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Sagittal Ankle Position Does Not Affect Axial CT Measurements of the Syndesmosis in a Cadaveric Model

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Abstract

Background: The purpose of this study was to evaluate the effect of ankle plantarflexion and the axial location of measurement on quantitative syndesmosis assessment.

Methods: Twelve fresh frozen cadaveric specimens were secured in three positions of ankle plantarflexion (0, 15, & 30 degrees) using an ankle spanning external fixator and underwent CT scans at each position. Syndesmotomic measurements were obtained on axial images using 3 previously described methods (6 measurements) at the level of the tibial plafond and 1cm proximal to the plafond. Method 1 evaluated the distance between the most anterior and posterior aspects of

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the fibula and tibia. Method 2 measured medial-lateral diastasis of the anterior and posterior aspects of the fibula, and fibular anterior-posterior translation. Method 3 evaluated axial rotation of the fibula. All measurements were performed by two independent observers. Inter-rater reliability of each measurement was evaluated using intra-class coefficients. Repeated measures analysis of variance (RM-ANOVA) was performed to evaluate within-specimen differences in measurements obtained at varying ankle positions.

Results: The anterior incisura component of method 1 demonstrated poor to moderate inter-rater reliability across all ankle positions and at both measurement locations. Inter-rater reliability was highest for method 2, especially when measured 1cm proximal to the plafond. Method 3 demonstrated moderate reliability 1cm proximal to the plafond. After correcting for multiple comparisons, RM-ANOVA and pairwise analysis revealed that none of the measurements changed significantly with varying ankle position.

Conclusion: The inter-rater reliability of the most common method of syndesmotom evaluation (method 1) was found to be lower than in previous studies. The most reliable syndesmotom evaluation can be made by measuring diastasis and anteroposterior translation 1cm proximal to the plafond (method 2). Ankle position from 0 to 30 degrees of plantarflexion did not change the measurements obtained.

Keywords

Malreduction; Ankle fracture; Tibio-fibular relationship; Ankle ligamentous stability; Computed tomography; Supination external rotation; Pronation external rotation

INTRODUCTION

The tibiofibular syndesmosis is frequently injured in operatively treated ankle fractures. [1-3] Several techniques for restoring the anatomy of the syndesmosis have been described with favorable results, including trans-syndesmotom screw fixation, anatomic reduction and fixation of posterior malleolar fractures, posterior and/or anterior inferior tibiofibular ligament repair, and suture-button type fixation.[3-8] Unfortunately, malreduction of the unstable syndesmosis has been reported to occur in as many as 50% of cases.[9] Syndesmotom malreduction has been associated with the risk of developing post-traumatic arthritis, which is thought to be related to the significantly increased contact forces generated across the tibiotalar joint in response to tibiofibular diastasis greater than 1mm or fibular rotation beyond 5-10 degrees.[10-12] Although the clinical impact of syndesmotom malreduction is controversial, several studies have demonstrated inferior clinical outcomes in patients with malreductions of the syndesmosis.[6,13-20] The precise degree of malreduction that is associated with inferior outcomes is unknown, in part due to the lack of understanding of how the tibiofibular relationship changes in varying ankle positions and with different measurement strategies.

The pitfalls of using radiographs for the assessment of syndesmotom reduction include variability in the standard measurements of tibiofibular relationships (tibiofibular overlap and tibiofibular clear space)[21] and several normal bony anatomic variants, including the deep crescent and shallow rectangular morphologies present in 67% and 33% of patients

respectively.[22] Computed tomography (CT) is widely thought to be the most sensitive means of assessing syndesmotoc reduction after fixation of rotational ankle fractures.[23-27] There is no standardized definition of syndesmotoc malreduction; however, recent studies have evaluated injured syndesmoses in comparison to the uninjured contralateral extremity with regards to fibular rotation and medial-lateral translation, using 1-2mm of side-to-side discrepancy as a cut-off which is indicative of malreduction.[28,29] Several CT methods of evaluating the tibiofibular relationship at the level of the ankle have been established.[30] By convention, measurements are obtained 1cm proximal to the tibial plafond.[31] To our knowledge, other locations for measurement have not been systematically evaluated. Additionally, while it is known that the fibula internally rotates within the incisura during ankle plantarflexion, no studies have calculated the effect of ankle position in the sagittal plane on the various methods of syndesmotoc measurement. Prior studies defining malreduction in comparison to the contralateral extremity have not standardized ankle position. It is unknown whether a change in ankle position causes variations in syndesmotoc measurements, and if so, how this has affected the reported incidence of malreduction in prior studies. Therefore, the purpose of this study was to evaluate the effect of ankle plantarflexion and the axial location of the measurement on quantitative syndesmosis assessment.

