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Research Article

Morphometric and CT Analysis of the Upper End of the Tibia: A Cross-sectional Study of Dry Bones and Three-Dimensional CT Images

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Abstract

Background:

Knee implants are often designed from data on Western populations. Local data on the upper end of the tibia are limited. This study measured the condylar and intercondylar areas of the upper tibia on dry bones and on three-dimensional computed tomography (CT) images, and compared the right and left sides.

Methods:

This cross-sectional study was conducted in the Department of Anatomy, Government Medical College, Cuddalore, from January 2023 to June 2023. The original study included 50 adult dry tibiae and 50 three-dimensional CT images of adult tibiae. This report focuses on eight condylar and intercondylar measurements. Dry bones were measured using a vernier caliper, and CT images using software measurement tools. Right-left comparisons were assessed using the t test, with $p < 0.05$ considered statistically significant.

Results:

Examination of the CT findings showed that the anteroposterior dimension of the medial condyle was 42.5 mm on the right and 39.6 mm on the left ($p = 0.007$). On dry bone, the corresponding means were 41.3 mm and 39.5 mm ($p = 0.0004$). The lateral condylar anteroposterior dimension did not differ significantly by side on either method. Four of the eight CT parameters and five of the eight dry-bone parameters showed significant right-left differences. The medial condyle was longer than the lateral condyle in the anteroposterior direction on both methods.

Conclusion:

The upper tibia showed side-related differences in several condylar and intercondylar dimensions. The medial condyle was longer than the lateral condyle front to back. These values can serve as baseline data for tibial component design in this population. Larger studies that record sex and age are needed.

Keywords: Anthropometry, Computed Tomography, Knee Arthroplasty, Morphometry, Tibia

Introduction

The knee is one of the main weight bearing joints of the lower limb. It allows walking, standing, climbing stairs, running and jumping. The joint is formed by the lower end of the femur and the upper end of the tibia. The tibia passes most of the body weight to the talus at the ankle. Its upper end is therefore exposed to heavy mechanical load during daily activity and sport. This makes the region prone to injury and to degenerative change. Knowing its normal dimensions helps in diagnosing and treating these conditions.

The upper end of the tibia is expanded into a medial and a lateral condyle. Their upper surfaces are covered by hyaline cartilage and are separated from the femoral condyles by the menisci. The medial articular surface is large and oval. The lateral surface is smaller and rounder. The intercondylar area lies between the two surfaces. It is narrow in the middle, where the intercondylar eminence rises, and wider in front and behind. The horns of both menisci and the anterior and posterior cruciate ligaments attach to the anterior and posterior parts of this area. Its dimensions are therefore useful when planning ligament surgery and when reading knee imaging.

Osteoarthritis is the most common reason for knee replacement. Total and Partial knee arthroplasty are accepted treatments for osteoarthritis and other degenerative disease of the knee. The aim is a stable knee that is free of pain and moves well. Correct implant design is also needed to correct varus and valgus deformity during the operation. The result depends largely on how well the tibial component fits the cut surface of the bone. A component that is too small may rest on weaker cancellous bone and sink over time. A component that is too large overhangs the edge of the bone and can upset soft tissue balance. Precise matching of the tibial component to the resected bone, together with correct rotation, is crucial for a good result.[1]

Most implants are designed on the anatomy of white patients. A systematic review of knee shape in different races compared the distal femur and proximal tibia across ethnic groups and noted that most knee prostheses are based on the anatomy of white patients.[2] Body size and bone size differ between populations. An implant made for one population may not suit another. In India, a component designed on Western data may not fit the resected bone well.

