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Research Article

Gender-Based Variations and Bilateral Symmetry of the Distal Tibiofibular Syndesmosis: A 3D Computed Tomography Study

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ABSTRACT

Objective: This study aimed to investigate the influence of gender and bilateral asymmetry on the complex anatomical features of the distal tibiofibular syndesmosis using computed tomography (CT)-generated 3D anatomical models in the Turkish population.

Methods: Bilateral non-weight-bearing CT scans of 80 adults (40 females, 40 males), totaling 160 ankles, were analyzed. 3D anatomical models of the tibia and fibula were created using Materialise Mimics. Key morphological parameters were measured, including incisura width, depth, angle, and version; anterior and posterior tibiofibular widths; and tibiofibular overlap.

Results: In the male group, all measured parameters in the right ankle and most in the left ankle were significantly higher than those in the female group. Specifically, incisura width, anterior tibiofibular width, posterior tibiofibular width, and incisura version were significantly higher in males. Despite these gender differences, intraclass correlation coefficient analysis demonstrated strong correlations between the right and left ankles across the majority of parameters in both gender groups, including incisura depth and incisura angle.

Conclusion: Although gender-based dimensional variations exist, there are no clinically significant differences between contralateral ankles within each gender group. The strong bilateral symmetry confirms that the contralateral ankle may serve as a reliable template for determining syndesmotic integrity or assessing intraoperative reduction quality.

Keywords: Tibiofibular syndesmosis, computed tomography, three-dimensional imaging, ankle fractures, bimalleolar fractures, trimalleolar fractures

INTRODUCTION

Malleolar fractures are common injuries with an incidence that has been increasing over the years.[1,2] Distal tibiofibular syndesmosis is an important and a complex structure to maintain the integrity of the ankle joint and the injuries of syndesmosis accompanying malleolar fractures are observed in approximately 20% of cases.[3,4] Accurate reduction and the stabilization of the syndesmosis is essential to obtain better functional outcomes and to avoid post-traumatic osteoarthritis of the ankle joint.[5,6] Therefore, understanding these complex anatomical features of the ankle joint is critical for preventing complications.

Morphological variations of different anatomical parts of the human body according to gender and race have been largely investigated in the literature.[3,6-9] The 3D anatomy of the distal tibiofibular joint is particularly important for detecting syndesmotic subluxation. The congruence of the ankle joint biomechanically affects the motion of the fibula within the tibial notch. Moreover, incongruence of the syndesmosis may cause post-traumatic osteoarthritis on long-term follow-up. Data obtained from these morphological studies have been used to develop new surgical methods and implant designs for orthopaedic interventions.

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Radiological modalities are the primary means of detecting distal tibiofibular syndesmosis injuries. Computed tomography (CT) is a common modality that is widely available in many medical centers.[7,10] Although there are many 2D CT studies investigating the syndesmosis anatomy in the current literature, conventional 2D measurements often fail to capture the true rotational geometry of the incisura fibularis.[7-9,11,12] Consequently, studies utilizing 3D CT-based anatomical models to analyze syndesmosis morphology remain limited.[10,13]

The present study aimed to investigate the influence of gender and bilateral asymmetry on complex anatomical features of the distal tibiofibular syndesmosis using CT-generated 3D anatomical models in the Turkish population.

MATERIALS AND METHODS

Institutional review board approval was obtained from Ethics Committee of Ankara City Hospital with, decision no: EI/1309/2020, date: 11.11.2020. prior to the study CT angiography scans of the lower extremities in patients aged 18-60 years who were admitted to İzmir Democracy University Buca Seyfi Demirsoy Training and Research Hospital were reviewed in the medical records. Patients with incomplete CT images; prior surgeries for fractures or deformities of the tibia, fibula, or ankle joint; ankle osteoarthritis; a history of knee or ankle arthroplasty; or oncological interventions were excluded from the study. Data from the adults were anonymized using Mimics Medical 27.0 software (Materialise, Leuven, Belgium). Forty female and forty male adults were randomly selected from adults who met the inclusion criteria. The randomization was made with true random number generator program (www.random.org).

