ESTIMATION OF THE TIBIAL LENGTH AND DEGREE OF TIBIAL TORSION

ODREĐIVANJE DUŽINE GOLENJAČE I STEPENA TIBIJALNE TORZIJE

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Abstract
Introduction. The tibia is a long, massive bone of the lower leg, the length of which is used in anthropological analyses to estimate body height. This bone is slightly rotated around its longitudinal axis, a condition known as tibial torsion. This study aimed to determine the total length of the tibia and the angle of tibial torsion, and to establish whether differences existed between right and left bones. **Material and Methods.** A total of 42 tibias from the osteological collection of the Department of Anatomy, Faculty of Medicine in Novi Sad were analysed (19 right, 23 left). Measurements of tibial length and the degree of torsion were performed, after which the measured values were compared to determine whether differences existed between right and left bones. **Results.** The average length of all bones was 37.45 cm, and the average value of the torsion angle was 28.68°. No statistically significant difference in length between right and left tibias was found, whereas the difference in the degree of torsion was statistically significant (t = 2.5690, p = 0.0141). Internal torsion was not recorded; in five tibias the angle of external torsion was over 40°, and in three cases it was exactly at the borderline value of 40°. **Conclusion.** No correlation was found between tibial length and the degree of tibial torsion. The torsion values of the tibias in the majority of the sample correspond to the most commonly described physiological range in the population.
Key words: Tibia; Torsion Abnormality; Anthropometry; Lower Extremity.

Sažetak
Uvod. Golenjača predstavlja dugu i masivnu kost potkolenice, čija se dužina koristi u antropološkim analizama za procenu telesne visine. Ova kost je blago rotirana oko svoje uzdužne osovine što se definiše kao tibijalna torzija. Cilj ovog istraživanja bio je određivanje ukupne dužine golenjače i ugla tibijalne torzije, kao i utvrđivanje razlike između desnih i levih kostiju. **Materijal i metode.** Analizirane su ukupno 42 golenjače iz osteološke kolekcije Zavoda za anatomiju Medicinskog fakulteta Novi Sad (19 desnih, 23 leve). Izvršena su merenja dužine golenjače i stepena njene torzije, a potom su izmerene vrednosti poređene, kako bi se utvrdilo da li postoje razlike između desnih i levih kostiju. **Rezultati.** Prosečna dužina svih kostiju iznosila je 37,45 cm, a prosečna vrednost ugla torzije 28,68˚. Nije utvrđena statistički značajna razlika u dužini između desnih i levih golenjača, dok je razlika u stepenu torzije bila statistički značajna (t = 2,5690, p = 0,0141). Unutrašnja torzija nije zabeležena; kod pet golenjača ugao spoljašnje torzije bio je preko 40˚, a u tri slučaja je iznosila graničnih 40˚. **Zaključak.** Nije utvrđena povezanost između dužine golenjača i stepena tibijalne torzije. Vrednosti torzije golenjača kod većine uzoraka odgovaraju najčešće opisanom fiziološkom opsegu u populaciji.
Ključne reči: tibija; torzija; antropometrija; donji ekstremiteti

Introduction

The tibia is a paired, inner bone of the lower leg and is a long bone. It has a shaft, a proximal end, and a distal end. There are three surfaces on the tibial shaft: lateral, medial, and posterior. The upper end is massive and consists of the medial and lateral condyles that articulate with the femur, and on the lateral surface of the proximal end, there is an articular surface for articulation with the proximal end of the fibula. The front of the upper end has a bulge called a tibial tuberosity. The distal end is smaller, in the shape of a four-sided pyramid whose lateral side serves to articulate with the distal end of the fibula. The medial side of the lower end extends downwards into a massive bony process called the medial malleolus [1].

A person's height may be approximated by applying anthropological equations derived from the total length of the tibia [2]. The length of the tibia is important for determining a person's height. However tibial length and torsion are largely independent traits. It is used in anthropology and forensic medicine [3]. Height assessment can be done using anatomical or mathematical methods. The former is applicable to live specimens, while the latter is preferable where the specimen consists only of body parts or corpses [4].

The total tibial length is defined as the linear distance extending from the articular surface of the lateral condyle to the apex of the medial malleolus [5].

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Tibial torsion is described as the rotational alignment of the tibia around its longitudinal axis. It increases with age until maturity [6].

