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The effects of weight bearing on the distal tibiofibular syndesmosis: A study comparing weight bearing-CT with conventional CT

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ABSTRACT

Background: Syndesmotic injures are common and weight bearing imaging studies are often advocated to assess disruption. Although studies have examined the anatomical relationship between the fibula and incisura, the effect of weight-bearing on the syndesmosis has not been well reported. We characterise the changes which occur at the syndesmosis during weight-bearing.

Methods: In this retrospective review we analysed the position of the fibula at the syndesmosis in a cohort of patients who underwent both non-weight-bearing and weight-bearing CT scans. The relative position of the fibula to the incisura was analysed to determine translation and rotation in the axial plane.

Results: 26 patients were included. Comparison of measurements revealed statistically significant differences between groups which indicated that on weight-bearing the fibula translated laterally and posteriorly, and rotated externally with respect to the incisura.

Conclusions: This is the first study to measure the differences in position of the syndesmosis during weight-bearing in a population of patients that have undergone both weight bearing and non weight bearing CT. Our study confirms that weight-bearing results in lateral and posterior translation, and external rotation of the fibula in relation to the incisura and our findings should help in future studies looking at the effect of weight bearing on syndesmotic pathology.

1. Introduction

Injuries involving the syndesmosis are common in ankle fractures and sprains, but may be difficult to diagnose. They commonly result from rotation of the talus which forces the fibula to externally rotate and translate laterally [1]. Hintermann *et al.* arthroscopically assessed 266 patients with ankle fractures and reported injury to the syndesmosis in 44% of cases [2]. Fallat *et al.* performed a retrospective analysis of 639 ankle sprains presenting to their unit and detected syndesmotic injuries in 4% [3]. Other studies looking at athletes report rates of syndesmotic injury up to 17% with ankle sprains [4].

Syndesmotic injury may result in diastasis of the distal tibia and fibula, allowing translation of the talus, increased tibiotalar stress, and reduced contact area. Ramsey and Hamilton reported a mean reduction in tibiotalar contact area of 42% with 1 mm talar shift [5]. Treatment in the majority of acute cases is surgical, often with a syndesmotic screw or suture-button. More recently there is also a trend towards reduction and fixation of the posterior malleolus in ankle fractures to restore syndesmotic integrity [6–8]. However, syndesmotic mal-reduction is common (up to 52% in one series) [9] and is associated with poor outcome [10,11]. It is therefore important to diagnose the injury, and identify when reduction has been suboptimal.

Historically, plain radiographs have been used to detect syndesmotic disruption and assess adequacy of reduction. Where possible, weight-bearing radiographs are preferred as they may unmask subtle injuries [12]. However, interpretation of radiographs is unreliable, in part due to the difficulty in standardising ankle rotation and the significant effect this has on apparent tibiofibular clear-space [9,13,14]. Other imaging modalities such as MRI [15] and ultrasound have been used to assess the syndesmosis [16], but axial computed tomography (CT) has been shown to most effectively and reproducibly define the anatomy of the distal tibiofibular joint [9,17,18]. However, in the clinical setting these modalities tend to be non weight bearing.

The relationship between the tibia and fibula at the incisura has been analysed by a number of authors using varying methods [17–25]. The majority of these studies were cadaveric, and those performed on patients or volunteers utilised non-weight-bearing CT scans. Examining the syndesmosis under load provides a functional assessment and weight-bearing CT scans may provide a useful tool to evaluate the syndesmosis.

Although some studies have attempted to examine the syndesmosis during weight-bearing [26,27], the advent of cone-

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beam CT has allowed axial imaging of the syndesmosis during weight-bearing which was not possible previously [28]. This has been shown as superior to radiographs and conventional CT in determining the relationship between the bones in the forefoot, midfoot and hindfoot [29]. Previous studies have demonstrated significant alterations in the position of the midfoot and hindfoot on weight-bearing [30,31], however, it is as yet unclear to what degree the fibula rotates or translates relative to the incisura on weight bearing, with contrasting results reported from non-CT based studies [26,27,32]. It is therefore firstly important to establish what change occurs at the syndesmosis during weight-bearing in normal patients before we are able to diagnose pathology.

Our aim in this study was therefore to compare the position of the fibula to the incisura in weight-bearing *versus* non-weight-bearing CT scans in a matched population.