The total sample size was calculated a priori using G Power 3.1 (Dusseldorf University, Dusseldorf, Germany) to be at least 26 adults per group. Therefore, two gender groups were created, each comprising 40 adults. A total of 160 ankles (both right and left sides) were investigated. CT scans were performed on a Siemens SOMATOM Emotion (Siemens) (110 kV- 90 mAs, slice thickness 1.2 mm).

The tibia and fibula bones were segmented using the Advanced Segment option of the software Mimics Medical 27.0 (Materialise, Leuven, Belgium) to create 3D anatomical models. Thresholding limits were determined to be between 180 and 2150 Hounsfield Units to isolate bone tissue from other tissues. The tibia and fibula were segmented separately. The inner articular surface of the medial malleolus was marked, and a mortise plane was created with "Fit to Surface" option, as described previously by Tanoğlu et al.[6] The length of the tibia was measured between the center points of the knee and ankle joint lines. The borders of the proximal and distal 1/3 of the tibial shaft were determined. These borders were marked circumferentially, and two different spheres were created on them using the "Best-Fit to Surface" option. The entire tibial anatomical axis was created using the center points of these two spheres.[14] The ankle plane, perpendicular to the tibial anatomical axis, was created using the "Plane Normal to Curve" option and represents the intersection of the most superior articular surface of the ankle joint and the anatomical axis of the tibia. The ankle plane was aligned 10 millimeters superior to the most superior articular surface of the ankle joint along the Z-axis (Figure 1). At this level of the incisura, the most prominent anterior and posterior points of the tibia and fibula were marked. The positions of these points were adjusted using the "Closest Point" option relative to the ankle plane (Figure 2). Finally, the anterior and posterior points of the tibia were connected to measure the incisura width (IW). By the same method, the deepest point of the incisura was identified.

MAIN POINTS

- No clinically significant differences were observed between contralateral ankles within each gender group.
- Strong correlations in the majority of measurement parameters observed between bilateral ankles.
- The contralateral ankle may serve as a reliable template for determining syndesmotic integrity.

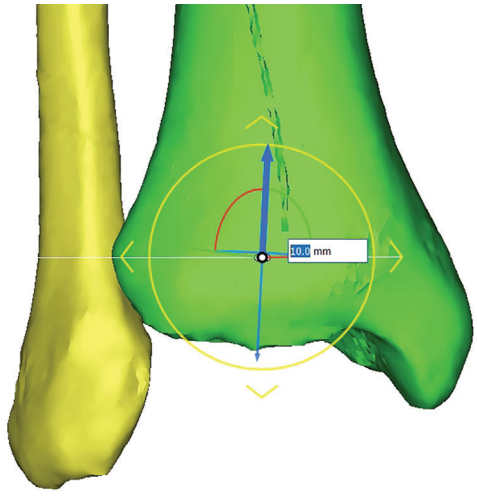


Figure 1. The ankle plane was aligned 10 millimeters superiorly from the most superior articular surface of ankle joint.

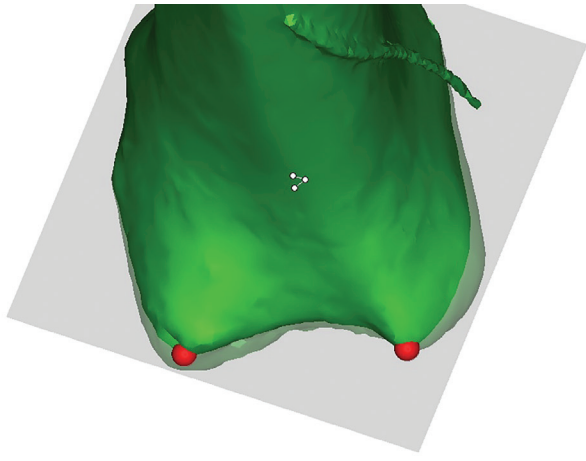


Figure 2. Marking of the most prominent anterior and posterior tibial points according to the ankle plane on 3D anatomical model.

