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ORIGINAL ARTICLE

Gerdy's tubercle as a novel anatomical landmark for the proximal tibial cut in total knee arthroplasty

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ABSTRACT

Objectives: This study aimed to explore the use of Gerdy's tubercle (GT) as an innovative and dependable anatomical landmark for the proximal tibial cut in total knee arthroplasty (TKA) in cases with extensive knee degeneration.

Materials and methods: One hundred dry tibia bones and 10 formalin-fixed cadaveric knee specimens of both sexes were examined. A Zimmer NexGen tibial cutting guide and a Mitutoyo digital caliper were utilized to align the guide with the tibia's mechanical axis. The procedure was replicated on cadaver knees using a standardized medial parapatellar arthrotomy approach. Measurements included the distance from GT superior border to the resection line and the length of the tibia. A radiological study involving magnetic resonance imaging examinations of 48 patients, which were evaluated focusing on the upper border of GT and the least degenerated segment of the posterolateral part of the lateral tibial condyle, was conducted.

Results: Anatomical measurements of GT and proximal tibial areas in 110 specimens showed slight but consistent variations with cadaver measurements. Magnetic resonance imaging analysis of 48 patients revealed notable sex differences in the distance between the superior border of GT and the tibia's posterolateral surface. There was also a significant negative correlation between the distance from GT to the posterolateral corner and cartilage thickness.

Conclusion: Proper alignment in TKA is crucial for success, but identifying an extra-articular landmark for horizontal tibial resection remains challenging, particularly in severely arthritic knees. This study introduces GT as a novel anatomical landmark for TKA, offering a more reliable reference for achieving desired joint levels in knees with significant degenerative changes.

Keywords: Arthroplasty, extraarticular, Gerdy's tubercle, joint line, knee, tibia.

Several studies conducted in the last few years indicate that dissatisfaction after TKA is a significant issue, with various factors influencing patient satisfaction.[1,2] The accuracy of prosthetic component implantation is crucial to the success of arthroplasty. It is known that improper prosthesis placement and positioning would affect clinical outcomes by causing aseptic prosthesis failure, instability, and premature wear of polyethylene.[3] Studies have shown that proper alignment of these components is essential for better postoperative outcomes and the long-term survival of TKAs.[4] Numerous instruments have been developed for the correct implantation and execution of surgery. Computer-assisted surgery has enabled more accurate component placement, yet studies have stated a notable outlier rate for tibial component alignment, and it cannot be commonly used worldwide.[5]

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Surgeons are trained to align the components based on the previously described anatomic landmarks, following the methods outlined during their residency and throughout their careers. Most surgeons prefer to use the method of aligning the tibial component horizontally to the tibial plafond and 90° to the mechanical axis of the lower extremity with an extramedullary guide system. This method is widely used. During the alignment of the system, various landmarks are used, including the medial one-third of the tibial tuberosity, anterior tibial crest, talar dome, and base of the second metatarsal bone. The level of horizontal resection is judged using a stylus either 10 mm from the least affected deepest point on the lateral tibial articular surface or 2 mm from the most affected medial articular surface of the knee joint. In knee joints with severe degeneration, horizontal resection using a stylus for intra-articular reference may result in imperfect reconstruction of the joint line and lead to unexpected complications.[6,8] Cutting with a standard stylus can lead to excessive and incorrect resection due to degeneration of the articular surface in inflammatory diseases such as rheumatoid arthritis.[7] This can result in patient dissatisfaction, which could potentially lead to unresolved issues for surgeons. Hence, surgeons interested in knee arthroplasty are in search of cost-effective and simple methods to address this issue.