MATERIALS AND METHODS

Six fresh-frozen matched pair (n=12) cadaveric thigh-to-foot specimens without history of lower extremity injury were studied. All specimens were skeletally mature (mean age 70.5, range 57 to 78). The proximal and distal tibiofibular articulations remained intact. Each specimen was secured in three different positions of ankle plantarflexion (0 degrees, 15 degrees & 30 degrees) using an ankle spanning external fixator with the ability to control ankle position in the sagittal plane (Figure 1), and then underwent a CT scan at each ankle position. A standard CT protocol was used including 0.5-mm slice thickness, 120-kVp voltage, 150-mA current, and 500-ms exposure.

The syndesmosis was evaluated using three previously described methods of measurement, including six individual parameters (Figure 2). [28,28,29,32,32-34] The included measurements were chosen because they had each been utilized in at least two different previous studies evaluating either malreduction of the syndesmosis or reliability of syndesmotoc measurements. Method 1 evaluates the shortest distance between the most anterior aspect of the fibula and tibia tubercles (AI, anterior incisura) and the shortest distance between the most posterior aspects of the fibula and tibia tubercles (PI, posterior incisura). Method 2 measures medial-lateral diastasis of the anterior and posterior aspects of the fibula, as well as fibular anterior-posterior translation. Medial-lateral diastasis was measured first by drawing a line through the fibula to define the fibular axis at its longest anterior-posterior dimension. Along this line, at the anterior and posterior most aspects of the fibula, a perpendicular line was drawn from the fibula to the tibial incisura. The anterior perpendicular line indicated anterior fibular diastasis (DA, direct anterior), while the posterior perpendicular line indicated posterior fibular diastasis (DP, direct posterior). Finally, to identify anterior-posterior translation of the fibula, the distance between the anterior diastasis line and the most prominent aspect of the anterior tubercle of the incisura

was measured in a direction parallel to the initial fibular axis line (DT, direct translation). Method 3 evaluates axial rotation of the fibula with respect to the tibia by comparing the anterior-posterior axis of the fibula with a line tangential to the anterior and posterior tubercles of the incisura, with positive values indicating internal rotation of the fibula (R, rotation). Each of the above methods have demonstrated acceptable reliability in prior literature.[28,29,32] Using 3-D rendering software in the Picture Archiving and Communication System (PACS), all syndesmotic measurements were obtained on axial images at the level of the tibial plafond (the distal most axial slice without articular cartilage present) and 1cm proximal to the plafond (12 measurements per specimen; Figure 3).

All measurements were independently performed by two investigators. Inter-rater reliability for the two observers were evaluated with intra-class coefficients (ICCs). ICCs were interpreted according to the ICC interpretation criteria of Koo and Li, with ICC values below 0.5 indicating poor reliability, between 0.5 to 0.75 indicating moderate reliability, above 0.75 indicating good reliability, and above 0.90 indicating excellent reliability.[35]

Repeated measures analysis of variance (RM-ANOVA) was performed on each of the averaged syndesmosis measurements to evaluate differences in measurements obtained at varying ankle positions within specimens. This maximizes statistical power by using each specimen as its own internal control. Bonferroni-corrected non-parametric pairwise comparisons were applied to determine significant pairwise differences. All comparative calculations were two-tailed and statistical significance was set at $p = 0.05$.

RESULTS

Thirty-six CT scans were reviewed (12 cadaveric specimens imaged at 3 ankle positions each). Measurements obtained from two independent observers were compared for all 6 parameters at both measurement locations respectively (the level of the plafond and 1cm proximal to the plafond). The absolute values (mean of two observers) and standard deviations for each of the 6 parameters, 2 measurement locations and 3 ankle positions are shown in Table 1. Standard deviations above the mean were seen with the direct translation (DT) and rotation (R) parameters when these measurements were obtained at the level of the plafond.