The tibia and fibula were osteotomized using the "Cut" option according to the ankle plane. The cortical borders of distal parts of the tibia and fibula were marked separately to create splines. The center points of these splines were connected to create the ankle-version line. All anatomical data were transferred to 3-Matic 19 (Materialise, Leuven, Belgium). The depth of the incisura was measured between its deepest point and the anteroposterior tubercular line. The incisura angle (IA) was determined as the angle between the line drawn from the anterior point of the tibia to the deepest point of the notch and the line drawn from the deepest point of the notch to the posterior point of the tibia. The widths of the anterior and posterior points on the tibia and fibula were calculated. The angle between the ankle line and the anteroposterior tubercular line was measured to calculate the incisura version (IV). The tibia and fibula were positioned perpendicular to the mortise and ankle planes, and the tibiofibular overlap was measured using the program's ruler (Figure 3).

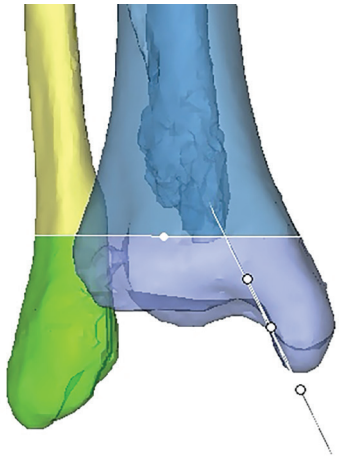


Figure 3. Determining the tibiofibular overlap according to the mortise plane on 3D anatomical model.

Statistical Analysis

Statistical analysis was performed with JASP 95.4 (University of Amsterdam, Amsterdam, Netherlands). The Shapiro-Wilk test indicated that the data were normally distributed. Therefore, the Student's t-test was used to compare data between gender groups. Reliability between right and left ankle measurements within gender groups was assessed using the intraclass correlation coefficient (ICC) analysis.

RESULTS

This study investigated bilateral ankle measurements in 80 adults, comprising 40 females (mean age: 42.8 ± 13.4 years) and 40 males (mean age: 42.5 ± 11.3 years). Descriptive statistics and comparisons of the right- and left-ankle measurements between gender groups are presented in Table 1.

All measurement parameters of the right ankle were higher in the male group than in the female group. Specifically, IW, anterior tibiofibular width (ATW), posterior tibiofibular width (PTW), and IV measurements were significantly higher in the right ankles of males than in those of females (Table 1).

Similarly, left-ankle measurements were higher in the male group, except for the mean ATW. Statistically significant gender differences were observed for IW, incisura depth (ID), and tibiofibular overlap (TO) in left ankle measurements.

The reliability of measurements between the right and left ankles within gender groups was evaluated using ICC analysis. In the male group, measurements revealed strong correlations between the bilateral ankles for IW, ID, IA, and TO (Table 2). In the female group, strong correlations were observed among ID, IA, ATW, PTW, IV, and TO (Table 3).

Table 1. Descriptives and the Comparisons of Right and Left Ankle Measurements Between Gender Groups

	Group	Right ankle Mean ± SD	*P*	Left ankle Mean ± SD	*P*
Incisura width	Female	17.8 ± 1.5	< 0.001*	17.8 ± 2	< 0.001*
	Male	22.8 ± 2.9		20.2 ± 2.7	
Incisura depth	Female	2.9 ± 1	0.051	2.8 ± 1	< 0.001*
	Male	3.4 ± 1.2		2.9 ± 1.1	
Incisura angle	Female	141.5 ± 11.9	0.256	141.5 ± 11	0.138
	Male	144.4 ± 10.2		145.1 ± 10.7	
Anterior tibiofibular width	Female	2.8 ± 0.9	< 0.001*	3 ± 1	0.576
	Male	3.4 ± 1		2.9 ± 1	
Posterior tibiofibular width	Female	2.8 ± 0.9	< 0.001*	2.9 ± 0.8	0.054
	Male	4.2 ± 1.5		3.3 ± 0.9	
Incisura version	Female	-7.1 ± 1.6	< 0.001*	-7.6 ± 5	0.054
	Male	-8.4 ± 1.6		-8.5 ± 4.7	
Tibiofibular overlap	Female	6.1 ± 4.7	0.931	7.3 ± 1.4	< 0.001*
	Male	6.2 ± 4.9		8.6 ± 1.6	

*Statistically significant.
SD: Standard deviation.