Gerdy's tubercle (GT) could present a novel and reliable method in the aforementioned scenario and alike. Gerdy's tubercle is defined as a facet-like bony eminence located lateral to the tibial tubercle and provides an attachment site for the iliotibial tract. The tractional force applied upon the iliotibial tract by the gluteus maximus shapes the GT.[9,10] Due to the traction of the active muscles, the shape and size of the GT are different for each bone.[11] The GT is already being used as a landmark for identifying the peroneal nerve position and in the anterolateral approach to the proximal tibia.[12,13]

This study hypothesized that GT can serve as a novel and reliable anatomical landmark for the proximal tibial cut in total knee arthroplasty (TKA), particularly in cases with over-degenerated knees, such as in rheumatoid arthritis. This hypothesis is grounded in the premise that the traditional use of an external guide for determining the tibial cut may not be the most effective or accurate method in the context of significant degenerative changes. We propose that GT, due to its consistent anatomical presence and relative preservation even in severely degenerated knees, can offer a more dependable reference point. This could potentially lead to improved surgical outcomes in TKA, with a specific emphasis on the precision of bone cuts and the overall alignment of the prosthetic components. This study sought to empirically test this hypothesis through a detailed anatomical and radiological analysis.

MATERIALS AND METHODS

Cadaver study

The study was conducted at the Department of Anatomy, Ankara University Faculty of Medicine. A total of 100 dry tibia bones and 10 formalin-fixed cadaveric knee specimens of both sexes were

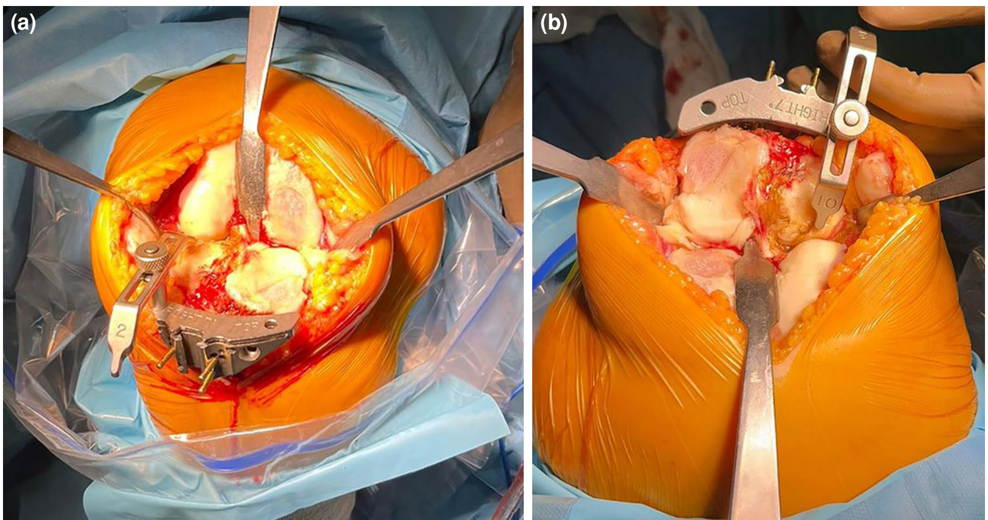

FIGURE 1. (a) Coronal and **(b)** axial view during total knee arthroplasty tibia resection. Zimmer Nexgen tibia resection guide, 10-mm stylus on the posterolateral surface of the lateral condyle.