Tibial torsion was first described by Le Damany [7]. Tibial torsion refers to any deviation or twisting of the tibia around its longitudinal axis [8]. Numerous clinical, anthropometric, and radiological studies were conducted to determine tibial torsion. The authors of these studies used different methods on the upper and lower edges of the tibia [6,9–12].

There are internal and external torsions. Internal tibial torsion represents the least complex of the three torsional conditions. This condition is characterised by inward rotation of the tibia and is the most frequent cause of intoeing in children between one and three years of age. It commonly affects both lower limbs and typically resolves spontaneously by six years of age. In infants, the mean internal tibial rotation is approximately 5° (range: –30° to +20°), while children aged eight years and above generally demonstrate a mean external rotation of about 10° (range: –5° to +30°) [13,14]. External tibial torsion is characterised by an outward orientation of the ankle joint, leading to pronation, eversion, and the development of *pes planus*. It generally does not resolve spontaneously during growth. Nevertheless, it does not necessitate surgical correction by osteotomy [13].

The authors have established that the baseline value of rotation is 0 degrees (when both ankles are in the frontal plane). Internal torsion is not physiological. It disturbs normal gait and is marked with negative values, while external torsion is physiological (0-40°) and is marked with positive values, and anything over 40° represents a pathological finding [15].

During a child's growth and development, the angle of tibial torsion changes. The intrauterine legs are limited in position by the uterus, and the pressure of the uterine wall can cause the bones to twist [16].

Fetal movements are important for normal musculoskeletal development [17]. Physiological tibial torsion is oriented externally along the proximodistal axis and progressively increases with advancing age [6]. Tibial torsion is minimal or absent at birth. It increases to 15–25° by approximately eight years with neuromotor activity [18]. Tibial torsion demonstrates substantial interindividual variability and contributes to the development of femoral torsion [19].

This study aimed to determine the total length of the tibia and the angle of tibial torsion, and to determine whether there is a difference between the right and left bones.

Material and Methods

The sample consisted of 42 tibias obtained from the Department of Anatomy of the Faculty of Medicine, University of Novi Sad. Out of the total 42 tibias, there were 19 right and 23 left tibias. Tibial length and torsion were measured for all bones, followed by a comparative analysis between the right and left sides. Tibial length was measured in 42 specimens, whereas the torsion angle was measured in 41, as one tibia was damaged at the proximal end and could not be assessed. The study was conducted in accordance with the ethical principles and approved by the Ethics Committee of the Faculty of Medicine, University of Novi Sad (approval number: 01-39/46).

All bones were photographed using an iPhone 14 Pro Max (Apple Inc., Cupertino, CA, USA) with a resolution of 12 MP (4032 x 3024 pixels) under standardised conditions. Each tibia was placed on a horizontal platform covered with a surgical compress. The bone was positioned with its posterior surface in contact with the platform, while the anterior border was oriented superiorly. The posterior surfaces of the medial and lateral condyles were in contact with the platform, providing a stable position of the specimen. At the distal end, the posterior surface of the distal tibial extremity was in contact with the platform, while the medial malleolus did not touch the platform. The specimens were aligned along their longitudinal axis, ensuring clear visualisation of anatomical landmarks and accurate morphometric measurements.

The length of the bones was measured using the ImageJ 1.48v program, from the intercondylar eminence to the apex of the medial malleolus at the lower end (**Figure 1**). After calibration of the images using the *Set Scale* function, tibial length was measured using the *Straight Line Tool*, and the obtained values were recorded using the *Measure command*.

The torsion angle was measured with a universal transparent plastic goniometer (Bauerfeind, Germany) with a 360° circular scale and integrated centimetre ruler. The method of measuring using a goniometer involves placing the bone on a flat surface, with its condyles (upper end) resting on it. The lower ends of the bones will form a certain angle (relative to the upper end, with the condyles resting on the flat surface of the table) that can be measured using a goniometer. The arms of the goniometer are positioned so that one arm is parallel to the edge of the table, and the other arm overlaps the line extending between the midpoint of the medial malleolus of the tibia and the midpoint of the fibular incisure (**Figure 2**). Measured values were recorded in the protocol. All measurements were performed by the same observer. Absolute and relative

Figure 1. Measurement of the: A - length of the tibia; B - total tibial length (d), distance between articular surfaces (d_1)

