Foot and Ankle Surgery 25 (2019) 51–58

Contents lists available at ScienceDirect

Foot and Ankle Surgery

journal homepage: www.elsevier.com/locate/fas

Anatomy of the tibial incisura as a risk factor for syndesmotic injury

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ARTICLE INFO

Article history:
Received 25 March 2017
Received in revised form 8 July 2017
Accepted 4 August 2017

Keywords:
Ankle joint
Anatomy
Tomography
Syndesmosis
Injury

ABSTRACT

Background: The study aims at comparing the bony anatomy of the syndesmosis in patients who sustained a high fibular fracture with syndesmosis disruption and that of the non-injured population. We hypothesised that there are certain anatomical features making the syndesmosis susceptible to injury.
Methods: The CT examinations of 75 patients who sustained a high fibular fracture with syndesmosis disruption and control group of 75 patients with unrelated foot problems were compared. The depth, fibular engagement and rotational orientation of the tibial incisura were analyzed.
Results: With the median values of the control group as cutoff there were 71% shallow, 71% disengaged and 77% retroverted syndesmoses in the injury group. The differences between the groups were statistically significant for every measure ($P < .002$ to $P > .0001$).
Conclusions: Patients with a shallow, disengaged and retroverted bony configuration of the syndesmosis are overrepresented among patients with syndesmosis disruption.

1. Introduction

The tibiofibular syndesmosis serves as a dynamic link between the distal tibia and fibula thus contributing to the integrity of the ankle mortise. The distal fibula is engaged into the tibial incisura. This connection is reinforced by a complex system of ligaments [1]. Syndesmosis injuries continue to receive wide attention in recent years as anatomic reduction of the distal fibula into the tibial incisura is an important prognostic factor in ankle fractures with relatively high rates of malreduction reported [2].

The bony anatomy of the tibiofibular syndesmosis has also been an area of interest. Several studies have analyzed the radiologic features of the syndesmosis in the normal population. These included measurements of groove depth, width, distances from the anterior and posterior tubercles to the fibular margins and many other linear parameters [3–7]. Höcker and Pachucki, in 1989, observed that the fibular incisura has a rotational variability [8]. Numerous studies analyzed the quality of syndesmosis reductions [9–12]. The features of the radiographic syndesmosis anatomy in patients with syndesmotic injury have not yet been studied.

The aim of this study was to compare the anatomy of the syndesmosis in patients who sustained a high fibular fracture with syndesmosis disruption to that of the non-injured control population. We hypothesized that the anatomy of the syndesmosis in patients who sustained syndesmotic disruption would differ from the anatomy of the noninjured group. In other words, we believed that there are certain anatomical features making the syndesmosis more susceptible to ligamentous injury ("syndesmotic dysplasia").

This situation would be analogous to femoral groove dysplasia leading to an elevated risk of patellar instability [13]. In knee surgery it is well understood, that certain anatomical features of the femoral condyles make the patella more prone to dislocation [14]. Patients with these anatomical features are overrepresented among patients with patellar dislocation. If "syndesmotic dysplasia" exists, patients with dysplastic syndesmoses would be overrepresented in the syndesmotic disruption group.

2. Material and methods

The study population consisted of two groups of 75 patients each with a complete set of bilateral CT scans of their ankles that were identified retrospectively over a period of five years. The CT

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http://dx.doi.org/10.1016/j.fas.2017.08.003
1268-7731/

examination was performed with the patient supine with a multidetector scanner (General Electric). Both feet were placed with the ankle in neutral position and parallel to each other in a holding device. The parameters for image acquisition were as follows: section collimation 0.75 mm, section thickness 0.75 mm with a reconstruction overlap of 0.5 mm, kV 120, mA 120.