Table 2. Reliability Between Right and Left Ankle Measurements of Male Group Using the Interclass Correlation Coefficient (ICC) Analysis

	ICC	Confidence Interval
Incisura width	0.783	0.591-0.885
Incisura depth	0.808	0.636-0.898
Incisura angle	0.814	0.648-0.901
Anterior tibiofibular width	0.661	0.359-0.821
Posterior tibiofibular width	0.577	0.201-0.776
Incisura version	0.471	-0.004-0.72
Tibiofibular overlap	0.782	0.587-0.885

Table 3. Reliability Between Right and Left Ankle Measurements of Female Group using the Interclass Correlation Coefficient (ICC) Analysis

	ICC	Confidence Interval
Incisura weight	0.709	0.449-0.846
Incisura depth	0.793	0.608-0.890
Incisura angle	0.847	0.710-0.919
Anterior tibiofibular weight	0.799	0.620-0.894
Posterior tibiofibular weight	0.801	0.624-0.895
Incisura version	0.891	0.795-0.943
Tibiofibular overlap	0.797	0.617-0.893

DISCUSSION

The primary finding of this study is the strong bilateral correlation between syndesmotic measurements for both gender groups, as assessed with 3D anatomical models.

Gender-based comparisons of the right ankle revealed that all investigated parameters were significantly greater in the male group. Statistically significant differences were observed in IW, ATW, PTW, and IV. Similarly, left ankle measurements showed that all parameters, with the exception of ATW, were higher in the male group. Statistically significant differences in the left ankle were noted for IW, ID, and TO. Despite these statistical differences, the variations in mean values were minimal and likely lacked clinical importance.

ICC analysis of IW demonstrated a strong correlation (ICC=0.78) between the right and left ankles in the male group, whereas a moderate correlation (ICC=0.7) was observed in the female group. A study by Yüzügüldü et al.[12] reported mean 2D IW measurements across gender groups that were higher than those observed in the present study. Despite the common Turkish origin of the sample populations in both studies, this disparity may be attributable to the use of 3D measurement methods in this study. Furthermore, Huysse et al.[10] also reported mean 3D IW measurements that were elevated relative to the results of this study. This divergence may stem from underlying racial differences between Western and Eastern Caucasians.

The ICC analysis of bilateral ankles revealed a strong correlation (ICC=0.8) for ID in both gender groups. In a 2D CT study by Misir et al.,[8] incisura morphology was classified into three categories based on depth: Type C (> 4 mm), Type I (< 4 mm) and Type R (=4 mm).[8] Applying the criteria established by Misir et al.[8], the following were observed: the right ankles of 31 males (77%), the left ankles of 34 males (85%), and bilateral involvement in 35 females (87%). The discrepancies in incisura-type distribution between studies may result from the application of 2D measurement definitions to 3D anatomical models. Defining a novel 3D measurement method that incorporates both ID and angle could yield different results. Although mean ID measurements showed minimal differences between 2D and 3D studies, the clinical importance of these findings remains controversial.[7,8,10,12] Unlike 2D CT images, which can be affected by leg positioning, 3D modeling allows for the acquisition of accurate ankle positioning; thus, spatial positioning may contribute to these observed differences.[11,13] Huysse et al.[10] determined a threshold of 4 mm for ID in a 3D CT study comparing patients with high ankle sprains to a control group, noting that the control group exhibited deeper incisura compared to unstable patients. The control group in this study has a deeper incisura compared with patients with unstable high ankle sprain. The mean ID of the control group in their study was higher than the mean presented here, potentially due to racial variation or differences in measurement methodology.

