Acta Clin Croat 2025; 64:150-156

doi: 10.20471/acc.2025.64.01.16

Professional Paper

# DISTAL FEMUR AND PROXIMAL TIBIA MORPHOMETRY AFTER TOTAL KNEE ARTHROPLASTY: 3D CT ANALYSIS IN OA *VERSUS* NORMAL KNEES

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SUMMARY – There is a paucity of data concerning morphological differences in the resected distal femur and proximal tibia between osteoarthritis (OA) and normal knees. The objective of this study was to determine if morphometric differences existed in the resected distal femur and proximal tibia surface between OA and normal knees in the Chinese population. Ninety-eight OA knees and 96 normal ones taken from the Chinese population were measured by computed tomography for femoral mediolateral (fML), medial anteroposterior (fMAP), lateral anteroposterior (fLAP), medial condylar width (fMCW), lateral condylar width (fLCW) and tibial mediolateral (tML), middle anteroposterior (tAP), medial anteroposterior (tMAP), and lateral anteroposterior (tLAP) dimensions to determine morphological differences between OA and normal knees. The mean tMAP and fMCW dimensions were 50.2±3.3 mm and 28.7±2.3 mm for OA, and 48.8±3.8 mm and 27.1±2.2 mm for normal knees, respectively. There were significant differences between OA and normal knees concerning tMAP and fMCW dimensions (p<0.05). The study revealed morphological differences in tMAP and fMCW between the OA and normal knee groups, which may provide guidelines for designing better knee implants that are more size-matching for OA knees.

Key words: *3D; Total knee arthroplasty; Osteoarthritis; Normal knee; Femur; Tibia; Morphometry; Resection*

## Introduction

Appropriate prosthesis size matching the resected bony surfaces is considered a crucial factor for success in total knee arthroplasty (TKA)[1,2]. If there is prosthesis overhang or underhang relative to the resected surface of the bone, it will increase the risk of the component. Underhang may cause early subsidence and loosening of the prosthesis, whereas overhang may cause residual pain, poorer knee flexion, and decreased functional results[3,4]. Thus, it becomes important to maximize coverage of the knee component

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Received January 24, 2020, accepted November 16, 2020

on the resected bony surface to ensure good clinical result and long-term survival of the prosthesis[5,6]. To design proper knee components, many researchers have measured resected surface of normal knees from imaging[7,8], whereas others analyzed anthropometric features of diseased knees during TKA[9,10]. It is unclear whether there are morphometric differences in the resected bony surface between diseased and normal knees.

Generally, most knees that undergo TKA are deformed and shaped differently from healthy knees. It suggests that the design of the prosthesis should be based on data from diseased knees[11]. However, most of the currently available TKA prostheses are designed based on the anthropomorphic features of normal knees[12]. Such prostheses may not necessarily provide the best fit for TKA candidates. Osteoarthritis accounted for more than 90% of the patients who underwent primary TKA. To the best of our knowledge, there are no studies that compared morphometric differences in the resected distal femur and proximal tibia surface between the OA knees and normal knees. Therefore, the aim of this study was to measure morphometric features of the resected distal femur and proximal tibia surface to determine whether there were morphometric differences between OA knees and normal knees.

## Material and Methods

This study was performed with consent provided by each subject and approved by the institutional review board. The study recorded morphology of 98 OA knees candidates for TKA and 96 normal knees without congenital anomalies or pathologic deformities around the knee joint from June 2016 to April 2017. No knee had a varus or valgus deformity of >15°. The median hip-knee-ankle angle of the subjects was 7.4° for OA knees and 1.0° for normal knees. The median age of the subjects was 64.9 years in OA group and 30.0 years in normal group. The median height was 165.6 cm in OA group and 170.2 cm in normal group.

Computer tomography (CT) imaging was performed using a helical CT scanner imaging machine (120kVp, 200mA, Somatom Sensation, Siemens Healthcare, Germany). The subjects were placed in the supine position on the scanner with knees in a fully extended position and their patella facing the ceiling. The scanning procedure was performed to acquire 1.0 mm CT slices (image size, 512×512 pixels). All CT images were burned into discs. The images of the knees were segmented using a region-growing method to construct 3D bony models by Mimics 17.0 (Materialise, Belgium). The measurements were performed using Geomagic Studio 14.0 software (Raindrop Geomagic, USA).