Group A (non injury control group) was free of ankle injury and received bilateral ankle CT for other conditions. These were in the order of frequency: sequel or suspicion of foot trauma, arthritis, suspected tumour, subtalar coalition, accessory foot bones and foot pain of unclear origin. Patients treated for conditions affecting the ankle joint like ankle fracture, ankle arthritis, syndesmotic injury, patients undergoing osteotomies around the ankle, and patients undergoing limb lengthening were excluded. Of 104 consecutive bilateral ankle CTs, 21 were excluded because of acute ankle trauma and another 8 were excluded because of signs of posttraumatic arthritis or deformity. This final control group consisted of 38 women and 37 men, with an average age of 46.1 (median 45.7; range 15.9–82.2) years. In a preliminary study of the first 25 pairs of CT data from both ankles we confirmed symmetry of the syndesmoses in this group. The intra-individual symmetry of the bony configuration of the syndesmosis has also been confirmed by recent studies [15–18]. Based on these observations, all further measurements were performed on left ankles resulting in a dataset of 75 CTs in Group A.

Group B (injury group) consisted of 75 patients treated operatively for syndesmotic disruption who received bilateral ankle CT as a routine postoperative follow-up within 3 days after their ankle fracture fixation. The initial diagnosis was made by standard radiographs. Patients with either high fibular fractures or medial malleolar fractures in combination with syndesmotic diastasis were included into this study. Patients received standard treatment of their malleolar fracture, and after fracture fixation an intraoperative external rotation test was performed [19]. Patients with confirmed syndesmotic disruption were treated with transsyndesmotic screw placement and included in the study. According to the Lauge-Hansen classification there were 4 PE II, 39 PE III and 32 PE IV injuries [20]. PE II represents a Maisonneuve injury variant without fibular fracture. The other 71 patients had a Weber type C fibular fracture, i.e. the lowest fracture line started above 4 cm from the tibial plafond as measured after reduction (suprasyndesmotic fracture). Patients with a PE IV fracture had an additional posterior tibial fracture or avulsion of the posterior syndesmosis. This group consisted of 33 women and 42 men, with an average age of 44.2 (median 43.1; range 16.7–74.4) years.

For measurements, we used the non-affected limb in both groups. At each CT, a horizontal cut parallel and ten millimetres proximal to tibial plafond were identified. In each cut, three measurements were performed by two independent investigators. For interrater variability assessment, the measurements were repeated at least one week apart. For further analysis, the results for each variable were averaged.

2.1. Measurement of incisura depth

First, a line tangential to the anterior and posterior border of the incisura was drawn—the intertubercular line (IL). Then, the depth of the incisura at its deepest point was measured perpendicular to the IL (Fig. 1).

2.2. Measurement of fibular engagement within the incisura

The engagement of the fibula within the incisura was measured as a distance between medial fibular cortex and the IL—Fig. 2. The engagement value was positive if the fibula crossed the IL and negative if it was not crossing the IL.

2.3. Measurement of rotational orientation

To measure the rotational orientation of the incisura, first the centre of the tibia was defined as the centre of the circle fitted to the anterior, posterior and medial border of the tibia. Second the centre of the incisura was defined as the middle of the IL. Then, the line orthogonal to the line connecting these points was drawn. The angle between this line and the IL was measured (Fig. 3).

2.4. Statistical analysis

Normality of the data was tested with the Shapiro-Wilk test. The differences between the measurements of Groups A and B were compared with the Wilcoxon signed rank test.