Sex is another source of variation. A CT study of osteoarthritic knees from a Chinese population found that the mediolateral, anteroposterior, medial anteroposterior and lateral anteroposterior dimensions of the proximal tibia all differed between men and women.[3] The ratio of mediolateral to anteroposterior length also fell as the anteroposterior dimension rose. This means that a single scaled component cannot match every knee. Disease may also change bone shape. A second Chinese CT study compared resected distal femurs and proximal tibias of osteoarthritic and normal knees, because data on these differences were scarce.[4]

The upper tibia can be studied using dry bone or CT. Dry-bone morphometry allows direct caliper measurement, whereas three-dimensional CT provides surface views of the tibial plateau in living individuals. These methods have different sources of measurement error, and results obtained from separate dry-bone and CT samples can be compared descriptively but cannot establish agreement between methods.]5] Dry bone also lacks the soft tissues and cartilage present in vivo.

Published literature on the upper tibia in South Indian populations is limited. Overall mediolateral and anteroposterior dimensions of the tibia have been reported more often than dimensions of each condylar surface and the overall and transverse dimensions of the intercondylar area. These measurements are clinically relevant to implant sizing and interpretation of knee imaging.

The right and left tibiae are often treated as equal when implants are chosen. If the two sides differ, this assumption needs a check. Reference values for the upper tibia may also help anthropologists and forensic experts, who use bone dimensions to describe skeletal remains. The value of such data depends on the population studied, so local measurements are needed.

This study focuses on eight selected condylar and intercondylar dimensions in a sample of 50 dry adult tibiae and 50 three-dimensional CT images. We have compared the right and left measurements within each modality and discussed our observation by comparing it with previously published research work.

Materials and Methods

This cross-sectional observational study was conducted in the Department of Anatomy, Government Medical College, Cuddalore, from January 2023 to June 2023. The original sample comprised 50 adult dry tibiae and 50 three-dimensional CT images of adult tibiae. Convenience sampling was used; no formal sample-size calculation was reported. Institutional ethics committee approved the study.

Dry bone measurements were taken with a vernier caliper, which was checked and calibrated before use. Each bone was placed on a flat, stable surface with its upper end facing up. The medial and lateral condyles, the tibial plateau and the intercondylar eminence were marked as landmarks. For the width of each condylar surface, one jaw of the caliper was placed on one edge of the surface and the other jaw on the opposite edge, and the reading was recorded. For the anteroposterior dimension, one jaw was placed on the anterior edge and the other on the posterior edge of the surface. The intercondylar width was measured by placing the jaws on either side of the intercondylar eminence. Each measurement was repeated at least three times and the average was taken. Protective gloves were used while handling the bones, and the caliper was cleaned after use.

CT images were studied as volume rendered 3D images of the tibial plateau. The images were reconstructed in the axial, coronal and sagittal planes, and 3D reconstruction was used to view the bone in three dimensions. The same landmarks were identified on the images. Distances were measured with the measurement tools of the CT software. The slice, the plane of measurement and any anomaly were noted for each image. The measurements were reviewed with a radiologist to check accuracy and consistency. Annotated images were prepared to show the measured areas and landmarks.

The present report focuses on eight parameters assessed on dry bones and CT images: (1) anteroposterior dimension of the superior articular surface of the medial condyle (MC-AP); (2) transverse dimension of the medial condyle (MC-T); (3) anteroposterior dimension of the lateral condyle (LC-AP); (4) transverse dimension of the lateral condyle (LC-T); (5) anteroposterior length of the overall intercondylar area (IA-AP); (6) transverse width of the intercondylar area at the anterior end (IA-TA); (7) transverse width at the middle narrow part (IA-TM); and (8) transverse width at the posterior end (IA-TP). All measurements were reported in millimetres.

The measurements were entered in a spreadsheet and analysed with SPSS 23.0 software. Data were summarised as mean and standard deviation (SD). The mean values of the right and left sides were compared for each parameter, separately for CT images and for dry bones, using the independent samples t test. A p value below 0.05 was taken as statistically significant.