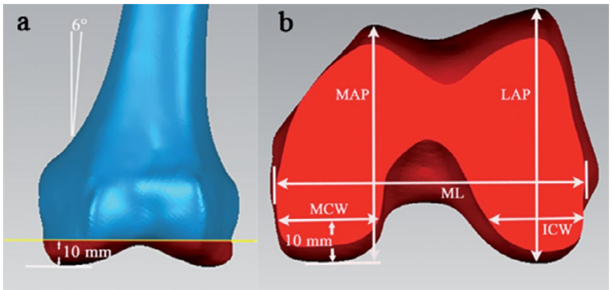


*Fig. 1. Distal femur resection and measurement on CT images: (a) resection method of distal femur; (b) measurements of resected femoral surfaces.*

Distal femur was cut 9 mm above the lowest point of medial condyle with 6° valgus to the anatomic axis (Fig. 1a). A line connecting medial sulcus of the medial epicondyle and lateral epicondylar prominence was defined as the surgical transepicondylar axis (STEA). The femoral mediolateral (fML) dimension was defined as the longest ML length of the distal cut femur surface; this line paralleled the STEA. The femoral lateral anteroposterior (fLAP) and medial anteroposterior (fMAP) dimensions were defined as the longest line drawn perpendicularly to the fML between the most posterior condylar and anterior trochlear point from the lateral and medial condyle of the femur. The medial and lateral condyle widths were measured 10 mm above the lowest point of the medial posterior condyles to simulate the optimal cutting thickness (Fig. 1b). The proximal tibial cut was performed perpendicularly to the mechanical axis of the tibia, 8 mm below the lateral tibial plateau with 5° of posterior inclination (Fig.2a).

The tibial mediolateral (tML) dimension was taken as the longest mediolateral length of the resected

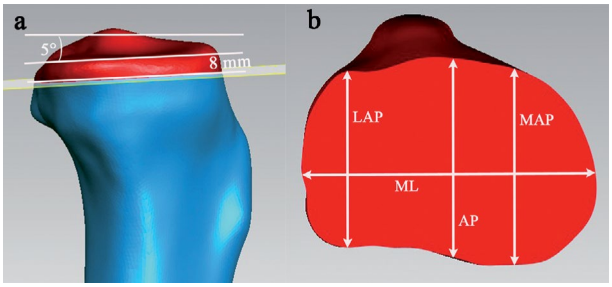


*Fig. 2. Proximal tibia resection and measurement on CT images: (a) resection method of proximal tibia; (b) measurements of resected tibial surfaces.*

tibial surface. This line is parallel to the surgical epicondylar axis of the femur and formed by connecting medial sulcus of the medial epicondyle and lateral epicondylar prominence. The tibial middle anteroposterior (tAP) dimension was taken as the length of the line drawn perpendicularly and passing through the midpoint of the tML line. The tibial lateral anteroposterior (tLAP) and medial anteroposterior (tMAP) dimensions were taken as the length of the line drawn perpendicularly to tML and passing through the posterior-most point of the lateral and medial tibial condyle (Fig. 2b).

***Statistical analysis***

The SPSS software 18.0 (SPSS, Chicago, IL, USA) was used on statistical analysis. The mean and standard deviation of measured dimensions were calculated. An independent sample t-test was used to determine the significance of morphological differences between OA knees and normal knees. The differences were considered significant at $p<0.05$.

## Results

Analysis revealed significantly larger femoral medial condylar width (fMCW) in OA knees compared to normal knees in both males (28.9±2.8 mm *vs.* 27.0±2.9 mm; $p<0.01$) and females (27.3±2.4 mm *vs.* 25.4±2.3 mm; $p<0.01$). The femoral condylar aspect ratio (fMAP/fML) also differed significantly ($p<0.05$). After height correction, fMCW and fMAP/fML remained significantly different in both sexes ($p<0.05$). These distal femoral morphological differences are summarized in Table 1.

Similarly, tibial medial plateau width (tMAP) and plateau aspect ratio (tMAP/tML) showed significant differences between OA and normal knees in both males and females ($p<0.05$). Height correction maintained significant differences in tMAP and tMAP/tML in both sexes ($p<0.05$), as detailed in Table 2.