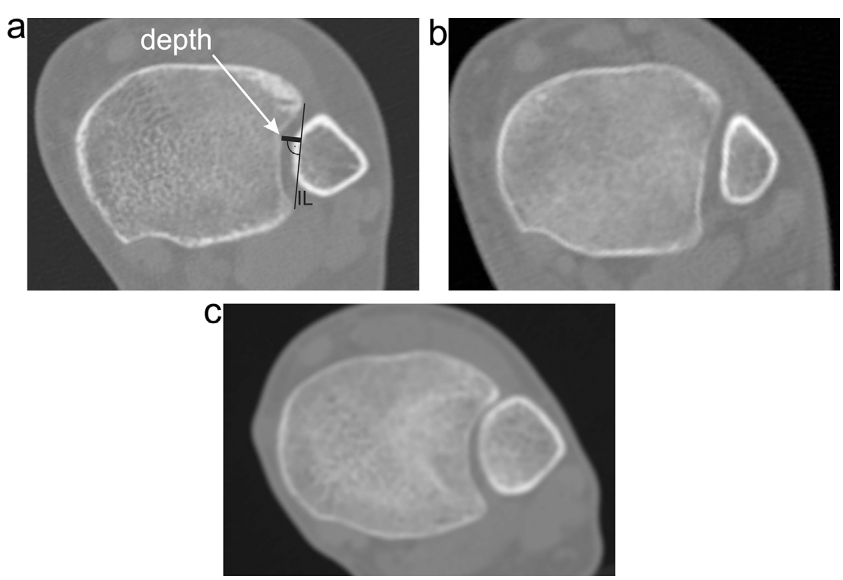

Fig. 1. (A) Technique of incisura depth measurement (see text for details), (B) an example of a shallow incisura, (C) an example of a deep incisura (IL—intermalleolar line).

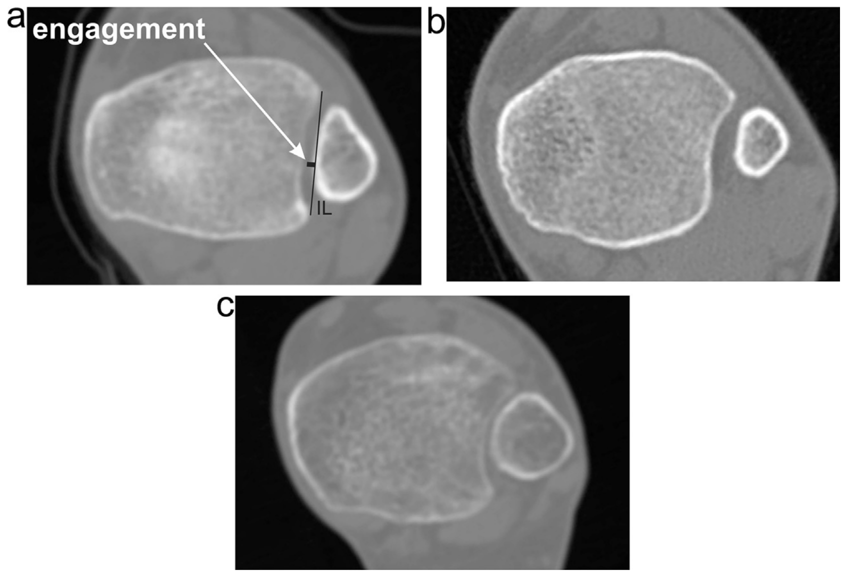

Fig. 2. (A) Technique of fibular engagement measurement (see text for details), (B) an example of a disengaged fibula, (C) an example of an engaged fibula (IL—intermalleolar line).

2.5. Reliability

Inter-rater and intra-rater reliability was tested by calculating Cronbach's alpha for each measurement repeated by single investigator and between the two investigators. The differences (error) between the measured values and the means were calculated.

3. Results

3.1. Reliability

For the noninjured group A Cronbach's alpha for intra-rater reliability was 0.97, 0.92, and 0.94 for depth, engagement and angular measurement and 0.93, 0.93, and 0.96 for inter-rater reliability, respectively. For the injured group B Cronbach's alpha for intra-rater reliability was 0.95, 0.96 and 0.94 for depth, engagement and angular measurement and 0.97, 0.97 and 0.93 for inter-rater reliability respectively. These numbers are consistent with excellent reliability for each measurement.

The mean error between the measured values and the calculated means was 0.2 mm (standard deviation 0.19 mm) for depth, 0.22 mm (standard deviation 0.23 mm) for engagement and 0.84° (standard deviation 0.7°) for rotational orientation.