The ICC was also determined for each parameter (Table 2). The anterior incisura (AI) measurement (method 1) demonstrated ICCs below 0.75 (ICC 0.601 at the plafond and 0.559 1cm proximal to the plafond). The posterior incisura (PI) measurement (method 1) had excellent inter-rater reliability when measured at the plafond (ICC 0.901). The PI measurement also demonstrated good reliability when measured 1cm proximal to the plafond (ICC 0.771), with moderate reliability when stratifying by ankle position (Appendix A). The three measurements included in method 2 (direct translation, direct anterior, direct posterior) showed good to excellent reliability with ICCs above 0.8 at the level of the plafond and 1cm proximal to the plafond. When stratified by individual ankle position, good to excellent reliability remained in the direct anterior (DA) and direct translation (DT) parameters when measured 1cm proximal to the plafond, while the direct posterior (DP) parameter showed overall moderate ICCs at this location. The fibular rotation measurement

(method 3) had good reliability (ICC 0.870) when measured at the plafond but only moderate reliability (ICC 0.615) when measured 1cm proximal to the plafond.

RM-ANOVA revealed statistically significant differences in syndesmosis measurements at 0, 15 and 30 degrees of plantarflexion when the posterior incisura (PI, method 1) were obtained at both the level of the tibial plafond and 1cm proximal to the plafond as well as the direct posterior measurement (DP, method 2) when measured 1cm proximal to the plafond. However, pairwise comparisons revealed no statistically significant difference between the ankle positions when corrected for multiple comparisons (Table 3).

DISCUSSION

The results of this cadaveric study reveal consistency in several of the commonly used syndesmotic measurements with varying ankle positions when measured at both 1cm above the plafond and at the plafond itself. None of the parameters at these two locations were altered significantly by changing ankle position. However, this study found notable differences in inter-rater reliability when compared to prior literature. A comparison of ICCs between this study and all three measurement methods presented by Warner et al. in 2015 are seen in Table 2 [29].

Although method 1 has been most widely used in the literature, the anterior incisura measurements in this study demonstrated only moderate inter-rater reliability when measured both at the plafond (ICC 0.601) and 1cm proximal to the plafond (ICC 0.559). This finding differs from Warner et al. in which good reliability (ICC 0.779) was found when measured 1cm proximal to the plafond, but is in keeping with those of Nault et al. in 2013 who found an ICC of 0.635 for the anterior incisura measurement.[29,32] The other component of method 1 measurements, the posterior incisura measurement, similarly had inconsistent results across studies. In contrast, method 2 demonstrated excellent inter-rater reliability for two of the three parameters in both the present study and in the study by Warner et al.[29] Comparisons could not be made to the study by Nault et al. due to a different measurement technique used in that study.[32]

The discrepancy between the results in these three studies may be due to subtle variations in measurement distance from the plafond (as limited by the precision of thin cut CT axial slices) as well as the fact that Warner et al. evaluated the ICC of measurement differences between injured and uninjured ankles, Nault et al. evaluated the ICC of absolute measurements of uninjured syndesmoses with concurrent foot trauma, and this study evaluated the absolute measurements in uninjured cadaveric specimens at varying ankle positions. Despite these differences, methods 1 and 3 show significant variation in measurement reliability between studies and between measurement location, and therefore may not be reliable in drawing conclusions about syndesmotic malreduction. Similarly, given its reproducibly high inter-rater-reliability across studies and at different measurement locations, as well as no apparent difference in measured values with respect to the studied ankle positions, method 2 appears to be the most reliable of the three methods studied.

With regard to measurement location, two of the six parameters (DT/method 2 and rotation/method 3) demonstrated unacceptably high standard deviations when measured at the plafond. Although these parameters had high inter-rater reliability, the high standard deviations limit the utility of using these parameters when measuring at the level of the plafond. In contrast, all parameters had acceptable standard deviations in keeping with normative values from prior literature when measured 1cm proximal to the plafond. [29,32-34] For this reason, measurements obtained 1cm proximal to the plafond appear to be more reliable and reproducible compared to measurements taken at the level of the plafond.

Limitations of this study include the small sample size, use of non-injured cadaveric specimens and lack of dorsiflexion imaging. In uninjured ankles, the fibula internally rotates within the incisura during ankle plantarflexion.[36] After injury to the syndesmosis or stabilization of a syndesmotic injury, this normal rotation may be altered, and this would not be reflected in this model. All imaging was obtained with non-weightbearing CT scans; therefore, conclusions cannot be drawn in relation to the effect of weight-bearing on these measurements. Additionally, the ankle position was determined grossly using a goniometer rather than on sagittal imaging; however, this method more closely imitates clinical practice.

