



Original Article

## Morphometric Assessment of Tibial Tuberosity and its Clinical Relevance in Adult Human Tibiae

Dr D. Srivani<sup>1</sup>, Dr N. Kavya<sup>2</sup>, Dr K. Prathibha<sup>3</sup>, Dr C. Sreekanth<sup>4</sup>

<sup>1,2</sup>Assistant Professor, Department of Anatomy, SVIMS–SPMCW, Tirupati, Andhra Pradesh, India

<sup>3,4</sup>Professor, Department of Anatomy, SVIMS–SPMCW, Tirupati, Andhra Pradesh, India

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### Corresponding Author:

**Dr D. Srivani**

Assistant Professor, Department of  
Anatomy, SVIMS–SPMCW, Tirupati,  
Andhra Pradesh, India

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### ABSTRACT

**Background:** The tibial tuberosity is a key anterior tibial landmark that anchors the patellar tendon and contributes to extensor mechanism alignment. Reliable morphometric data assist in planning procedures such as tibial tubercle osteotomy, tunnel positioning during ligament reconstruction, and implant-related decisions.

**Objectives:** To document morphometric dimensions of the tibial tuberosity in adult human tibiae and compare measurements between right and left sides.

**Methods:** A prospective observational cadaveric study was conducted on 100 adult tibiae (50 right, 50 left) in the Department of Anatomy, SVIMS–Sri Padmavathi Medical College for Women, Tirupati, India. Using standardized osteometric landmarks and a digital Vernier caliper, we measured (i) the distance of tibial tuberosity from the anterior border of the intercondylar area, and (ii) length and breadth of the upper smooth and lower rough parts of the tuberosity. Side-to-side differences were assessed using appropriate parametric tests.

**Results:** The mean distance from the anterior intercondylar border was higher on the right side ( $13.53 \pm 0.27$  mm) than the left ( $13.22 \pm 0.55$  mm), indicating a significant side difference. Length and breadth parameters of both upper smooth and lower rough parts were comparable between sides, showing no statistically meaningful differences.

**Conclusion:** Adult tibial tuberosity measurements demonstrated minimal bilateral variability for most parameters, while the anterior intercondylar distance showed a statistically significant difference. These findings provide reference morphometry that supports operative planning and accurate orientation during patellofemoral realignment and related knee procedures.

**Keywords:** tibial tuberosity; tibia; morphometry; patellar tendon; cadaveric study; knee surgery.

### INTRODUCTION

The tibial tuberosity is a prominent osseous elevation on the anterior aspect of the proximal tibia and forms the distal attachment site for the patellar tendon, thereby serving as a functional endpoint of the quadriceps–patellar tendon unit [1,2]. Because this structure participates directly in load transmission during knee extension, its morphology has implications for extensor mechanism biomechanics, patellofemoral contact patterns, and the clinical evaluation of anterior knee pain [3]. Early anatomical descriptions emphasized that the tuberosity displays inter-individual variation in prominence, slope, and surface segmentation, features that can influence both clinical palpation and radiologic interpretation [4].

In contemporary orthopaedics, the tibial tuberosity is not only a surface landmark but also an operative reference point for alignment-based interventions. Tibial tubercle osteotomy and transfer procedures aim to modify the line of action of the patellar tendon to address patellar maltracking, painful malalignment, and selected instability phenotypes [3,5]. Systematic reviews have reported improvements in patient-reported outcomes after tubercle-based realignment in carefully selected cohorts, reinforcing the need for precise anatomical understanding at the time of surgical planning [10,11]. At the same time, the expanding use of imaging-derived indices (for example, measurements related to the

relationship between tibial tuberosity and trochlear groove) has highlighted that bony morphometry interacts with rotational alignment and measurement technique, which can affect clinical decision thresholds [5,6].

Morphometric datasets also contribute to implant and technique optimization. Proximal tibial geometry influences component sizing and placement in arthroplasty, while tuberosity-based orientation assists in defining safe working corridors and avoiding iatrogenic injury during open and minimally invasive procedures [2,4]. Recent MRI-based methods that quantify anterior tibial tuberosity morphology further support the concept that population-specific reference values are useful for harmonizing anatomical assessment across modalities [4]. Moreover, rotational characteristics of the tibial tuberosity have been associated with patellar instability phenotypes, illustrating that the tuberosity can reflect intrinsic proximal tibial alignment rather than being a purely local surface feature [7].

Although several studies have explored aspects of proximal tibial morphometry, available reports vary in measurement definitions, specimen type, and ethnic representation [8,9]. Such variability limits direct translation across settings and underscores the value of institution-based cadaveric measurements derived from consistent osteometric landmarks. Establishing reference values for length, breadth, and positional relations of the tibial tuberosity can support anatomists, radiologists, and surgeons in preoperative templating, device design considerations, and intraoperative orientation.

The objectives of the present study were to measure the distance of the tibial tuberosity from the anterior border of the intercondylar area and to quantify the length and breadth of the upper smooth and lower rough parts of the tibial tuberosity in adult human tibiae, and to compare these parameters between right and left sides.