3.2. Study power and data distribution

A normal distribution of data was not confirmed. A post-hoc power calculation was undertaken revealing a power of 92.9% to detect the difference in depth, 100% for difference in engagement and 99.2% for difference in rotation.

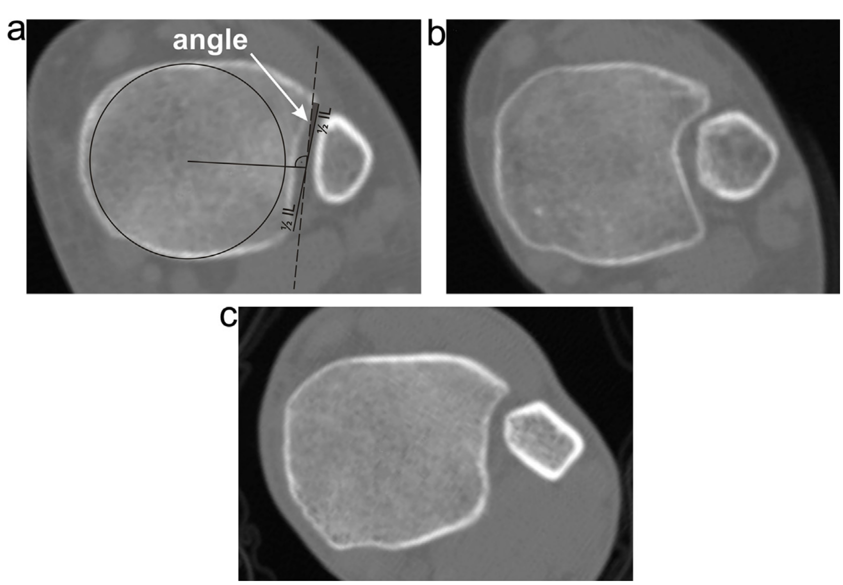

Fig. 3. (A) Technique of measuring the rotational orientation of the incisura (see text for details), (B) an example of an anteverted incisura, (C) an example of a retroverted incisura (IL—intermalleolar line).

Table 1
Distribution of syndesmosis types among patients with syndesmotic injury [number of cases; percentage in brackets ()].

	Anteverted	Retroverted
Shallow	7 (9%)	46 (61%)
Deep	10 (13%)	12 (16%)

3.3. Depth

The incisura depth ranged 1.2–6.9 mm (mean 4.0, median 4.0 mm, standard deviation 1.2 mm) for the group A and 0–6.3 mm (mean 3.3; median 3.3 mm, standard deviation 1.3 mm) for the injured population. The difference between the groups was statistically significant (P = .002).

The incisurae with a depth value higher than median for non-injured population (group A) were termed deep and those with a lower value were termed shallow. There were 22 (29%) deep and 53 (71%) shallow syndesmoses in the injured population (group B). The control group served to define the norm. We took a median value for the control group as a cut off. Because the median of the control group served as a cutoff, by definition there were 37 deep and 37 shallow syndesmoses in the non-injured population.

3.4. Engagement

The fibular engagement ranged from −2.0 to 3.8 mm (mean 0.7, median 0.7 mm, standard deviation 1.2 mm) for group A and −3.9 to 2.7 mm (mean −0.6, median −0.8, standard deviation 1.7 mm) for group B. The differences between the groups were statistically significant (P < .0001).

The syndesmoses with an engagement value higher than the median for the non-injured population (group A) were termed engaged and those with lower value were termed disengaged. There were 22 (29%) engaged and 53 (71%) disengaged syndesmoses in the injured population (group B).

3.5. Rotation

The orientation angle of the incisura ranged from −1 to 25° (mean 8.2°, median 8.0°, standard deviation 4.1°) for group A and −2 to 27° (mean 11.3°, median 12.0°, standard deviation 4.6°) for group B. The difference between the groups was statistically significant (P < .0001).