Inclusion criteria:

- Adult dry tibia bone specimens from the study institution
- Three-dimensional CT images of the upper end of the adult tibia
- Upper end of the tibia available for measurement

Exclusion criteria:

- Damaged bones (dry bone specimens)
- Previous fracture or dislocation of the knee (CT images)
- History of trauma (CT images)
- History of knee surgery (CT images)

Results

The present analysis reports eight parameters of the upper end of the tibia measured on 50 dry bones and 50 CT images (Table 1). On CT, four of the eight reported parameters differed significantly between right and left sides (Table 2). The anteroposterior dimension of the medial condyle was larger on the right (42.5 mm) than on the left (39.6 mm; Figure 1), whereas the transverse dimension of the medial condyle was

larger on the left. Neither lateral-condylar parameter showed a significant right-left difference. The transverse widths of the intercondylar area at the middle narrow part and posterior end were larger on the left. The overall intercondylar anteroposterior length and its anterior transverse width did not differ significantly between sides.

No.	Parameter	Abbreviation
1	Medial condyle, anteroposterior	MC-AP
2	Medial condyle, transverse	MC-T
3	Lateral condyle, anteroposterior	LC-AP
4	Lateral condyle, transverse	LC-T
5	Intercondylar area, anteroposterior	IA-AP
6	Intercondylar area, transverse at anterior end	IA-TA
7	Intercondylar area, transverse at middle narrow part	IA-TM
8	Intercondylar area, transverse at posterior end	IA-TP

Table 1: Eight selected morphometric parameters reported for dry tibiae and three-dimensional CT images.

Table 2: CT measurements of the upper end of the tibia, right and left (mean ± SD, mm)

Parameter	Right (mean ± SD)	Left (mean ± SD)	p value
MC-AP	42.5 ± 3.39	39.6 ± 4.05	0.007
MC-T	26.9 ± 2.23	29.7 ± 1.48	0.0001*
LC-AP	36.6 ± 4.11	36.5 ± 3.75	0.9430
LC-T	27.0 ± 3.75	28.3 ± 2.75	0.166
IA-AP	49.5 ± 4.16	50.6 ± 3.70	0.3512
IA-TA	25.3 ± 3.20	27.1 ± 3.20	0.0596
IA-TM	12.5 ± 1.06	13.5 ± 1.03	0.00127
IA-TP	20.8 ± 2.87	23.2 ± 2.75	0.0035

* $p < 0.05$ was considered to be statistically significant

Table 3: Dry-bone measurements of the upper end of the tibia, right and left (mean ± SD, mm).

Parameter	Right (mean ± SD)	Left (mean ± SD)	p value
MC-AP	41.3 ± 0.74	39.5 ± 2.29	0.0004 *
MC-T	27.8 ± 2.71	28.8 ± 1.91	0.1611
LC-AP	36.9 ± 0.77	37.4 ± 2.78	0.3902
LC-T	29.6 ± 1.18	31.2 ± 1.38	0.0001*
IA-AP	47.5 ± 2.33	46.6 ± 3.23	0.2461
IA-TA	16.3 ± 1.43	25.3 ± 2.40	<0.001*
IA-TM	14.1 ± 1.82	16.0 ± 1.66	0.0002*
IA-TP	20.4 ± 1.38	21.3 ± 1.41	0.0222*