*Table 1. Distal femur dimensions in osteoarthritis (OA) and normal knees (mm)*

| Parameter | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | OA | Normal | p | Corrected p | OA | Normal | p | Corrected p |
| fML | 76.8±3.5 | 76.3±3.2 | 0.493 | 0.121 | 71.4±4.3 | 70.7±3.2 | 0.401 | 0.136 |
| fMAP | 64.0±3.7 | 64.7±2.7 | 0.267 | 0.262 | 59.8±3.2 | 60.5±3.6 | 0.320 | 0.188 |
| fLAP | 66.7±3.8 | 67.3±3.3 | 0.431 | 0.193 | 61.4±3.1 | 61.7±4.8 | 0.790 | 0.239 |
| fMCW | 28.9±2.8 | 27.3±2.4 | 0.018 | <0.01 | 27.0±2.9 | 25.4±2.3 | <0.01 | <0.01 |
| fLCW | 26.8±2.9 | 26.4±2.7 | 0.299 | 0.062 | 24.6±2.1 | 24.2±2.0 | 0.358 | 0.103 |
| fMCR | 23.7±2.1 | 24.2±2.3 | 0.392 | 0.061 | 21.6±2.0 | 22.2±2.2 | 0.296 | 0.290 |
| fLCR | 22.1±2.1 | 22.3±1.8 | 0.610 | 0.293 | 20.5±2.2 | 20.9±2.2 | 0.356 | 0.537 |
| fMAP/fML | 0.83±0.03 | 0.85±0.03 | 0.028 | 0.028 | 0.84±0.04 | 0.86±0.03 | 0.027 | 0.028 |

Dimensions: fML = femoral mediolateral; fMAP = femoral medial anteroposterior; fLAP = femoral lateral anteroposterior; fMCW = femoral medial condylar width; fLCW = femoral lateral condylar width; fMCR = femoral medial posterior condyle curvature radii; fLCR = femoral lateral posterior condyle curvature radii

*Table 2. Proximal tibia dimensions in osteoarthritis (OA) and normal knees (mm)*

| Parameter | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | OA | Normal | p | Corrected p | OA | Normal | p | Corrected p |
| tML | 78.6±3.5 | 78.8±3.2 | 0.836 | 0.148 | 72.2±3.2 | 71.9±3.1 | 0.651 | 0.135 |
| tMAP | 55.0±3.1 | 53.7±2.1 | 0.017 | <0.01 | 50.6±2.7 | 48.9±2.3 | 0.002 | <0.01 |
| tAP | 52.7±3.2 | 52.3±3.0 | 0.371 | 0.054 | 47.7±2.7 | 47.4±2.2 | 0.570 | 0.116 |
| tLAP | 50.7±3.6 | 50.1±3.3 | 0.382 | 0.067 | 45.6±3.0 | 45.3±2.6 | 0.529 | 0.087 |
| tMAP/tML | 0.70±0.03 | 0.68±0.02 | <0.01 | <0.01 | 0.70±0.02 | 0.68±0.03 | 0.027 | 0.027 |

Dimensions: tML = tibial mediolateral; tMAP = tibial medial anteroposterior; tAP = tibial middle anteroposterior; tLAP = tibial lateral anteroposterior

## Discussion

Optimal coverage of the component to the resected bony surface is essential for long-term good outcomes after TKA. If the implant mismatches the resected bone surface, it will be undersized or overhang, which could result in worse clinical outcomes[13]. Thus, it is critical to design a size-matching component for TKA candidates according to knee morphology. Various morphological studies of the resected bony surfaces from normal[7,14] or OA knees[9,15] have been conducted to provide data for proper size-matching. Incavo *et al.*[11] have suggested that the design of the knee component should be based on data from the diseased knee rather than the normal knees. To date, no studies have looked into the morphology differences of resected femoral and tibial surfaces between the diseased and normal knee to determine which morphological data are more suitable for designing proper components.