The syndesmoses with an orientation angle higher than the median for the normal population (group A) were termed retroverted and those with a lower value were termed anteverted. There were 58 (77%) retroverted and 17 (23%) anteverted incisurae in the injured population (group B).

3.6. Distribution of depth and rotation

When grouping the syndesmoses of the injured patients (group B) according to the median values of the uninjured patients (group A), the shallow and retroverted type was overrepresented with 46 out of 75 cases (61%) falling into this category (Table 1, Fig. 4).

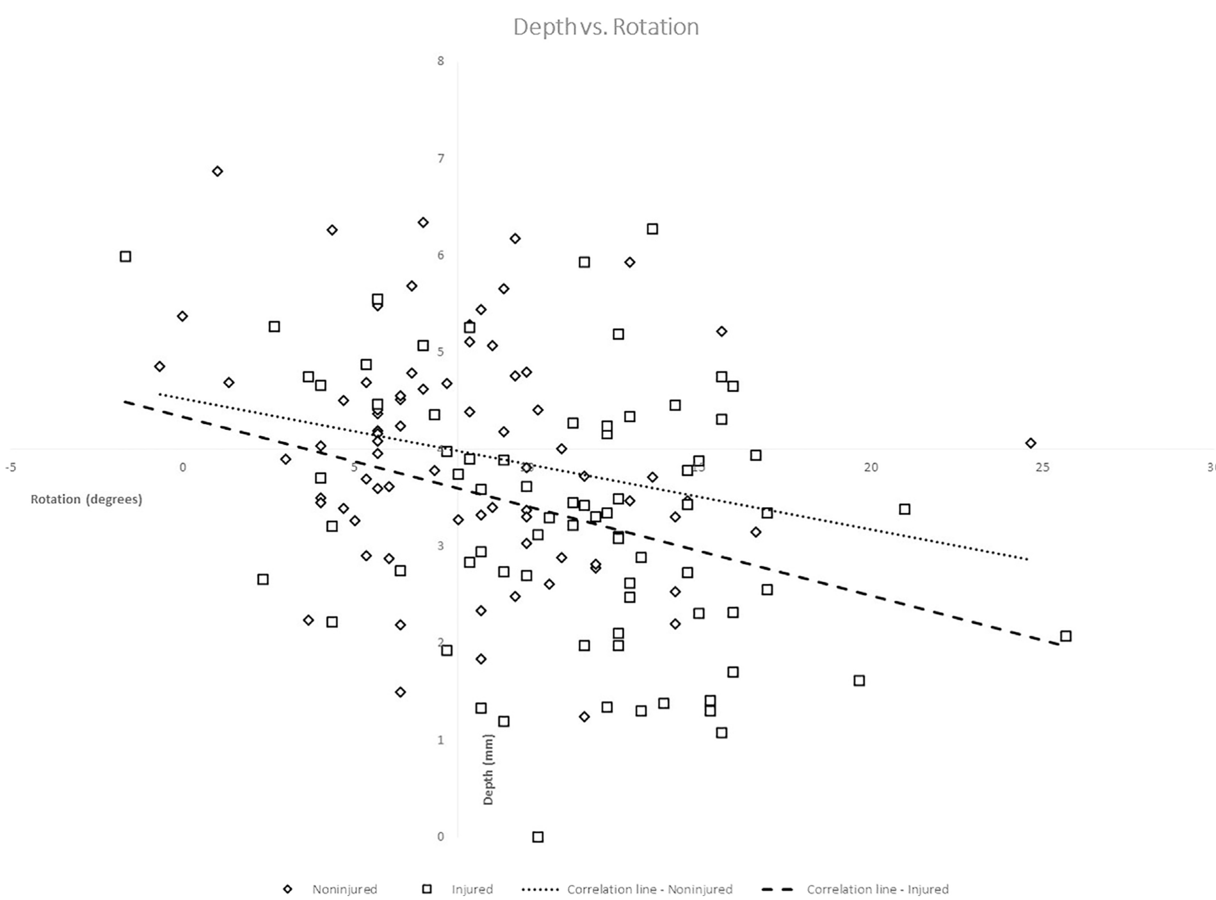

Fig. 4. The shallow and retroverted syndesmosis configuration (right-lower quadrant of the graph) is overrepresented among patients with syndesmotic injury (as illustrated by correlation lines). The X and Y lines intersect at the medians for depth and rotation among the noninjured population.