Despite these limitations, this study has implications for measuring syndesmotic reduction after fracture surgery, as the inter-rater reliability of the most common method of syndesmosis evaluation (method 1) was found to be poorer than in previous studies. While there remains a need for identifying the precise amount of syndesmotic malreduction that is clinically relevant, the results from the current study suggest that the optimal measurement method for future research is method 2 (including anteroposterior and medial-lateral translation of the fibula relative to the tibia) when measured 1cm proximal to the plafond. This method demonstrated the highest inter-rater reliability seen in both clinical studies of injured and uninjured syndesmosis as well as cadaveric studies. Ankle position between 0-30 degrees of plantarflexion does not seem to affect syndesmotic measurements, indicating that comparisons to contralateral extremities should not be significantly affected by position of the uninjured ankle.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1:
Cadaveric specimen with ankle spanning external fixator in place

Figure 2:
Methods of measuring syndesmotibiofibular relationship

Figure 3:

Example of coronal and sagittal and reformatted images with associated axial location of measurements: proximal (1cm proximal to the tibial plafond) and distal (at the level of the tibial plafond)

Table 1:

Mean and Standard Deviation of Absolute Syndesmotic Measurements for Varying Ankle Positions

Measurement Location	Parameter	0 degrees	15 degrees	30 degrees
Plafond	Anterior Incisura (AI)	6.05 ± 1.48	6.11 ± 1.19	6.03 ± 1.23
	Posterior Incisura (PI)	7.39 ± 1.51	7.39 ± 1.47	7.07 ± 1.42
	Direct Anterior (DA)	5.95 ± 1.65	5.92 ± 1.48	5.83 ± 1.23
	Direct Posterior (DP)	7.25 ± 1.63	7.25 ± 1.72	7.00 ± 1.56
	Direct Translation (DT)	1.29 ± 2.03	1.24 ± 2.11	1.09 ± 2.37
	Rotation (R) *	2.65 ± 3.88	2.48 ± 3.17	1.94 ± 3.65
1cm proximal to plafond	Anterior Incisura (AI)	4.43 ± 0.77	4.50 ± 1.02	4.48 ± 0.96
	Posterior Incisura (PI)	8.19 ± 1.31	7.78 ± 1.49	7.79 ± 1.46
	Direct Anterior (DA)	5.46 ± 1.64	5.11 ± 1.54	4.97 ± 1.24
	Direct Posterior (DP)	8.63 ± 2.01	8.57 ± 2.82	8.67 ± 2.5
	Direct Translation (DT)	2.77 ± 1.25	2.83 ± 1.31	3.13 ± 1.52
	Rotation (R) *	13.54 ± 7.53	12.88 ± 7.29	13.55 ± 7.75

* Rotation measurements reported in degrees with positive values indicating internal rotation of the fibula. All other measurements reported in mm.

Table 2:

Intra-class Coefficients (ICCs) Evaluating Inter-Rater Reliability of Syndesmotomic Measurements

Measurement Location	Parameter	ICC (Present study, 2 independent observers)	ICC (Warner et al. 2015, 2 independent observers)
Plafond	Anterior Incisura (AI)	0.601 [‡]	-----
	Posterior Incisura (PI)	0.901	-----
	Direct Anterior (DA)	0.832	-----
	Direct Posterior (DP)	0.920	-----
	Direct Translation (DT)	0.874	-----
	Rotation (R)	0.870	-----
1 cm proximal to plafond	Anterior Incisura (AI)	0.559 [‡]	0.779
	Posterior Incisura (PI)	0.771	0.721
	Direct Anterior (DA)	0.933	0.821
	Direct Posterior (DP)	0.916	0.807
	Direct Translation (DT)	0.801	0.544
	Rotation (R)	0.615 [‡]	0.605

[‡] Parameters excluded from further analysis due to ICC < 0.7

Table 3:

Repeated Measures ANOVA Evaluating Differences Between Measurements at Varying Ankle Position

Measurement Location	Parameter	RM-ANOVA p-value
Plafond	Anterior Incisura (AI)	0.954
	Posterior Incisura (PI)	0.022 *
	Direct Anterior (DA)	0.654
	Direct Posterior (DP)	0.018 *
	Direct Translation (DT)	0.631
	Rotation (R)	0.308
1cm proximal to plafond	Anterior Incisura (AI)	0.793
	Posterior Incisura (PI)	0.038 *
	Direct Anterior (DA)	0.073
	Direct Posterior (DP)	0.880
	Direct Translation (DT)	0.103
	Rotation (R)	0.976

* No statistically significant pairwise comparisons after Bonferroni correction for multiple comparisons