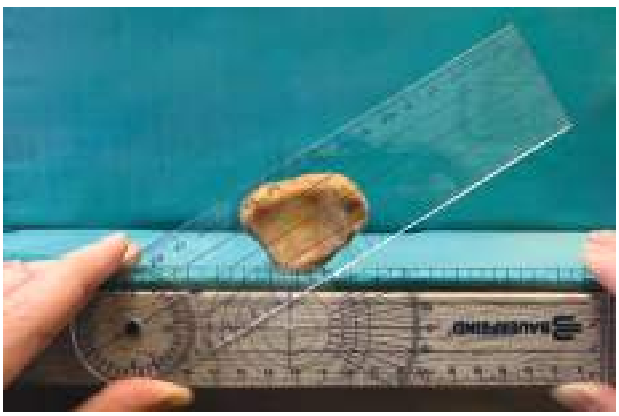

Figure 2. Measurement of tibial torsion

numbers were used, and statistical significance was assessed using Student's t-test. Measured values of tibial torsion (in degrees) were interpreted according to reference ranges from the literature [15], defining negative values as internal torsion, values between 0° and 40° as physiological external torsion, and values greater than 40° as pathological external torsion (**Figure 3).**

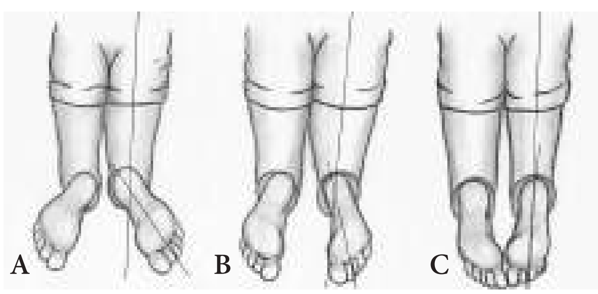

Figure 3. Tibial torsion: A - pathological external (above 40°); B - physiological external (0-40°); C - pathological internal (less than 0°)

Results

The mean tibial length for the entire sample was 37.45 cm, with a mean torsion angle of 28.68°. Tibial length was measured in 42 specimens, whereas the torsion angle was measured in 41, as one tibia was damaged at the proximal end and could not be assessed.

Among the 23 left tibias, the mean length was 37.34 cm (SD = 2.49 cm) and the mean torsion angle was 25.43° (SD = 9.82°). In the 19 right tibias, the mean length was 37.59 cm (SD = 2.74 cm) and the mean torsion angle was 32.83° (SD = 8.21°).

Figure 4 presents the mean tibial torsion values for the right and left sides. No statistically significant difference was observed in tibial length between sides ($t = 0.3101$, $p = 0.758$). In contrast, the difference in torsion angle between right and left tibias was statistically significant ($t = 2.5690$, $p = 0.014$).

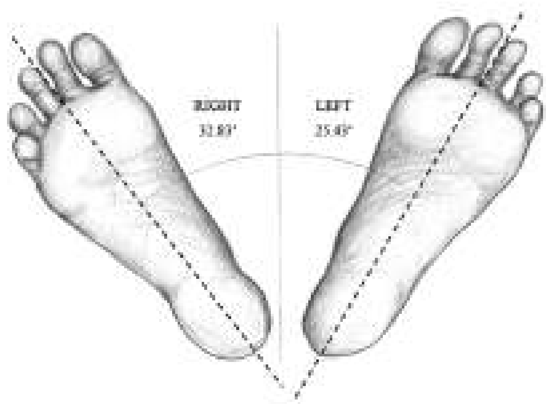

Figure 4. Average tibial torsion values (right and left side)

Among the total number of bones, external torsion angles greater than 40° were recorded in five cases: four in right tibias and one in a left tibia. In three additional cases, the external torsion angle reached the threshold value of 40° (**Figure 5**).

Figure 5. Distribution of tibial torsion patterns according to body side

Table 1. Descriptive analysis of the left and right tibial length

	Min (cm)	Max (cm)	x ±SD (cm)	p
Left	31	41.9	37.34 ± 2.49	0.758
Right	30.6	40.5	37.59 ± 2.74	

Min - minimal value, Max - maximal value, SD - standard deviation, $p<0.05$

Table 2. Descriptive analysis of the left and right tibial torsion

	Min (°)	Max (°)	x ±SD (°)	p
Left	10	46	25.43 ± 9.82	0.014
Right	25	50	32.83 ± 8.21	

Min - minimal value, Max - maximal value, SD - standard deviation, $p<0.05$

No cases of internal torsion or torsion with a baseline value of 0° were observed.

The ranges of tibial length and torsion angle are presented in **Tables 1 and 2**.