Table 2
Distribution of syndesmosis types among patients with syndesmotic injury [number of cases; percentage in brackets ()].

	Anteverted	Retroverted
Engaged	9 (12%)	13 (17%)
Disengaged	8 (11%)	45 (60%)

3.7. Distribution of engagement and rotation

When grouping the syndesmoses of the injured patients (group B) according to the median values of the uninjured patients (group A), the disengaged and retroverted type was overrepresented with 45 out of 75 cases (60%) falling into this category (Table 2, Fig. 5).

3.8. Distribution of depth and engagement

When grouping the syndesmoses of the injured patients (group B) according to the median values of the uninjured patients (group A), the disengaged and shallow type was overrepresented with 46 out 75 cases (61%) falling into this category (Table 3, Fig. 6).

3.9. Influence of posterior tibial fracture

The injury group (B) consisted of patients with a posterior tibial fracture (documented as PE IV fracture) and patents without posterior fracture (documented as PE II and PE III fracture). There were no statistically significant differences in depth, engagement and rotation between these two subgroups.

4. Discussion

The tibiofibular syndesmosis is crucial for maintaining ankle stability while providing a dynamic support between the distal tibia and fibula. The fibula is engaged into its incisura within the distal tibia [1]. Wide variations in the bony and ligamentous anatomy of the syndesmosis have been reported [4,8,21,22]. These features have attracted renewed interest in recent years with wider use of CT scanning and understanding the prognostic relevance of syndesmosis injuries in the wake of malleolar fractures [19,23–25]. There are multiple studies on the assessment of syndesmotic reduction [10–12,15,25,26]. Many different measurements have been proposed [4,5,27]. Mostly, these are linear measurements of distances from the distal tibia to the distal fibula in discrete positions [3–5]. Angular measurements concentrated on rotational orientation of fibula in the tibial incisura [11,17,26].

In the present study we focused on comparing syndesmotic anatomy in injured patients and the non-injured population. We compared the depth of the incisura, the depth of fibular engagement into the incisura and rotatory orientation of the incisura itself. The selected parameters showed an excellent intra-rater and inter-rater reliability.

Our results for the non-injured population are comparable to the findings obtained in other studies on syndesmotic anatomy [3–7]. The measurement of rotational variability lead to the same range as in the study by Höcker and Pachucki, yet different reference points led to different numerical results [8].

To the best of our knowledge, ours is the first study to show that patients with syndesmosis disruption have a shallower and more

Fig. 5. The disengaged and retroverted syndesmosis configuration (right-lower quadrant of the graph) is overrepresented among patients with syndesmotic injury (as illustrated by correlation lines). The X and Y lines intersect at the medians for engagement and rotation among the noninjured population.

Table 3
Distribution of syndesmosis types among patients with syndesmotic injury [number of cases; percentage in brackets ()].

	Shallow	Deep
Engaged	7 (9%)	15 (20%)
Disengaged	46 (61%)	7 (9%)

retroverted incisura fibularis and a less engaged fibula than the normal population. These differences, although small in absolute values, are statistically highly significant. This observation has several implications:

First, current studies on techniques of syndesmotic reduction assume a typical anatomy in the injured patients. The differences between patients with syndesmotic disruption and uninjured subjects as shown in our study may influence future reduction and fixation techniques. Failure to observe this anatomic feature may result in overcompression [28,29]. Our observation may increase the surgeons' awareness of a more shallow and disengaged syndesmosis in patients with a high fibular fracture that has also been recently shown to be associated with an increased risk of malreduction [30].