2. Patients and methods

This was a retrospective review of imaging data conducted at our tertiary foot and ankle unit. All patients to our centre consent to their radiographic imaging being used for the purposes of research and institutional review board approval was obtained prior to commencing the study.

Cone beam CT scanning uses a point source which emits of cone of X-ray radiation which is captured by a planar detector. The source and detector rotate around the foot and ankle achieving volumetric coverage and data acquisition of the area of interest in a single pass [33]. The software has a 3D window that can be fully manipulated to show axial reformats, parasagittal reformats and coronal reformats.

In 2013 our unit procured a cone-beam weight-bearing CT scanner: pedCAT (Curve Beam, Warrington, USA). Since then we routinely use cone-beam CT to assess bony anatomy, deformity, arthritis and union. At the time if writing this paper, we had a database of over 2000 patients and as part of their longitudinal care, some of these patients had undergone both non-weight bearing conventional CT scans (NWB-CT) as well as a cone-beam weight-bearing CT scan (WB-CT).

We first identified all patients undergoing NWB-CT scan of the ankle. We excluded all patients that had pathology related to the syndesmosis to derive a list of all patients that could be considered normal patients (for the purposes of assessing the syndesmosis). We next compared these patients to our WB-CT database to identify how many patients had both NWB-CT and WB-CT on the same ankle. Seventy-five such patients were identified and their notes were reviewed. Patients were excluded if they had pathology or symptoms related to the syndesmosis, or if they had undergone any surgical procedure involving the ankle or hindfoot between scans.

2.1. Measurements of the syndesmosis

Although a number of syndesmotic measurements have been described there is no standardised, accepted method for assessment. Nault *et al.* describe a comprehensive, validated technique, with good inter- and intra-observer reliability [24]. Their method incorporates many of the most commonly described measurements used in previous studies [17–20,22,24,25,28]. In this study we have applied their methodology of assessment to determine the relative position of the fibula to the incisura.

CT images were manipulated in the axial, sagittal and coronal planes as required. The images were orientated in the axial plane perpendicular to the long axis of the tibia at the level of the ankle joint. All measurements were taken on an axial slice 9.9 mm proximal to the tibial plafond (0.9 mm thick slices $\times$ 11 slices), as measured on the NWB-CT. The WB-CT was measured at the same height. This is in keeping with the methodology employed by Nault *et al.* and previous authors have used similar levels for assessment of the syndesmosis (10 mm from the tibial plafond) [9,18,28]. The measurements recorded included six lengths and one angle, with 3 calculated measurements. These are summarised in Table 1 and Fig. 1. All measurements were independently taken by two authors (KM and MW) and the mean values were used for analysis.

We additionally measured the degree of dorsiflexion of the ankle to determine whether there was a significant difference between the weight-bearing and non-weight-bearing CT scans that might account for any observed change in fibula position. We performed those measurements on the sagittal slice through the middle of the first metatarsal. We measured the angle between the sagittal mid talar axis and a line joining the anterior and posterior tibial plafond on this slice. A positive value was taken as plantarflexion, and therefore a lower value indicated greater dorsiflexion. We refer to this measurement as the talar plantar flexion angle. Although traditionally the talar plantar flexion angle is measured against the anatomical axis of the tibia, we employed this modified method of measurement as sufficient tibial diaphysis could not be visualised on all scans.

2.2. Statistical analysis

All statistical analysis was performed using SPSS 22.0 (IBM, Armonk, New York). Inter-observer error was determined using interclass correlation, which was calculated using Cronbach's Alpha. Measured variables were tested for normality using the

Table 1
The various variables measured on the axial CT slice 9.9 mm from the tibial plafond. Based on measurements by Nault et al. and illustrated in Fig. 1. [24].