In this study, we measured the morphology of the resected distal femur and proximal tibia surfaces in OA knees and normal knees. The major findings were that the tMAP and fMCW dimensions in OA subjects were significantly larger than those of normal knee. In a study by Puthumanapully *et al.*, the authors found that varus knees had a larger femur dimension of medial condyle compared with normal knees[16]. The morphological differences of medial condyle between OA and normal knees may be explained by the pathological change of OA knees. Most OA knees of TKA candidates were varus deformity, and the medial condyle experienced destroying and remodeling as a response to larger loads during gait[17], which could eventually result in bony structural change in the medial condyle of OA knees. Many studies have reported on the measurements of resected proximal tibia surface in Asian knees. Cheng *et al.*[7] report the mean tML, tAP , tMAP, and tLAP values of 73.0 mm, 48.8 mm, 50.7 mm, and 45.3 mm in 172 Chinese normal tibias on CT imaging, which was similar to our data in normal tibias. Kwak *et al.*[18] studied 200 normal cadaver tibias and determined that tML, tAP , tMAP, and tLAP values were 71.9 mm, 48.8 mm, 45.9 mm and 42.2 mm, respectively, on CT imaging. Uehara *et al.*[19] studied 100 TKA tibias from the Japanese population on CT scan and determined that the tML and tAP dimensions were 74.3 mm and 48.3 mm. The results in our Chinese subjects were a little larger than these in other Asians, which might be due to difference between the heights of study groups. Charlton *et al.*[20] report a significant difference in the femoral bicondylar width between short and tall subjects, with taller subjects having larger values. The mean height (166.9 cm) in our study was a little higher than in the Japanese (151.9 cm) and Korean subjects (161.2 cm). Several researchers have studied the dimensions of distal femur in Asian populations. Wemedke *et al.* and Cheng *et al.*[6,7] report the mean fML and fLAP values on CT to be 71.0 mm and 64.1 mm, respectively, in Chinese normal femurs. Lim *et al.*[14] showed that femoral fML, fMAP and fLAP dimensions were 78.6 mm, 59.6 mm and 58.7 mm in a Korean population using magnetic resonance imaging. Urabe *et al.*[21] studied knees using CT imaging in a Japanese population and report on the values of the fML, fMCW and fLCW dimensions of 70.6 mm, 30.1 mm, and 24.8 mm in OA subjects. Our results showed minor differences from these Asian populations. These differences may be due to different imaging technique and difference in the height of the study groups. In addition, depth of the resection affects the sizing of the resected bony surface. The depth of the distal femoral resection in our study at a thickness of 9 mm below the medial condyle was lower than the 10 mm[14,21] depth used in other studies. To date, many studies have confirmed the knee anatomic differences of the Caucasian and Asian populations[22,23]. However, nearly all existing TKA components were designed based on the anatomy of Caucasian populations and not suitable for Asian patients[7,24]. In clinical setting, Iorio *et al*. followed-up (9 *vs*. 6.6 years) American and Japanese patients after primary TKA, and showed that American patients required significantly larger size implants than Japanese patients. The authors also found that Japanese patients had a significantly less postoperative range of motion (93.7 *vs*. 106.6°) and higher revision rate (4.1% *vs*. 2.6%) than American patients[25]. Anatomy studies and clinical outcomes all demonstrated that ethnic differences should be considered on designing proper TKA components for the Asian population. We acknowledge that this study included a limited number of subjects and may not reflect the real features of knees in OA and normal knees. If a larger sample size was studied, other significant differences may be noticed. We are also aware that only one bone resection level was measured. However, resection depth varies according to the stage of disease during TKA. In the future, we will report data on a larger sample size and measure depth at different resection levels.

## Conclusion

Analysis of resected specimens revealed distinct morphological characteristics in OA knees *versus* normal knees. Key differences included significantly altered dimensions of the femoral medial condylar width (fMCW), tibial medial plateau width (tMAP) and MAP/ML aspect ratios at both distal femur and proximal tibia. These findings underscore the necessity of accounting for OA-specific anatomic variations when engineering TKA implant components.

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Sažetak

## CT VOĐENE 3D MORFOMETRIJSKE RAZLIKE U DISTALNOM FEMURU I PROKSIMALNOJ TIBIJI IZMEĐU KOLJENA S OSTEOARTRITISOM I NORMALNIH KOLJENA

*S. A. Jami* i *M. K. Sallam Ma'aitah*

Malo je podataka o morfološkim razlikama reseciranog distalnog femura i proksimalne tibije u koljenu s osteoartritisom (OA) i normalnih koljena. Cilj ovog istraživanja bio je utvrditi postoje li morfometrijske razlike u površini reseciranog distalnog femura i proksimalne tibije između koljena s OA i normalnih koljena u kineskoj populaciji. Kod 98 koljena s OA i 96 normalnih koljena dobivenih iz kineske populacije provedeno je mjerenje kompjutoriziranom tomografijom za sljedeće dimenzije: femoralna mediolateralna (fML), medijalna anteroposteriorna (fMAP), lateralna anteroposteriorna (fLAP), medijalna kondilarna širina (fMCW), lateralna kondilarna širina (fLCW) te tibijalna mediolateralna (tML), središnja anteroposteriorna (tAP), medijalna anteroposteriorna (tMAP) i lateralna anteroposteriorna (tLAP) dimenzija kako bi se utvrdile morfološke razlike između koljena s OA i normalnog koljena. Srednje dimenzije tMAP i fMCV iznosile su 50,2±3,3 mm i 28,7±2,3 mm za koljena s OA te 48,8±3,8 mm i 27,1±2,2 mm za normalna koljena. Utvrđene su značajne razlike u dimenzjama tMAP i fMCW između koljena s OA i normalnih koljena ($p<0,05$). U ovom istraživanju utvrđene su morfološke razlike u tMAP i fMCW između skupina koljena s OA i normalnih koljena, što može poslužiti u izradi smjernica za izradu boljih koljenskih implantata koji će bolje odgovarati koljenima s OA.


Ključne riječi: *3D; Totalna artroplastika koljena; Osteoartritis; Normalno koljeno; Femur; Tibija; Morfometrija; Resekcija*