Second, the observation that the rotational orientation of the incisura is variable may also have potential clinical implications. As has been shown by Mendelsohn et al. [6], reduction clamps must be orthogonal to fibular incisura in order to obtain compression in a proper direction. In clinical practice it may be beneficial to recognize anteversion or retroversion of the incisura before reducing and stabilizing the syndesmosis.Further studies should try to investigate the correlation between the bony anatomy of the syndesmosis and malreduction.

Third, our observation may offer an explanation why the same mechanism of injury may result in different fracture patterns in different patients. This discrepancy has been observed in studies trying to reproduce the original Lauge-Hansen experiments in which both forced pronation-external rotation [31,32] and supination-external rotation [33] resulted in inconsistent fracture patterns. This leads to the conclusion that besides the mechanism of injury and foot position, other factors are responsible for the pattern of ankle fractures.

From the results of our study we hypothesize that different anatomical syndesmotic configurations may have a different resistance to rupture. Deep, anteverted and engaged syndesmoses would be more resistant, while shallow, retroverted, and disengaged syndesmoses would be more prone to ligamentous injury. This is in accordance with observations from biomechanical cadaver studies, that in syndesmotic disruption the posterior translation of the fibula precedes lateral shift [34]. If such is the case, deep, engaged and anteverted syndesmosis would offer stronger bony support. With syndesmotic configurations that are more resistant to ligamentous disruption, a higher prevalence of low fibular fractures could be expected. This hypothesis, however, needs to be tested in further studies with different fracture morphologies.

The strength of our study lies in demonstrating for the first time in a large patient cohort with uniform and reliable CT-based measurements that certain bony anatomic features of the syndesmosis are overrepresented in patients with syndesmotic disruption.

Our study also has several potential weaknesses: First, we performed our measurements retrospectively on the CT scans on the healthy ankles of the injured patients. However, it has been shown repeatedly, that despite high inter-individual variance the intra-individual variance of the bony syndesmosis configuration is minimal, i. e. these features are symmetrical [15–18]. Therefore, we assume that the measurements from the non-injured extremity are representative for the injured side.