* $p < 0.05$ was considered to be statistically significant

Figure 1: Mean anteroposterior dimension of the medial condyle on CT

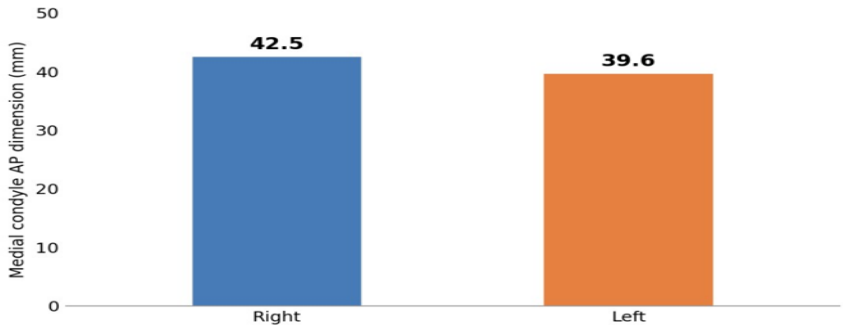


Figure 2: Mean anteroposterior dimension of the medial condyle on dry bone

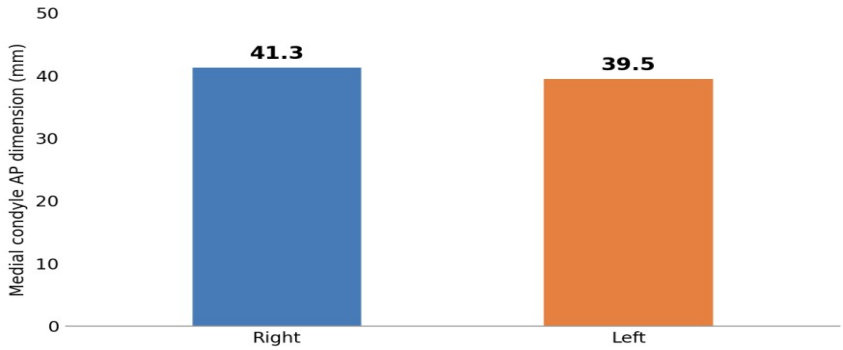
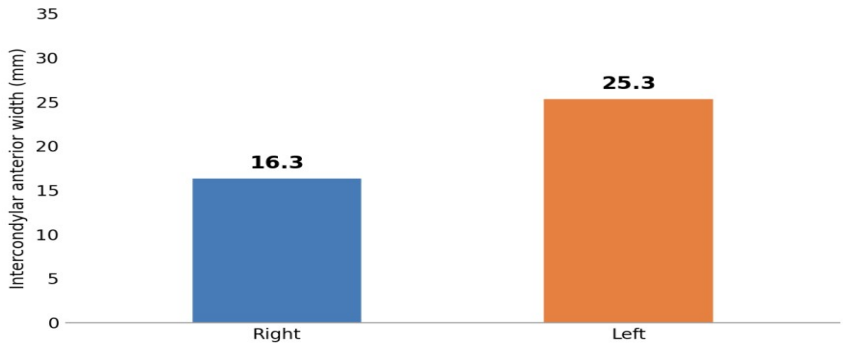


Figure 3: Mean transverse width of the intercondylar area at its anterior end on dry bone



On dry bone, five of the eight reported parameters showed significant right-left differences (Table 3). The medial condylar anteroposterior dimension was greater on the right (41.3 mm) than on the left (39.5 mm; Figure 2). The lateral condylar transverse dimension was greater on the left. The intercondylar transverse widths at the anterior end (16.3 mm on the right and 25.3 mm on the left; Figure 3), middle narrow part and posterior end were greater on the left. Medial condylar transverse dimension, lateral condylar anteroposterior dimension and overall intercondylar anteroposterior length did not differ significantly by side.

Discussion

This study analysed eight selected condylar and intercondylar parameters on 50 dry bones and 50 CT images. The medial condylar articular surface was longer than the lateral surface in the anteroposterior direction using both measurement methods. On CT, medial condylar AP means were 42.5 mm on the right and 39.6 mm on the left, compared with lateral condylar means of 36.6 mm and 36.5 mm. On dry bone, the corresponding medial means were 41.3 mm and 39.5 mm, compared with lateral means of 36.9 mm and 37.4 mm. Several measurements differed by side, although the pattern varied by method and sample.

The longer medial surface agrees with earlier work. Servien et al. measured operated knees on CT and found a medial anteroposterior dimension of 50.8 mm against 47.2 mm on the lateral side, a significant difference.[6] Our values are lower by about 8 to 11 mm. Their measurements were taken at the resection level, and most of their patients were women. Ours were taken on the articular surface of adult bones and images.

Kwak et al. measured the cut surface of the proximal tibia on 3D CT in 200 knees of Korean cadavers. The mean mediolateral and anteroposterior dimensions were 73.5 mm and 47.3 mm, smaller than those of common implants.[7] We did not measure the whole plateau, so a direct comparison is not possible.

