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ORIGINAL ARTICLE

Tibiofibular relationships of the normal syndesmosis on axial computed tomography in the Turkish population

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Statements and Declarations

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Author Contributions: All authors have made substantial contributions to the conception and design, or acquisition of data, or analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be published, and agree to be accountable for all aspects of the work if questions arise related to its accuracy or integrity.

Ethical approval: All procedures followed were by the ethical standards of the responsible committee on human experimentation and with the 2013 version of the Declaration of Helsinki.

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This retrospective study was notified to our local ethics committee and authorized by our university and hospital authorities (Protocol No. 2022/87, July 01, 2022). Given the study's retrospective nature, the need for informed consent was waived.

Abstract

Objective. Computed tomography (CT) is superior to plain radiography for evaluating ankle syndesmosis, but anatomic variations can affect the measurements. This study aimed to assess the radiological parameters of incisura fibularis and the factors that could affect these parameters.

Materials and Methods. Lower extremity CT angiography images were used to evaluate the morphology of the incisura fibularis, anterior/posterior tibiofibular distance, longitudinal/transverse length of the distal fibula, length/depth of the incisura fibularis notch, tibiofibular clear space, tibiofibular overlap, and fibular rotation. Each measured parameter was compared based on gender and body sides. Also, the effect of age, height, weight, and body mass index (BMI) on parameters was evaluated.

Results. A total of 123 patients (83 males, 40 females) were included, and 246 ankles were measured. CT measurements demonstrated excellent intra-observer and interobserver reliability. No significant gender or side differences were found in tibiofibular overlap (TFO) and

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tibiofibular clear space (TFCS), the most used parameters in x-rays. Age, weight, and BMI were found to be correlated with TFO.

Conclusions. The present study has provided CT measurements of the normal tibiofibular syndesmosis in the Turkish population. Also, the correlations of the parameters with age, height, weight, and BMI were presented. Therefore, TFO and TFCS of the uninjured side can be used to plan the treatment of ankle injuries.

Keywords. Syndesmosis, Tibiofibular relationship, Computed tomography, Incisura fibularis

Introduction

Ankle fractures are among the most common injuries in orthopedic trauma, and 11-13% of these fractures include the distal tibiofibular joint and syndesmotic ligament complex [1-4]. Syndesmosis should be reduced to achieve an excellent clinical outcome and avoid posttraumatic arthritis [2, 3, 5, 6]. Anatomic reduction of the distal tibiofibular joint required for better functional results cannot be achieved via a closed reduction of up to 52% [6, 7]. The congruity of the ankle is affected in syndesmotic injuries. The incongruity of the joint increases the stress forces in the joint and decreases the contact area of the joint, which leads to degenerative changes and chronic instability [8-10].

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Diagnosis of syndesmotic injuries can be made by some clinical findings and stress tests (tenderness in palpation, bruising, squeeze test, Frick test, Cotton test). However, the sensitivity and specificity are low [1, 2]. Although the alignment of the joint cannot be evaluated under physiological loads on plain radiographs, routine radiological evaluation includes plain radiographs. Tibiofibular clear space (TFCS) and tibiofibular overlap (TFO) are the most used parameters to evaluate syndesmotic injuries in X-rays [11-13]. However, plain radiographs cannot determine subtle injuries and are also affected by the position [3, 13-15]. The advantage of obtaining an axial view highlighted the role of computerized tomography (CT) in diagnosing and treating ankle fractures. Also, the effect of the position of the ankle during radiological evaluation is minimal in CT [14]. Wide anatomic variations of distal tibiofibular joint and ankle anatomy can make the diagnosis of ankle injuries complex and affect the treatment plan [3,16]. Although the anatomy of distal tibiofibular syndesmosis in dry bones and with magnetic resonance imaging (MRI) in sprains was studied, the morphology of syndesmosis in the Turkish population has yet to be investigated [17-20].

This study aimed to determine the radiological measurements of distal tibiofibular syndesmosis from CT images of normal ankles in the Turkish population. We used CT angiography images of patients without acute or previous ankle injuries.

Materials and Methods

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This retrospective study was conducted with the approval of the ethical board. This study used lower extremity CT angiography images taken for any reason except trauma between January 2020 and March 2022. Patients with new or previous fractures in the lower extremities, those with deformity-acquired or congenital malformation, and those with systemic inflammatory disease were excluded.