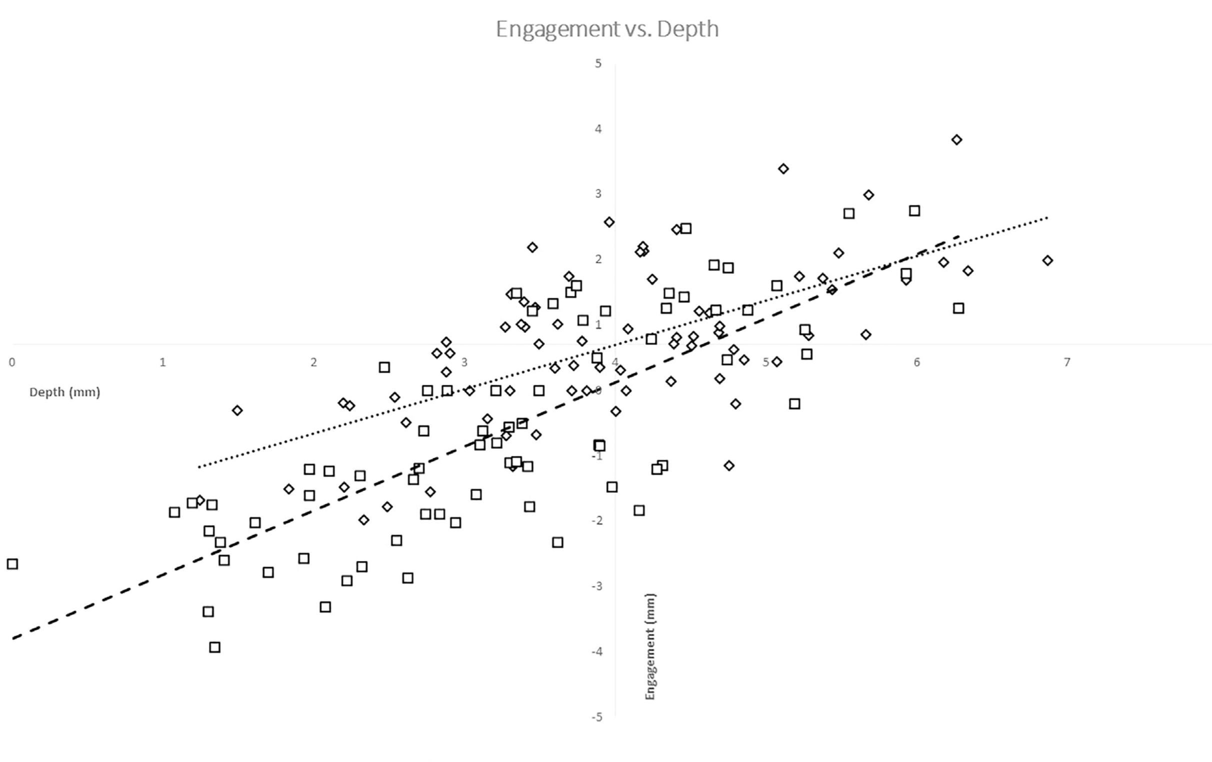

Fig. 6. The disengaged and shallow syndesmosis configuration (left-lower quadrant of the graph) is overrepresented among patients with syndesmotic injury (as illustrated by correlation lines). The X and Y lines intersect at the medians for engagement and depth among the noninjured population.

Second, all measurements were performed at 10 mm above the tibial plafond which is a standard point of reference in the literature for analyzing the bony configuration of the incisura [3–6,8,17]. The value of 10 mm is absolute and does not respect different heights of individual patients, and thus different lengths of the lower leg [35]. However, we are not aware of any study showing a change of the principal configuration of the incisura that extends on average 50 mm above the joint line [36]. Additionally, our aim was to describe the morphology of the incisura at the level of the syndesmotic ligaments including the interosseous tibio-fibular ligament and not the direct contact area between the distal tibia and fibula that extends up to 5 mm from the joint line, if present [1,36].

Third, The CT, being static imaging modality, does not offer the possibility of dynamic assessment of calculated parameters. Our study was, however, mainly concentrated on bony anatomy, that would not change with movement. Additionally, we are not aware of any clinical application of dynamic CT syndesmosis assessment.

Fourth, although interesting from a clinical standpoint the question whether anatomic features pose a risk for malreduction is not the subject of the present study. This issue has been recently addressed by Cherney et al. [30] but we feel it warrants further investigation.

5. Conclusions

Patients with syndesmoses that are shallow, disengaged, and/or retroverted are overrepresented among patients with a high, suprasyndesmal fibular fracture. These bony anatomical features seem to be predisposing to syndesmotic disruption. Studies dealing with syndesmosis reduction should take into account that the anatomy of the tibial incisura in patients with syndesmotic disruption may not be representative for the whole population.

Funding

The work was supported by Centre of Postgraduate Medical Education. Grant no 501-1-07-18-16.

Ethical approval

Ethical approval was granted on 08.06.2016 by Ethic Committee of Centre of Postgraduate Medical Education.

Conflicts of interest

Andrzej Boszczyk, Sławomir Kwapisz, Martin Krümmel, Rene Grass have nothing to declare.

Stefan Rammelt is receiving non-financial support from AO Trauma (Travel/Housing for AO Meetings, Courses as Member of the Foot & Ankle Expert Group) not directly related to this work.

Acknowledgement

The authors wish to thank Agata Boszczyk, BEng, MSc in Architecture, for help in preparing the illustrations.

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