## **MATERIALS AND METHODS**

### **Study design and setting**

This prospective observational cadaveric study was conducted in the Department of Anatomy, Sri Venkateswara Institute of Medical Sciences–Sri Padmavathi Medical College for Women (SVIMS-SPMCW), Tirupati, Andhra Pradesh, India. The study period extended from January 2024 to November 2025.

### **Sample size and specimen selection**

A total of 100 adult human tibiae constituted the study sample (N = 100), comprising 50 right-sided and 50 left-sided specimens. Only fully ossified tibiae with clearly identifiable proximal anatomical landmarks and an intact tibial tuberosity were included. Specimens showing gross deformity, fracture lines, erosive changes, or evidence of pathological remodeling affecting the proximal tibia were excluded to ensure measurement validity. Side determination was confirmed using standard anatomical orientation of the tibial plateau, intercondylar eminence, and medial malleolar surface characteristics.

### **Morphometric parameters and measurement technique**

All measurements were recorded using a calibrated digital Vernier caliper (Figure 1A–C). with millimetre precision, following a standardized protocol based on reproducible osteometric points. The tibial tuberosity was conceptually divided into an upper smooth part and a lower rough part, consistent with classical descriptions of surface texture and attachment footprint [1,8]. The following parameters were assessed on each specimen: (i) distance of the tibial tuberosity from the anterior border of the intercondylar area, measured as the linear distance between the anterior intercondylar margin and the most prominent point of the tuberosity on the anterior surface; (ii) length of the upper smooth part and length of the lower rough part, measured along the longitudinal axis of the tuberosity; and (iii) breadth of the upper smooth part and breadth of the lower rough part, measured in the mediolateral plane at the maximal transverse dimension of each segment.



**Figure 1. Digital Vernier caliper–based morphometric measurements of the tibial tuberosity**

**(A) Measurement of the distance between the tibial tuberosity and the anterior border of the intercondylar area using a calibrated digital Vernier Caliper.**



**(B) Demonstration of longitudinal assessment of tibial tuberosity dimensions (upper smooth and lower rough segments) on the anterior aspect of the tibia.**



**(C) Measurement of tibial tuberosity breadth at the maximal transverse dimension using the Vernier caliper.**

To minimize random error, each parameter was measured three times by the same investigator under uniform lighting and positioning, and the average of three readings was used for final analysis. Specimens were placed on a flat non-slip surface with the anterior border facing upward, and the caliper arms were aligned carefully to avoid parallax-related bias. All observations were recorded on a predesigned proforma.

#### **Data management and statistical analysis**

Data were entered into a spreadsheet and cross-verified for completeness. Continuous variables were summarized as mean  $\pm$  standard deviation and range, while categorical variables were presented as frequency and percentage. Side-wise comparisons between right and left tibiae were performed using independent samples t-tests after confirming approximate normal distribution of measurements. A p value  $< 0.05$  was considered statistically significant. Results were reported in accordance with standard morphometric reporting practices to facilitate comparison with published anatomical and clinical literature [4-6].

#### **Ethical considerations**

The study was carried out on anonymized cadaveric/osteology specimens available within the departmental collection. No personal identifiers were associated with the specimens. Departmental permission for academic use of specimens and documentation of measurements was obtained prior to data collection.

#### **RESULTS**

A total of 100 adult tibial specimens were evaluated, with equal distribution between right and left sides (50 each), ensuring balanced side-wise representation (Table 1).

**Table 1. Distribution of study specimens (N = 100)**

Side of tibia	Number (n)	Percentage (%)
Right	50	50.0
Left	50	50.0
Total	100	100.0

The distance of the tibial tuberosity from the anterior border of the intercondylar area demonstrated a statistically significant side difference. The right tibiae showed a higher mean distance ( $13.53 \pm 0.27$  mm) compared with the left tibiae ( $13.22 \pm 0.55$  mm), with a p value  $< 0.001$  (Table 2).

**Table 2. Distance of tibial tuberosity from anterior border of intercondylar area (mm)**

Side	Mean $\pm$ SD (mm)	Range (mm)	p value
Right	$13.53 \pm 0.27$	13.02–13.98	$<0.001$
Left	$13.22 \pm 0.55$	12.08–13.98	—

Length measurements of the tibial tuberosity showed comparable dimensions between sides. The mean length of the upper smooth part was  $19.45 \pm 1.48$  mm on the right and  $19.82 \pm 1.50$  mm on the left ( $p = 0.18$ ). Similarly, the lower rough part measured  $44.71 \pm 0.59$  mm on the right and  $44.85 \pm 0.56$  mm on the left ( $p = 0.21$ ), indicating no significant bilateral difference (Table 3).