Bilateral comparison revealed a strong correlation in both the male (ICC=0.80) and female (ICC=0.84) groups. In the 3D study by Huysse et al.[10], the mean IA in the control group was measured lower than the findings of the current study. Although similar methods were used to determine the ankle reference plane for the prominent anterior and posterior tibial points, different results were obtained in the study.

ICC analysis of bilateral ankles showed a moderate correlation (ICC=0.66) in the male group and a strong correlation (ICC= 0.79) in the female group. In a 3D study, Peiffer et al.[13] found no significant differences in ATW weight-bearing and non-weight-bearing CT scans of bilateral ankles, and their mean ATW measurements were similar to the results of this study. The means of ATW measurements in the gender groups were similar to our study results. Conversely, compared to the 3D results of Chen et al.[11], the mean ATW measurements in the present study were similar for the male group but higher for the female group.

ICC analysis indicated a moderate correlation (ICC=0.57) in the male group and a strong correlation (ICC=0.80) in the female group. While the 3D study by Chen et al.[11] reported approximate results, Peiffer et al.[13] reported higher mean PTW measurements using non-weight-bearing CT-based 3D models compared to the current findings. Additionally, 2D studies by Misir et al.[8] and Yüzügüldü et al.[12], both conducted on Turkish populations, reported higher mean PTW measurements. Additionally, 2D studies by Misir et al.[8] and Yüzügüldü et al.[12], both conducted in Turkish populations, reported higher mean PTW measurements. These differences may be attributable to racial characteristics or to the distinct measurement methods used in 2D CT, although they are likely of minimal clinical significance.

An ankle line was established linking the centers of the tibia and the fibula across the ankle plane. The IV was calculated as the angle between this ankle line and the anteroposterior

tubercular line. Most adults exhibited a retroverted incisura, present in 87% of right ankles and 90% of left ankles, with no statistically significant differences between right and left ankles. ICC analysis revealed a moderate correlation in the male group (ICC=0.47) and a strong correlation in the female group (ICC=0.89). To the best of the author's knowledge, this is the first study to evaluate IV using 3D anatomical models.

TO, a critical clinical parameter for evaluating syndesmosis injury, was measured with the tibia and fibula positioned perpendicular to the mortise and ankle planes. The mean TO results showed no significant difference for right ankles, but showed a statistically significant difference for left ankles (7.3 vs. 8.6 degrees) between gender groups. Nevertheless, the ICC analysis demonstrated strong correlations for TO in both gender groups. Higher mean TO results were obtained in the present study using the mortise plane, which may be attributable to the use of a 2D measurement method and a different reference axis in the study of Yüzügüldü et al.[12], despite both studies examining Turkish populations. This is the first, based on a review of current literature, to measure TO using 3D anatomical models.

Study Limitations

This study has certain limitations. First, the sample size, comprising the bilateral ankles of 80 adults, may appear limited; however, a post-hoc power analysis indicated 94% power. Second, while a single investigator performed the 3D analysis, reliance on automated computer-aided protocols ensured that measurement errors were minimized. Finally, this study utilized non-weight-bearing CT images. Different measurements may be obtained using weight-bearing CT imaging.

CONCLUSION

The results of this study corroborate the existing literature by demonstrating no clinically significant differences between contralateral ankles within gender groups. ICC analysis revealed strong correlations for the majority of measurement parameters between the bilateral ankles. Consequently, based on the 3D anatomical data, the contralateral ankle may serve as a reliable template for determining syndesmotic integrity or assessing intraoperative reduction quality.

Ethics

Ethics Committee Approval: Institutional review board approval was obtained from Ethics Committee of Ankara City Hospital with, decision no: EI/1309/2020, date: 11.11.2020.

Informed Consent: There is no need for informed consent due to the retrospective design of the study.

Footnotes

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Declaration of Interests: The author declare no conflict of interest regarding the publication of this paper.

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