Variable	Description	Measure of (significance of change)
Line 1	A line joining the most anterior and posterior points of the incisura	–
Distance *a*	Most anterior point of incisura to the nearest, most anterior point of fibula	–
Distance *b*	Most posterior point of incisura to the nearest, most posterior point of fibula	–
a/b ratio	–	Rotation (increase = external rotation of the fibula)
$b-a$	–	Rotation (decrease = external rotation of the fibula)
Distance *c*	Shortest distance between tibia and fibula measured at the midpoint of the incisura	Lateral translation (increase = lateral translation of the fibula)
Distance *d*	Shortest distance from the perpendicular bisector of Line 1 to the most anterior point on the fibula	–
Distance *e*	Shortest distance from the perpendicular bisector of Line 1 to the most posterior point on the fibula	–
d/e ratio	–	Anterior–posterior translation (decrease = posterior translation of the fibula)
Distance *f*	Shortest distance from the perpendicular of Line 1, drawn at the most anterior point of the incisura, to the most anterior point on the fibula	Anterior–posterior translation (increase = posterior translation of the fibula)
Angle 1	Angle between Line 1 and the axis of the fibula (negative value = internal rotation)	Rotation (less negative = external rotation of the fibula)

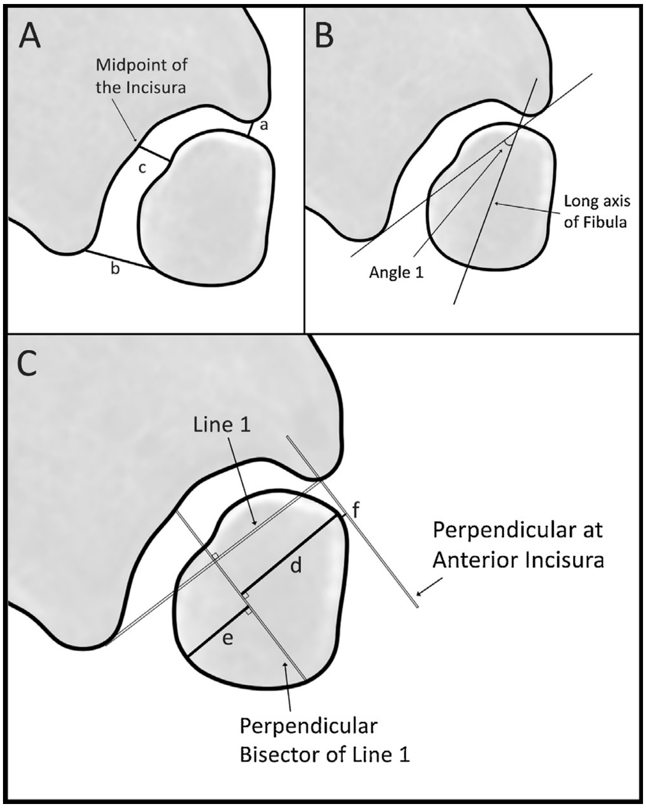

Fig. 1. The various measurements recorded in this study, illustrated over one of the CT scans. (A) depicts the measurements of distances *a*,*b* and *c*. Distance c represents the shortest distance from the midpoint of the incisura to the fibula. (B) depicts the measurement of *Angle* 1. (C) depicts distances *d*, *e* and *f*, which are each the perpendicular distances from lines drawn perpendicular to *Line* 1 to the most anterior and posterior points on the fibula. Further descriptions are given in Table 1.

Shapiro–Wilks test for normality and it was determined that none of the variables were normally distributed. Therefore, analysis of differences between paired variables was conducted using the non-parametric Wilcoxon Signed Ranks test. Data are presented as means $\pm$ standard deviations (SD). Our null hypothesis was that there would be no difference in the measurements between the two methods of imaging. A *p*-value of <0.05 was considered statistically significant, and therefore, as an indication that a significant difference was present between observed variables.

3. Results

After excluding patients who had pathology or symptoms related to the syndesmosis, or who had undergone any surgical procedure involving the ankle or hindfoot between scans, 26 ankles remained for analysis. The mean age of patients in this study was 48.2 ± 14.01 years (range: 22–82 years). There were 11 males and 15 females. The mean interval between NWB-CT and WB-CT was 321 ± 349 days (range: 29–1161 days). Diagnoses and previous procedures in patients included are summarised in Table 2.

Interclass correlation revealed Cronbach's Alpha values of 0.833 for *a*, 0.904 for *b*, 0.964 for *c*, 0.854 for *d*, 0.905 for *e*, 0.851 for *f*, and 0.661 for *Angle* 1. This suggests excellent agreement in all measurements apart from *Angle* 1, where the agreement was good.

The mean talar plantar flexion angle in the NWB-CT group was $23.0^\circ \pm 9.89^\circ$ (range: 5°–46°), and $21.46^\circ \pm 9.38^\circ$ (range 3°–38°) in the WB-CT group. This difference was not statistically significant ($p = 0.358$) suggesting no clinically significant difference in dorsiflexion of the ankle between groups.

