases	-
Distal Fibula Position - Asymmetric	43 cases (28.7%)	-
Side Differences in Distal Fibula Position	30 cases (20.0%)	-
Height of Incisura Fibularis (Overall)	26.6 mm (Range: 21.1–32.7 mm, SD: 2.51)	-
Height of Incisura Fibularis in Men	26.2 ± 2.76 mm	0.067
Height of Incisura Fibularis in Women	27.07 ± 2.21 mm	0.067
Height of Cadaver with Flat Joint Type	161.1 ± 7.56 cm	0.560
Height of Cadaver with Crescent Joint Type	160.2 ± 7.00 cm	0.560
Odds Ratio for Symmetry Impact on Side Difference	3.50 (95% CI: 1.235–9.936)	0.018

DISCUSSION

The management of syndesmotic injuries poses two key challenges: identifying subtle instability and evaluating intra- and postoperative reduction adequacy without relying on specialized software or equipment. [17] This computational anatomy and simulation study highlights consistent radiological indicators that can assist in assessing reduction adequacy while accounting for variations in tibial torsion and the depth of the incisura fibularis. The findings provide practical insights that can be applied without the need for advanced tools:

1. The optimal screw trajectory was determined to be parallel to the ground when the leg was internally rotated sufficiently to create either linear or nonlinear overlap between the proximal fibula and tibia. This relationship was consistent regardless of individual variations in tibial torsion and joint morphology.
2. Due to the relatively high frequency of side differences (19.6%) and joint asymmetry (29.4%) in the syndesmotic joint, careful preoperative evaluation of the contralateral syndesmotic joint is essential to guide reduction adequacy. During surgery, maintaining the alignment of the lateral talar border just medial to the anterior tibial tubercle in the syndesmotic

AP projection could serve as a reliable intraoperative reference for assessing reduction adequacy.

3. The proposed screw trajectory, which bisects the fibula and incisura fibularis, minimizes eccentric movement of the fibula caused by compressive forces, offering improved outcomes.

Initially, the tibial tubercle (TT view) was employed to determine the internal rotation required for screw placement. However, this method occasionally led to suboptimal trajectories due to inadequate or excessive rotation. Clinical experience demonstrated that the degree of overlap between the proximal fibula and tibia is a more consistent and practical landmark. Computational simulations confirmed this overlap to be superior to the tibial tubercle as a landmark, showing less variation.

Using the syndesmotic AP projection, this study demonstrated that screw trajectory, screw height, and reduction adequacy could be reliably evaluated in real-time under standard fluoroscopic imaging. This method also allowed verification of talar positioning in response to the compressive force of the screw. Given the difficulties in detecting subtle syndesmotic widening and fibular malreduction using standard radiographic views, the proposed technique is a practical alternative that does not require additional equipment.

The study further highlighted notable findings on syndesmotic joint morphology. Symmetry and side differences in the ankle syndesmosis were observed with relatively high frequencies of 29.4% and 19.6%, respectively. Symmetric joints were found to have a 3.4-fold increased risk of side differences, underscoring the need for caution when using the contralateral normal ankle as a reference. The syndesmotic joint type distribution showed 41.9% flat joints, while the incisura fibularis averaged 26.6 mm in depth, with no significant differences by joint type or sex. The proximal end of the incisura fibularis consistently served as an ideal screw insertion point, regardless of individual variations. [18]
Despite these findings, this study has several limitations. Measurements were based on normal ankle joints, which may result in a descriptive rather than comparative analysis. Accuracy and precision in assessing areas with known variability are critical, and errors in the results cannot be ruled out. The overlapping method may increase fluoroscopy exposure compared to traditional techniques, and identifying proximal fibular overlap may be challenging in patients with multiple fractures or tibial deformities. In cases such as high fibular fractures (e.g., Maisonneuve fractures), anatomical reduction and fixation must take precedence.

Nevertheless, the findings provide valuable insights into the anatomy of syndesmotic joints and the optimal trajectory for screw placement. They also highlight practical techniques for assessing reduction adequacy using standard imaging. Considering reports that up to 80% of malreductions occur after syndesmotic fixation, further comparative clinical studies incorporating postoperative CT evaluations are warranted to validate and refine these methods.

CONCLUSION

This study provides important insights into the management of syndesmotic injuries, emphasizing practical approaches to assess reduction adequacy without requiring specialized equipment. By identifying consistent radiological indicators such as proximal fibula overlap and optimizing the screw trajectory, this research offers reliable, clinically applicable methods for intraoperative and postoperative evaluations.

Key findings highlight the significance of the proposed screw trajectory, which bisects the fibula and incisura fibularis, as well as the importance of preoperative assessment of the contralateral syndesmotic joint, given the observed high frequencies of joint asymmetry and side differences. The use of syndesmotic AP projection and its ability to reliably evaluate screw placement and reduction adequacy in real-time further strengthen the practicality of this method.

Despite inherent limitations, such as reliance on normal joint data and potential increased fluoroscopy exposure, the study underscores the value of computational anatomy and simulation in advancing syndesmotic fixation techniques. Future research should focus on comparative clinical studies, particularly those incorporating postoperative CT scans, to validate and refine these findings, with the ultimate goal of reducing malreduction rates and improving patient outcomes.

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