Lower extremity CT angiography images were obtained from a 320-row CT (Aquilion One, Toshiba Medical Systems Corporation). The CT data acquisition was performed with the following technical parameters: 100-120 kV, 50-500 mA, 0.3 second rotation time, matrix size 512 x 512, pitch 0.8, and section thickness of 0.5 mm. For analysis, studies were transferred into Dicom viewer software (Radiant Dicom Viewer 1.1, Medixant, Poland). The images were reviewed using the bone window setting (WL: 500, WW: 3600). Measurements were made 1 cm proximal to the ankle joint line, which was determined as the location of the syndesmosis in previous studies. Images parallel to the plafond in neutral rotation were reformatted to produce a standard axial CT scan. Neutral rotation was defined by the bimalleolar axis [3, 17, 21]. In addition, age, height, and weight data were obtained from medical records, and the patient's body mass index was calculated.

The following parameters were evaluated at the level of the distal tibiofibular syndesmosis:

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1- Morphology of incisura fibularis (concave or shallow). A fibular incisura with a depth of ≥4 mm indicates the syndesmosis has deep.
2- The length and depth of the incisura fibularis notch (Figure 1A-a,b)
3- Anterior tibiofibular distance (ATFD) is the distance between the anterior border of the fibula and the nearest point of the anterior tibial tubercle (Figure 1B-c), posterior tibiofibular distance (PTFD), the distance between the posterior border of the fibula and the nearest point of the posterior tibial tubercle (Figure 1B-f)
4- Longitudinal and transverse length of the distal fibula (Figure 1B-d,e)
5- Anterior tibiofibular interval (ATFI), the distance from the anterior tibia to the anterior fibula (Figure 1C-g)
6- Tibiofibular overlap (TFO), the interval from the medial fibula to the anterior tibial tubercle (Figure 1C-i)
7- Tibiofibular clear space (TFCS), the interval from the medial fibula to the tip of the posterior tibial tubercle (Figure 1C-h).
8- Q angle, the rotation of the fibula relative to the incisura. (Figure 1D)

When comparing the parameters according to gender, parameters were calibrated as ratios of the longitudinal length of the fibula to avoid the effect of anatomical variations on the parameters, as was done in previous studies [21, 22].

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Mean, standard deviation, median, minimum, and maximum values were given in descriptive statistics for continuous data, and number and percentage values were given in discrete data. Kolmogorov Smirnov test was used to examine the conformity of the data to the normal distribution. A t-test (Independent Samples t-test) was used for normally distributed data in comparing continuous data between genders. The Mann-Whitney U test was used for data that did not comply with normal distribution. Chi-square and Fisher's Exact tests were used for group comparisons (cross tables) of nominal variables. The Pearson Correlation coefficient analyzed relationships between continuous data and ankle measurements. In comparing right and left ankle measurements, the t-test (Paired Samples t-test) was used for normally distributed data, and the Wilcoxon test was used for data that did not fit the normal distribution. The difference between the right and left incisura fibularis types was evaluated by the McNemar test. Intraclass Correlation Coefficient (ICC) was used for the intra-observer and inter-observer reliability. IBM SPSS for Windows 20.0 (SPSS Inc. Chicago, IL) program was used in the evaluations, and $p<0.05$ was accepted as the statistical significance limit.

Results

A total of 123 patients (83 males, 40 females) were included in this study. The mean patient age was 57.2±14.7 years (19-86). The morphology of the incisura fibularis was concave in 17 females (42.5%) and shallow in 23 females (57.5%). The morphology of the feet was different in

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one male. The morphology of the incisura fibularis was concave in 127 feet (76.5%) and shallow in 39 feet (23.5%) in males.

The mean depth of incisura fibularis was 4.25±0.94, and the mean length was 22.4±2.48. The depth of the incisura fibularis, the length of the incisura fibularis, the longitudinal length of the fibula, ATFD, PTFD, and ATFI measurements were significantly greater in males than in females. However, calibrated ratios of these parameters did not differ between the genders. Overall measurements are summarized in Table 1. When the measurements of the right and left feet were compared, the depth of the incisura fibularis and the longitudinal and transverse length of the fibula were significantly different. The other measurements were similar between the feet (Table 2).