Gandhi et al. measured 100 adult tibiae with a caliper. Anteroposterior dimensions were larger than transverse dimensions for both condyles, and medial dimensions were larger than lateral ones on both sides.[8] We found the same for the anteroposterior dimension, and each anteroposterior value was larger than the transverse value of the same condyle. The transverse dimension did not follow their pattern. On dry bone the lateral surface was wider than the medial surface on both sides (29.6 and 31.2 mm against 27.8 and 28.8 mm). On CT the two surfaces were close on the right, and the medial surface was wider on the left. They also reported sex differences in all measurements. We could not test this because sex was not available.

Moghtadaei et al. studied 150 knee CT scans of Iranian patients and found the medial and lateral condyles almost symmetrical.[9] Our data do not show this. The medial anteroposterior dimension exceeded the lateral by 2 to 6 mm. They measured on simulated cuts, and we measured the superior articular surface.

Uehara et al. examined the proximal tibia in osteoarthritic knees undergoing total knee arthroplasty.[10] Their measurements concerned a different anatomical level and patient population, limiting direct comparison. In the present study, some condylar means were similar between the dry-bone and CT samples; for example, the right medial condylar AP means were 41.3 mm and 42.5 mm, respectively. The right anterior transverse intercondylar width was 16.3 mm on dry bone and 25.3 mm on CT. Since the modalities were assessed in different samples, these differences cannot be attributed to modality alone or used to establish agreement between methods.

Indian studies have used caliper, CT and MRI. Mukhopadhaya et al. measured 100 knees with a caliper during replacement and found larger dimensions in men than in women and a mismatch with three commercial implants.[11] Ranjan et al. measured 150 osteoarthritic knees on CT. The mean mediolateral and anteroposterior dimensions of the proximal tibia were 69.1 mm and 43.8 mm.[12] Mohan et al. used MRI in 100 non-arthritic Indian knees. The Indian proximal tibia was smaller than the Caucasian and Hispanic tibia in both dimensions, and smaller than the Chinese tibia in the mediolateral dimension.[13] These studies measured the whole tibial surface. Ours measured each condylar surface and each part of the intercondylar area.

Nair et al. compared Indian and Arabian knees with a caliper and found no difference in aspect ratio between the men or between the women of the two groups.[14] Mahfouz et al. analysed 1000 normal knees from three ethnic groups and found differences between the sexes and between the groups.[15]

Four of the eight reported parameters differed significantly between right and left sides on CT, compared with five on dry bone. The medial condylar anteroposterior dimension was greater on the right using both methods. The overall intercondylar anteroposterior length did not show a statistically significant side difference in either sample. The dry-bone anterior transverse intercondylar width was markedly greater on the left.

The study has limitations. Samples were drawn from one institution using convenience sampling, and age and sex were unavailable. The dry-bone and CT observations came from different subjects and thus do not support paired

modality comparisons. Reproducibility and observer error were not evaluated.

The values can still serve as baseline data. A surgeon planning a unicompartmental replacement needs the size of each condylar surface. The medial surface was longer than the lateral surface, and a symmetric component would not match this. Larger studies should record age, sex and side, and should compare the measurements with the sizes of available implants.

Conclusion

The medial condyle of the upper tibia was longer than the lateral condyle in the anteroposterior direction on both dry bone and CT. Several condylar and intercondylar dimensions differed between the right and left sides, and the pattern was not the same on the two methods. These values come from a single institution and give baseline data for planning tibial components in a South Indian sample. Larger studies that record age and sex, and compare the values with implant sizes, are needed.

Declarations

Ethical Approval

The study protocol was approved by the Institutional Ethics Committee of Government Thoothukudi Medical College, Thoothukudi, India, before commencement of the study.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Informed Consent

Written informed consent was obtained from the participants before enrolment in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to applicable institutional and ethical requirements.

Use of Artificial Intelligence

The authors used AI-assisted tools solely for grammatical correction, language refinement, and improving the readability of the manuscript. No AI tools were used to generate research data, perform statistical analyses, interpret findings, or draw scientific conclusions. The authors take full responsibility for the accuracy and integrity of the manuscript.

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