Comparison between groups revealed a statistically significant difference in *a/b ratio* ($p = 0.024$), $b - a$ ($p = 0.010$) *(both measures of fibular rotation)*, *c* ($p = 0.003$) *(measure of fibular lateral translation)*, and *d/e ratio* ($p = 0.008$) *(measure of fibular antero-posterior translation)*. The differences suggested that the fibula translates laterally and posteriorly, and externally rotates on weight-bearing. There was no statistical difference between groups in *Angle* 1 ($p = 0.260$) and *f* (0.333). These results are summarised in Table 3 and an example is illustrated in Fig. 2.

In both NWB-CT and WB-CT groups the mean *a/b ratio* was less than 1.0 (0.58 and 0.65 respectively) and *Angle* 1 was negative (-16.0° and -15.0° respectively), indicating the average axis of the fibula is in internal rotation with respect to the incisura. In both groups the mean lateral translation was greater than 4 mm, with the minimum translation during weight-bearing measured as 2.1 mm and the maximum as 9.5 mm. Finally, in both groups the *d/e ratio* was greater than 1 (1.64 and 1.45 respectively) suggesting that the fibula normally rests in the anterior portion of the incisura.

4. Discussion

The syndesmosis functions to dynamically accommodate the talus in the mortise during weight bearing and ankle movement. It is comprised of the anterior inferior tibiofibular ligament (AITFL), the posterior inferior tibiofibular ligament (PITFL), the interosseous ligament (IOL) [34], the transverse tibiofibular (TTFL) and posterior inter-malleolar ligaments (PIML) [35]. The AITFL, PITFL, and IOL hold the fibula and tibia together. The AITFL is the weakest of the ligaments. The IOL represents the thickened distal portion of the interosseous membrane. The TTFL is located in a deep part of the PITFL, forms part of the articular surface for the talus, and helps prevent posterior talar translation. The role of the PIML remains largely unknown.

These ligaments function as springs, allowing only limited fibular movement about the incisura [36,37]. The talus is wider anteriorly and therefore there is increased stress across the syndesmosis in dorsiflexion. If the talus rotates externally, this force increases further, resulting in translation and rotation of the fibula [38].

Previous studies report lateral translation of the fibula with dorsiflexion and loading [26,27,32]. These studies did not utilise axial imaging or compare weight-bearing and non-weight-bearing patients. Lepojarvi *et al.* utilised weight-bearing CT to measure

Table 2
Table summarising the diagnoses of patients included in this study and any previous procedures prior to scans.

Diagnosis	Number of patients (n = 26)	Previous procedures	Number of patients (n = 26)
Hindfoot osteoarthritis	6 (23.1%)	Midfoot fusion	4 (15.4%)
Ankle osteoarthritis	5 (19.2%)	Triple fusion	2 (7.7%)
Talar osteochondral lesion	5 (19.2%)	Calcaneal fixation	2 (7.7%)
Calcaneal fracture	3 (11.5%)	Subtalar fusion	1 (3.9%)
Midfoot osteoarthritis	3 (11.5%)	OATS procedure	1 (3.9%)
Tibialis posterior dysfunction	2 (7.7%)		
Forefoot pathology	2 (7.7%)		

Table 3
Differences in measured variables between non-weight-bearing CT (NWB-CT) and weight-bearing CT (WB-CT) groups. Means are presented with standard deviations and ranges. *P*-values are only reported for variables which indicate the position/orientation of the fibula. Significant differences are highlighted by an '*'.