The depth of incisura fibularis positively correlates with height (r=0.261, p=0.019) and negatively correlates with BMI (r=-0.275, p=0.014) in females. The length of incisura fibularis positively correlates with the height (r=0.327, p=0.003) and the weight (r=0.282, p=0.011) in females. The depth and the length of incisura fibularis positively correlate with height and weight. (Table 3).

Women's weight affects ATFD (r=0.327, p=0.003) and PTFD (r=0.353, p=0.001). These parameters have a negative correlation with age in males and positive correlations with height, weight, and BMI (only with PTFD). While there are no correlations between the parameters and

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ATFI in females, the height (r=0.165, p=0.033) positively correlated with ATFI. As the age increases in both genders, TFO increases. The weight and BMI negatively correlate with TFO in all populations. No relations were found between BMI and the morphology of the incisura fibularis. While the height, weight, and Q angle decrease in males (Table 3). All correlations are detailed in Table 3.

The intra- and inter-observer reliabilities of the radiographic measurements are shown in Table 4. All CT measurements showed high intra- and inter-observer reliabilities (Table 4).

Discussion

An intact distal tibiofibular syndesmosis is an important anatomical structure for normal ankle function and plays an essential role in joint stability and load transfer [17, 18, 21, 23, 24]. Furthermore, anatomic reduction of syndesmosis provides joint congruity and avoids posttraumatic arthritis in ankle traumas [21, 25]. Therefore, an exact measurement of distal tibiofibular syndesmosis can help medical professionals to treat ankle injuries. In this study, we demonstrated the radiological measurements of distal tibiofibular syndesmosis using CT images obtained from angiography images of patients without ankle injuries and previous trauma in the Turkish population. Also, we evaluated the correlations between the radiological parameters and age, weight, height, and BMI.

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Because of the effects of the rotation of the ankle and the position of the foot during radiological evaluation, measurements with radiographs avoid obtaining precise results [14, 15, 21, 26]. The superiority of CT over plain radiographs has been demonstrated in previous studies [21, 24, 27]. Measurements that are difficult or impossible to evaluate with direct radiographs can be made with CT in 3D [28]. Previous studies assessed the morphology of the incisura fibularis on dry bones or with MRI in the Turkish population [17, 20]. However, CT allowed us to evaluate exact measurements of incisura fibularis in living persons. Using CT images for choosing anatomic landmarks allowed flawless measurements in this study. Intra- and inter-observer reliability of our measurements supported the results of this study.

In this study, the most distinct difference between males and females was the morphology of the incisura fibularis. Unlike the study of Tonogai et al., which demonstrated no significant difference in morphology of the incisura fibularis between genders in the Japanese population, most women had a shallow type, and most men had concave type incisura fibularis in the Turkish population in this study [3]. Previous studies in the Turkish population found similar results to our study [18, 20].

The length and the depth of incisura fibularis, ATFD, PTFD, ATFI, and the fibula length showed a gender-specific difference in this study. Previous studies demonstrated similar variations between genders but concluded that these were true anatomic variations, not actual

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differences when compared as ratios to the transverse length of the fibula [21, 22]. Similarly, we did not find a significant difference between the genders when these parameters were compared as a ratio of the longitudinal length of the fibula.

The depth of the incisura fibularis, the transverse, and the longitudinal length of the fibula were different according to the body side in this study. Also, one male had different incisura fibularis morphologies on his left and right feet. No significant difference was found for the other radiological parameters. In their MRI-based study, Yildirim et al. revealed the differences in the depth of incisura fibularis and ATFD in both genders [20]. On the other hand, a more recent and CT-based study by Park et al. demonstrated no differences in radiological parameters between the feet [22]. In this study, the parameters that can guide surgeons to treat ankle injuries compared with uninjured side (ATFI, TFO, and TFCS) were similar between the feet. Therefore, these parameters in CT images of the uninjured side can be reliable in planning treatment strategies for ankle injuries.

Park et al. divided 120 volunteers into three age groups to evaluate distal tibiofibular syndesmosis with CT and found that age was the most critical factor affecting the radiological parameters [22]. As the age increased, their subjects' ATFD, PTFD, and ATFI decreased. They advocated that the reason for this correlation could be a result of physiological changes of aging or arthritic changes [22]. The patients in this study were investigated for correlation between age and radiological parameters without dividing them into age groups. Similar to this study, a negative correlation between ATFD, PTFD, and age was found in our study but only in males. The decrease with age in females was not statistically significant. Unlike Park's study, we also found a positive correlation between age and TFO in both genders. As the age increased, patients had higher TFO measurements.