Discussion

Over the past two decades, studies conducted in Serbia have reported methods for estimating stature based on measurements of the long bones of the limbs [20,21].

Previous research has demonstrated sex-related differences in mean tibial length. The average length of the tibia in males ranges from 37 to 41 cm, while in females it ranges from 35 to 38 cm, in accordance with population differences [21–24].

Due to insufficient data, it was not possible to determine the sex of the person to whom the tibia belonged in our study. The mean tibial length measured in our study was 37.45 cm, which is in agreement with previously published findings [21–25].

It should be noted that estimated calculated heights based on the mean tibial length are not entirely precise, as the mean tibial length was applied without consideration of sex.

Most authors have observed that in humans, the most common external tibial rotation is between 10 and 30° [16,26–28].

According to our results, the measured torsion values in 25 cases (60.98%) fell within this interval, and in 16 cases (39.02%) exceeded it.

In a cadaveric study by Villamin et al. [29], conducted on 28 limbs of Filipino adults, the average value of tibial torsion was 28.9° ± 10.8°, with a range of 10° to 50°. The obtained values are comparable, although the methodologies differ, primarily in the choice of anatomical reference points and the approach to establishing the proximal and distal tibial axes. The average value of tibial torsion in our sample is identical to the value obtained in the mentioned study, without internal torsion.

It has been observed that right tibias tend to show greater external torsion, while internal torsion, where present, occurs more frequently on the left side [REF]. Similar results were obtained in our study, in which the angle of external torsion was significantly greater on the right side.

Based on tibial length, body height can be estimated using *the anthropological formula* proposed by Trotter and Gleser (1952, 1958): for women, $h = 72.572 + 2.533*T$; for men, $h = 81.688 + 2.392*T$, where h denotes the estimated stature in centimetres, and T represents tibial length in centimetres, and T represents tibial length (cm). The regression coefficients (2.533 and 2.392) expresses the contribution of tibial length to the predicted stature, whilst the constant (72.572 and 81.688) represents the intercept of the equation, corresponding to the theoretical stature value when tibial length equals zero [30–32].

Similar results were obtained in our study because the angle of external torsion is significantly larger on the right side.

In a CT-based study by Gallo et al. [33], the average value of tibial torsion was 27.5 ± 8.3°, with pronounced individual variability and frequent differences between the left and right sides. In our sample, the average value of tibial torsion was 28.68°, which is very close to the values reported by Gallo et al. Also, in both studies, asymmetry between the right and left sides was observed, with a higher degree of external torsion of the right tibia.

Pronounced tibial torsion may be associated with clinical manifestations involving the knee, including anterior knee pain, gait disturbances, and patellar instability [34].

The tibial torsion values observed in the present study fall within the physiological range reported in the literature and are consistent with the findings of Hawi et al. [35]. A statistically significant side-related difference was identified, with greater external torsion in the right tibia, in line with previously reported lateral asymmetry in tibial rotation.

Tibial torsion is almost always corrected by growth. Previously, various splints, corsets, and special shoes were used to correct torsion. However, none of this is an effective therapeutic modality [36].

Operative treatment may be indicated in patients above eight years of age when significant functional or aesthetic deformity is present, particularly in cases of anteversion greater than 50° and internal rotation exceeding 80° [37]. Patients aged 13-17 years experienced significantly longer hospitalisation and a longer time from admission to surgery compared with those under 13 years ($p<0.05$) [38].

According to our results, external torsion would be a much more common indication for surgical treatment. No cases of internal torsion were recorded, and external pathological torsion was observed in five cases. Given that these were adult bones, all five cases would be candidates for rotational osteotomy.

Several limitations of this study should be considered. These include the relatively small sample size and the measurement methodology, as digital measurements performed using specialised software may provide greater precision. Additionally, the lack of information on the age and sex of the individuals, as well as the inability to match left and right tibias from the same individual, may have influenced the interpretation of the results.

Conclusion

Analysis of the sample revealed a mean tibial length of 37.45 cm, with slightly higher values observed on the right side (37.59 cm) compared to the left (37.34 cm). The overall mean tibial torsion was 28.68°, with mean values of 32.83° in the right tibias and 25.43° in the left tibias. Pathological external tibial torsion (>40°) was more frequently identified on the right side (right: 4 cases; left: 1 case).

No association was found between tibial length and the degree of torsion. In 60.98% of cases, the measured tibial torsion values fell within the range most commonly reported in the literature as prevalent in the general population.

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