Variable	NWB-CT group (n = 26)	WB-CT group (n = 26)	*p*-Value	Change seen on weight-bearing
a (mm)	3.6 ± 1.74 (1.6–10.0)	3.8 ± 1.70 (1.2–8.4)	–	–
b (mm)	6.3 ± 1.9 (3.5–11.0)	5.9 ± 1.8 (3.4–9.8)	–	–
a/b (ratio)	0.58 ± 0.18 (0.25–1.09)	0.65 ± 0.18 (0.33–1.06)	0.022*	External rotation
b − *a* (mm)	2.7 ± 1.6 (−0.8 to 6.0)	2.0 ± 1.3 (−0.5 to 5.5)	0.026*	External rotation
c (mm)	4.2 ± 2.0 (1.2–8.7)	4.8 ± 1.9 (2.1–9.5)	0.001*	Lateral translation
d (mm)	11.0 ± 1.7 (8.4–15.0)	9.7 ± 1.6 (7.0–13.8)	–	–
e (mm)	7.1 ± 1.6 (3.2–10.0)	7.1 ± 1.6 (4.7–11.1)	–	–
d/e (ratio)	1.64 ± 0.49 (1.05–3.06)	1.45 ± 0.43 (0.70–2.24)	0.007*	Posterior translation
f (mm)	1.1 ± 2.0 (−2.5 to 7.0)	1.4 ± 1.4 (−2.2 to 3.8)	0.248	Posterior translation *(not statistically significant)*
Angle 1 (°)	−16.0 ± 7.0 (−35 to −4)	−15.0 ± 6.7 (−30 to −4)	0.331	External rotation *(not statistically significant)*

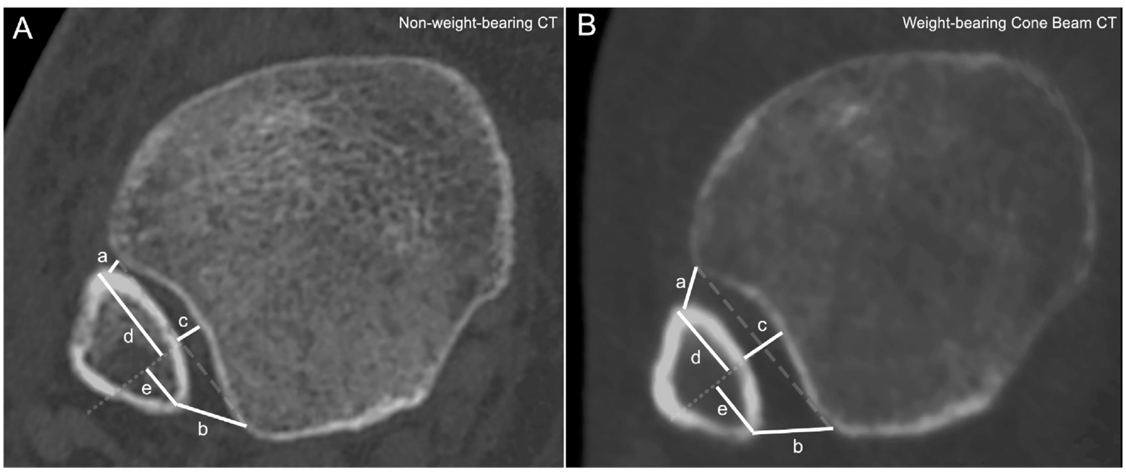

Fig. 2. Side by side comparison of the measurements taken on non-weight-bearing (A) and weight-bearing (B) CT scans. In this patient it can be seen that upon weight-bearing, in relation to the tibia, the fibula has translated laterally (measurement c is increased by 1.6 mm), translated posteriorly (the d/e ratio is decreased by 0.22), and rotated externally (the a/b ratio is increased by 1.84).

changes to fibular position with rotation of the ankle, and found that the fibula translates laterally and externally rotates with external rotation of the talus [28].

Our study confirms and quantifies these previous findings in the first study to compare a cohort of patients that had undergone both non weight bearing and weight bearing CT. We noted the fibula translates laterally and posteriorly, and rotates externally on weight-bearing, although these differences appear small. There was no significant increase in ankle dorsiflexion in our WB-CT group as most of our non-weight-bearing CTs were captured with the ankle in a near neutral position. This suggests that the translation/rotation observed is not solely a consequence of ankle position, but that the act of weight-bearing affects the syndesmosis as well. One possible explanation is that during weight-bearing, up to 17% of the load is transmitted through the distal fibula [39,40], which will in turn be transmitted to the syndesmosis.

The boundaries of the syndesmosis are not well defined [37] and the cross-sectional anatomy varies from distal to proximal, with the incisura being deeper more distally [17,22,37]. It is therefore important that measurements be taken at a consistent height about the tibial plafond to reduce this variability. Most studies examined the syndesmosis approximately 10 mm from the tibial plafond [9,18,24,28]; this does not, however, take into account differences in patient height and tibial length. There are also gender differences in the shape and size of the incisura, with a shallower incisura seen in women [15]. Because our study uses paired analysis of measurements taken in the same patients it eliminates these confounding demographic factors seen in studies comparing two different groups of patients.