Tonogai et al. demonstrated the relation between BMI and the morphology of the incisura fibularis [3]. The subjects of their study with concave morphology had higher BMI. They suggested that higher weight is responsible for this correlation as the force across the ankle joint can increase up to 4 times the body weight [3, 29]. Although there was no such correlation in this study, we demonstrated all correlations between the radiological parameters of incisura fibularis and the height, weight, and BMI in both genders. We expect that the correlations we found will contribute to the treatment planning of physicians dealing with ankle injuries.

The most used radiological parameters to evaluate syndesmotic injuries in X-rays are TFO and TFCS [11-13]. This study found these parameters to be similar between genders and sides. Also, we found no correlations in TFCS. On the other hand, the TFO of the patients had a positive correlation with age, while it had negative correlations with weight and BMI. In light of these findings, we have demonstrated that age, weight, and BMI affect TFO, as shown in previous studies [21, 22].

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Our study demonstrated the radiological parameters of incisura fibularis in CT in the Turkish population, but it has some limitations. Firstly, the retrospective design of this study prevents us from matching every parameter to compare. Also, we could not evaluate the parameters according to foot dominance. Thirdly, this study did not investigate the effect of radiological parameters on ankle injuries or the impact of physiological loads on these parameters.

In conclusion, this study demonstrated the radiological parameters of incisura fibularis according to gender and side in the Turkish population with CT. Also, the correlations of the parameters with age, height, weight, and BMI were presented. Although the clinical relevance of these parameters could not be demonstrated in this study, we showed the parameters that could be taken as a reference from the uninjured side. Therefore, TFO and TFCS of the uninjured side can be used to plan the treatment of ankle injuries.

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Fig. 1- Axial computed tomography image of the right ankle in a 38-year-old man

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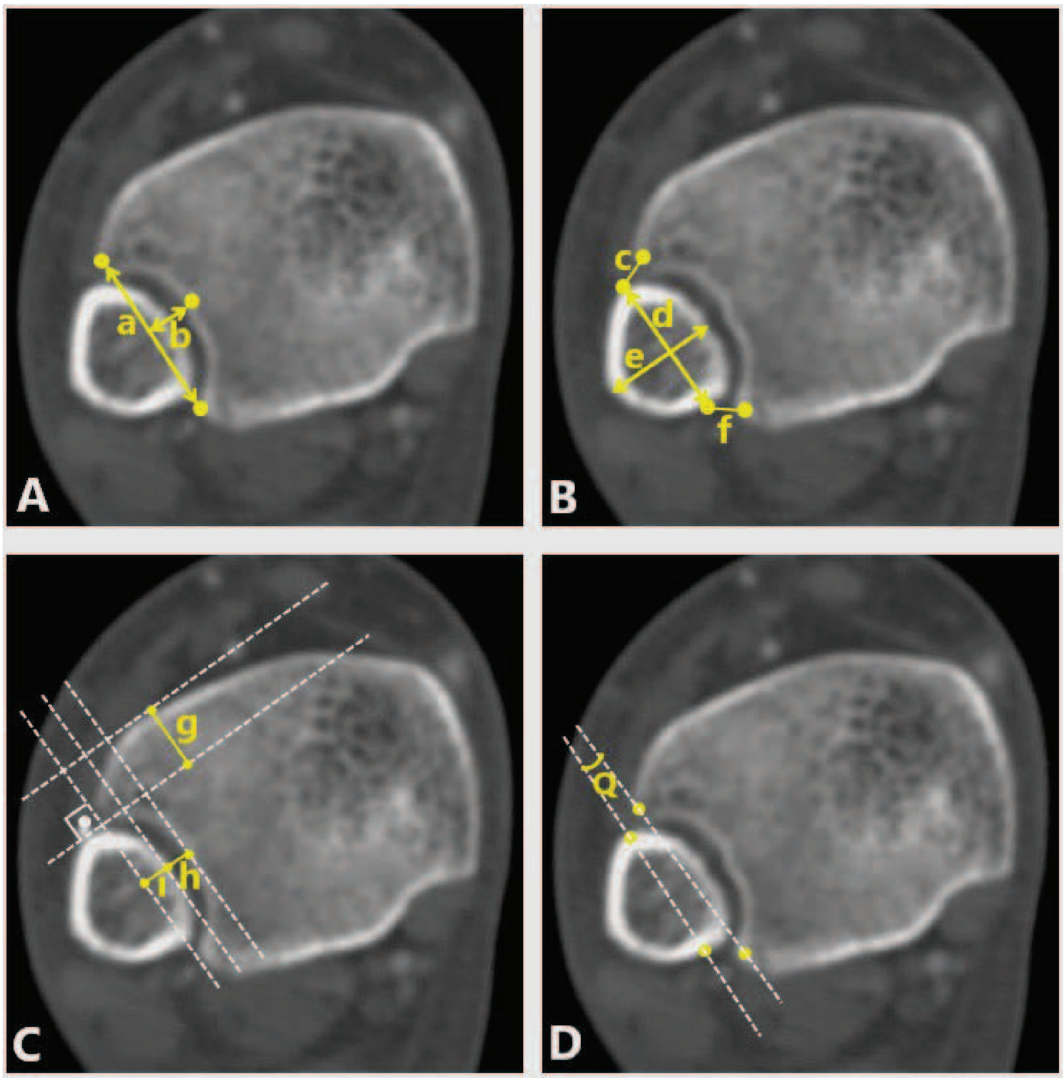