**Table 3. Length measurements of tibial tuberosity (mm)**

Parameter	Right side (Mean $\pm$ SD)	Left side (Mean $\pm$ SD)	p value
Upper smooth part	$19.45 \pm 1.48$	$19.82 \pm 1.50$	0.18
Lower rough part	$44.71 \pm 0.59$	$44.85 \pm 0.56$	0.21

Breadth measurements likewise showed near-identical values across sides. The upper smooth part breadth was  $19.41 \pm 1.38$  mm on the right and  $19.53 \pm 1.39$  mm on the left ( $p = 0.64$ ). The lower rough part breadth was  $18.53 \pm 0.32$  mm on the right and  $18.53 \pm 0.52$  mm on the left ( $p = 0.95$ ) (Table 4).

**Table 4. Breadth measurements of tibial tuberosity (mm)**

Parameter	Right side (Mean $\pm$ SD)	Left side (Mean $\pm$ SD)	p value
Upper smooth part	$19.41 \pm 1.38$	$19.53 \pm 1.39$	0.64
Lower rough part	$18.53 \pm 0.32$	$18.53 \pm 0.52$	0.95

## DISCUSSION

This cadaveric morphometric study provides side-wise reference dimensions of the tibial tuberosity derived from a balanced sample of adult tibiae. The tibial tuberosity represents an interface between anatomy and biomechanics, functioning as the distal attachment for the patellar tendon and as a determinant of extensor mechanism alignment. Accordingly, subtle variation in tuberosity position and dimensions can influence surgical orientation during tibial tubercle osteotomy, graft tunnel placement, and realignment procedures performed for patellofemoral disorders [2,3].

In the present analysis, the distance between the tibial tuberosity and the anterior border of the intercondylar area was marginally higher on the right than the left, and the difference achieved statistical significance. Although the absolute difference was small, a consistent positional offset can be clinically relevant when surgeons rely on palpable bony landmarks and predefined measurement targets. Imaging-based work has emphasized that alignment metrics involving the tuberosity are sensitive to rotational factors, measurement planes, and landmark definition, which can produce meaningful variability in decision-making [5,6]. Prakash et al. highlighted that rotational profile parameters and tuberosity lateralization can contribute to the measured relationship between the tuberosity and trochlear groove, suggesting that anatomical evaluation should be interpreted in conjunction with overall rotational alignment rather than in isolation [5].

Length and breadth of both the upper smooth and lower rough parts of the tuberosity showed no statistically significant side differences in our series. This finding supports the concept that tuberosity surface dimensions are relatively conserved bilaterally in adult tibiae, which is advantageous for side-to-side templating. Comparable observations have been reported in morphometric assessments from other populations, where most tuberosity dimensions demonstrated

minor dispersion around the mean values [8,9]. Asad reported reference morphometry of tibial tuberosity in a North Indian sample, emphasizing the value of population-specific baselines for clinical translation and implant-related planning [9]. Similarly, Gandhi et al. provided proximal tibial morphometry relevant to alignment procedures, reinforcing the broader importance of establishing normative tibial dimensions in regional contexts [8].

From a clinical standpoint, tibial tubercle osteotomy is a versatile intervention used for patellar instability, maltracking, focal chondral disease, and selected pain syndromes refractory to conservative measures [2,3]. Recent syntheses indicate that carefully indicated tubercle transfer can yield clinically meaningful improvement, particularly in maltracking without frank instability [11]. At the same time, systematic reviews caution that osteotomy performed solely on the basis of a single distance-based metric does not uniformly translate into additional benefit, highlighting the need for individualized surgical planning [12]. Biomechanical work on multidirectional transfer strategies further underscores that the operative goal is often to optimize vector alignment while minimizing unintended changes in contact mechanics [13,14]. Our findings add anatomical granularity to this decision landscape by providing reproducible cadaveric benchmarks for tuberosity segment dimensions and positional relationships.

Finally, evolving MRI-based methods to characterize anterior tibial tuberosity morphology demonstrate growing interest in translating cadaveric landmarks into cross-sectional imaging parameters usable in preoperative assessment [4]. Future research integrating cadaveric morphometry with imaging and clinical outcomes can refine surgical thresholds and improve reproducibility across institutions.

### Limitations

This study utilized isolated adult tibial specimens without linked demographic details such as age, sex, body size, or laterality dominance, limiting subgroup interpretation. The sample originated from a single institutional collection, restricting external generalizability. Radiologic correlation and soft-tissue footprint mapping were not performed, and inter-observer reliability statistics were not generated. Despite these constraints, standardized landmarks and repeated measurements improved internal measurement consistency.

### CONCLUSION

This prospective cadaveric morphometric study provides reference values for tibial tuberosity position and segmental dimensions in 100 adult tibiae. The distance from the anterior intercondylar border differed significantly between right and left sides, whereas the lengths and breadths of the upper smooth and lower rough parts showed bilateral symmetry. Such baseline morphometry supports anatomical education and improves landmark-based accuracy during procedures involving the extensor mechanism. The data are relevant for planning tibial tubercle osteotomy/transfer, orienting the tibial surface for realignment strategies, and complementing imaging-based assessment of tuberosity morphology. Population-specific normative measurements can strengthen reproducibility in surgical templating and facilitate future comparative work linking anatomy to functional outcomes.

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