None of our measurements were normally distributed. We believe this is the result of a small number of patients coupled with a wide variability in the anatomy of the distal tibiofibular joint. This is important to highlight as a number of studies have suggested reference range values for syndesmotic mal-reduction, which fall within the normal range we have observed [9,24,41]. For this reason analysis of side to side differences may ultimately be a better predictor of syndesmotic injury/reduction than absolute values [25,42]. The pedCAT scanner allows simultaneous scanning of both feet and ankles. The time taken for a single scan is between 19 and 68 s and the radiation dose for one scan is 3.8×10^{-6} Sv [43,44]. By contrast a standard series of three foot and ankle radiographs has a radiation dose of 0.6×10^{-6} Sv, and the average daily background radiation dose in the United Kingdom is estimated at 7.4×10^{-6} Sv [45]. It is therefore currently routine practice in our unit to perform bilateral weight-bearing CT scans for the assessment of syndesmotic pathology.

Not all our measurements of fibular rotation demonstrated a difference on weight-bearing. The *a/b ratio* and *b* − *a* demonstrated a difference, but *Angle* 1 did not. One possible reason is that of all our measurements *Angle* 1 had the lowest interclass correlation and was the most subjective. It requires estimation of the axis of the fibula which may not be obvious depending on the fibular shape. Another possible explanation is that whilst the *a/b ratio* and *b* − *a* measure rotation, as they are determined by measuring distances, they may also be effected by translation of the fibula. It is perhaps for this methodological reason that that external rotation of the fibula appears coupled with posterior translation [28]. The differences in *d/e ratio* suggested posterior translation of the fibula, but the differences in *f* did not. This may be due to the relatively small translations observed and the small number of patients. Differences in a single value, *f*, may not be sufficient to reflect the translation, but a composite value, the *d/e ratio*, is a more sensitive indicator of translation.

4.1. Limitations

This study has a number of limitations. Although we excluded patients with documented syndesmotic pathology it is possible that some patients sustained an injury between scans without our knowledge. It is also possible that some patients may have had pathology affecting syndesmotic mobility unrelated to their reason for presentation (for example talar osteophytes). The CT scans were separated by an average of one year in time and by up to 3 years in some cases, and this could have had bearing on our findings. Due to the nature of our study we had only a small cohort of patients with foot and ankle pathology available to us and therefore cannot draw conclusions about the generalisability of the data and hence normal population values. Similarly, we can also not make any meaningful analysis of age or gender differences. All measurements taken have some element of subjectivity although we have taken steps to ensure validity and reproducibility of the data. We have only assessed movement in the axial plane and have not examined distal-proximal migration. We can only hypothesise on the reasons for the differences in measurements observed, but further work will be required to determine how the syndesmosis translates after injury and to determine tolerances for mal-reduction. Furthermore, the CT slices were 0.9 mm thick and therefore changes less than 1 mm may be difficult to reliably detect. However, even small changes in joint configuration have been shown to significantly impact the volume in the joint on three-dimensional volume-rendered CT [23].

Injuries to the syndesmosis can have significant functional consequences and it is important to adequately assess fibular position and reduction. CT scanning allows axial evaluation of the syndesmosis which provides accurate imaging less affected by image rotation. Furthermore, examining the syndesmosis under load provides a more functional assessment and may have the added benefit of unmasking subtle injuries. It therefore follows that weight bearing CT scans may provide a useful tool to evaluate syndesmotic pathology.

4.2. Conclusions

Despite suggestions to use weight bearing radiographs to demonstrate syndesmotic pathology, the effect of weight bearing on the normal syndesmosis has been scarcely and variably reported. This is the first study using axial imaging to measure the differences in position of the syndesmosis during weight-bearing in a population of patients that have undergone both weight bearing and non weight bearing CT. Our study demonstrates that weight-bearing results in lateral and posterior translation, and external rotation of the fibula in relation to the incisura.

We have demonstrated weight bearing CT scanning provides a reproducible method of assessing the syndesmosis, and that there are indeed changes to the syndesmosis attributable to weight bearing. We are currently conducting further work to establish reference ranges of normal values on weight-bearing CT. These can then be used to identify syndesmotic pathology.

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