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	Overall	Female	Male	p
Depth of incisura fibularis (mm)	4.26±0.94 (2.12-7.06)	3.79±0.76 (2.37-5.82)	4.46±0.94 (2.12-7.06)	**<0.001** [a]
Length of incisura fibularis (mm)	22.44±2.47 (16.4-32.7)	20.84±2.01 (16.4-25.60)	23.21±2.31 (17.10-32.70)	**<0.001** [a]
ATFD (mm)	3.25±0.82 (1.69-5.80)	2.93±0.71 (1.69-4.45)	3.40±0.83 (1.80-5.80)	**0.002** [a]
PTFD (mm)	4.26±1.21 (1.92-9.58)	3.91±1.23 (1.92-9.58)	4.43±1.16 (2.51-7.74)	**0.002** [b]
Longitudinal length of fibula (mm)	17.82±1.69 (13.50-22.50)	17.07±1.68 (13.50-22.50)	18.19±1.58 (14.80-22.10)	**<0.001** [a]
Transverse length of fibula (mm)	14.19±1.60 (10.20-19.80)	13.79±1.40 (10.28-16.90)	14.32±1.66 (10.20-19.80)	0.079 [a]
ATFI (mm)	11.68±1.98 (6.63-17.90)	10.60±1.89 (6.63-17.90)	12.20±1.83 (8.02-17.50)	**<0.001** [b]
TFCS (mm)	2.54±0.68 (1.25-5.90)	2.37±0.56 (1.38-3.92)	2.62±0.72 (1.25-5.90)	0.102 [b]
TFO (mm)	4.17±1.15 (1.60-9.85)	4.08±1.25 (1.99-9.85)	4.20±1.11 (1.60-7.31)	0.564 [a]
Q angle (°)	10.72±3.13 (4.3-21.60)	10.73±3.22 (5.7-21.6)	10.41±3.07 (4.3-18.6)	0.134 [b]

Table 1- Summary of CT measurements. Data are presented as *Mean ±SD (Min-Max)* a: Independent t-test, b: Mann-Whitney U test

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	Right	Left	p
Depth of incisura fibularis (mm)	4.30±0.99 (2.37-7.06)	4.21±0.89 (2.12-6.81)	**0.001** [d]
Length of incisura fibularis (mm)	22.53±2.59 (16.4-32.7)	22.36±2.38 (16.50-29.40)	0.082 [d]
ATFD (mm)	3.24±0.86 (1.69-5.80)	3.25±0.77 (1.96-5.65)	0.728 [d]
PTFD (mm)	4.23±1.16 (2.30-7.74)	4.29±1.27 (1.92-9.58)	0.689 [e]
Longitudinal length of fibula (mm)	17.92±1.73 (13.60-22.10)	17.73±1.66 (13.50-22.50)	**0.001** [d]
Transverse length of fibula (mm)	14.33±1.60 (10.30-19.80)	14.06±1.59 (10.20-18.0)	**0.022** [d]
ATFI (mm)	11.64±2.00 (6.63-16.90)	11.72±1.98 (9.0-17.90)	0.909 [e]
TFCS (mm)	2.54±0.74 (1.38-5.90)	2.53±0.63 (1.25-4.51)	0.067 [e]
TFO (mm)	4.10±1.13 (1.89-7.31)	4.24±1.18 (1.60-9.85)	0.107 [d]
Q angle (°)	10.62±3.24 (4.3-18.6)	10.81±3.03 (5.40-21.60)	0.991 [e]

Table 2- CT measurements according to the body side. Data are presented as *Mean ±SD (Min-Max)* d: paired samples t-test, e: Wilcoxon test

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		Female				Male			
		Age	Height	Weight	BMI	Age	Height	Weight	BMI
Depth of incisura fibularis	r	0.104	**0.261**	0.110	**-0.275**	-0.089	**0.289**	**0.267**	0.032
	p	0.358	**0.019**	0.331	**0.014**	0.253	**<0.001**	**0.001**	0.680
Length of incisura fibularis	r	0.079	**0.327**	**0.282**	-0.161	-0.083	**0.469**	**0.460**	0.070
	p	0.483	**0.003**	**0.011**	0.151	0.289	**<0.001**	**<0.001**	0.369
ATFD	r	-0.145	0.217	**0.327**	0.066	**-0.265**	**0.311**	**0.361**	0.128
	p	0.200	0.053	**0.003**	0.559	**0.001**	**<0.001**	**<0.001**	0.100
PTFD	r	-0.007	0.183	**0.353**	0.152	**-0.206**	**0.162**	**0.323**	**0.258**
	p	0.948	0.103	**0.001**	0.180	**0.008**	**0.037**	**<0.001**	**0.001**
Longitudinal length of fibula	r	0.170	0.177	0.023	**-0.247**	0.152	**2.225**	**0.163**	-0.056
	p	0.131	0.117	0.841	**0.027**	0.051	**0.004**	**0.036**	0.476
Transverse length of fibula	r	0.035	0.159	-0.127	**-0.399**	0.137	0.094	0.058	-0.037
	p	0.756	0.158	0.261	**<0.001**	0.079	0.230	0.459	0.634
ATFI	r	0.091	0.162	0.189	-0.016	-0.098	**0.165**	0.144	0.007
	p	0.423	0.150	0.094	0.886	0.209	**0.033**	0.065	0.932
TFCS	r	-0.160	0.196	0.203	-0.059	-0.080	0.082	0.125	0.068
	p	0.157	0.082	0.070	0.606	0.308	0.295	0.110	0.384
TFO	r	**0.265**	0.015	**-0.244**	**-0.330**	**0.341**	-0.064	**-0.266**	**-0.290**
	p	**0.017**	0.898	**0.029**	**0.003**	**<0.001**	0.414	**0.001**	**<0.001**
Q angle	r	0.022	-0.144	-0.192	-0.014	0.020	**-0.285**	**-0.264**	-0.029
	p	0.848	0.204	0.087	0.904	0.794	**<0.001**	**0.001**	0.710

Table 3- Correlations measurements and between age, height, weight, and BMI values

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	Intra-observer ICC (95% CI)	Inter-observer ICC (95% CI)
Depth of incisura fibularis	0.967 (0.938-0.982)	0.927 (0.897-0.948)
Length of incisura fibularis	0.988 (0.976-0.994)	0.913 (0.878-0.938)
ATFD	0.968 (0.938-0.983)	0.947 (0.925-0.962)
PTFD	0.979 (0.960-0.989)	0.977 (0.967-0.984)
Longitudinal length of fibula	0.991 (0.982-0.995)	0.938 (0.926-0.963)
Transverse length of fibula	0.981 (0.964-0.990)	0.854 (0.800-0.896)
ATFI	0.969 (0.942-0.984)	0.935 (0.909-0.954)
TFCS	0.977 (0.957-0.988)	0.928 (0.898-0.943)
TFO	0.971 (0.945-0.985)	0.908 (0.871-0.934)
Q angle	0.932 (0.857-0.960)	0.902 (0.864-0.931)

Table 4- Intra- and inter-observer correlation coefficients of the measured CT parameters. ICC: Intraclass correlation coefficient, CI: confidence interval