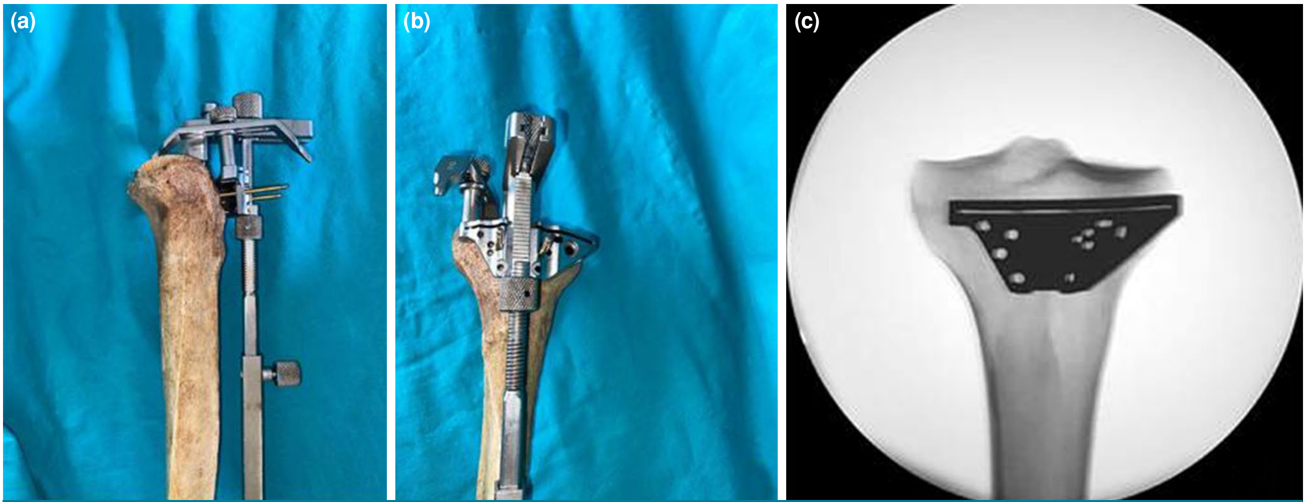

FIGURE 2. Dry bone examination. **(a)** Sagittal view of the dry bone, external guide, tibia proximal cutting guide with 7° slope and stylus on the lateral tibial condyle. **(b)** Coronal view. **(c)** Fluoroscopy view of the dry bone and tibia cutting guide.
GT: Gerdy's tubercle.

examined. The exclusion criteria included any deformity or damage to GT. The dry bones were fixed appropriately for the procedure.

A Zimmer NexGen (Zimmer, Warsaw, IN, USA) tibial cutting guide and a Mitutoyo digital caliper were utilized for the procedure. The guide was aligned with the mechanical axis of the tibia, positioning its proximal part at the medial third of the tibial tuberosity and the midpoint of the tibial plafond in the coronal plane (Figure 1). A 7° posterior tibial slope cutting guide was employed. The gauge point was estimated on the lateral tibial plateau's least affected deepest side using a 10-mm resection stylus. The horizontal tibial resection line was then marked. The tip of GT and the superior border were identified and marked (Figure 2).

The procedure was similarly applied to six right and four left cadaver knees, following dissection via a standardized medial parapatellar arthrotomy approach. The extramedullary guide's position used the medial third of the tibial tubercle for proximal positioning and a point 5 mm medial to the middle of the palpable medial and lateral malleoli and the base of the second metatarsal for distal orientation. The iliotibial band was carefully dissected to expose the intact GT. The perpendicular distance from the superior border of GT to the resection line was measured and adjusted from the 10-mm resection evaluation on the cutting guide (Figure 3). The length of the tibia and the distance between the tibial tuberosity and the tibia plateau's lowest point were measured on all specimens.

Radiological study

Patients who underwent knee magnetic resonance imaging (MRI) at Gazi University Hospital Radiology Department between 12/02/2023 and 29/05/2023 were included. The study comprised 48 patients (20 females, 28 males; median: 32 years; range, 18 to 53 years). The inclusion criteria were patients with no history of knee surgery, periarticular fractures, sepsis, or advanced tibial cartilage degeneration. Magnetic resonance imaging examinations were conducted using a 1.5 Tesla Magneton Aera system (Siemens Healthcare, Erlangen, Germany) with a 16-channel knee coil. The routine knee MRI protocol and additional three-dimensional T1-weighted SPACE (sampling perfection with application-optimized contrasts using different flip angle evolution) sequences were employed.

Magnetic resonance imaging was jointly evaluated by an experienced musculoskeletal radiologist (25 years of experience) and a radiology resident (four years of experience). Five patients were excluded due to various reasons, including tibial lateral plateau fractures and previous operations. The upper border of GT was determined by evaluating three-dimensional T1-weighted sagittal sequences and reformatted axial and coronal sections.

The least degenerated segment of the posterolateral part of the lateral tibial condyle was identified in the sagittal plane. Parallel lines were drawn from this point and the GT's superior border,

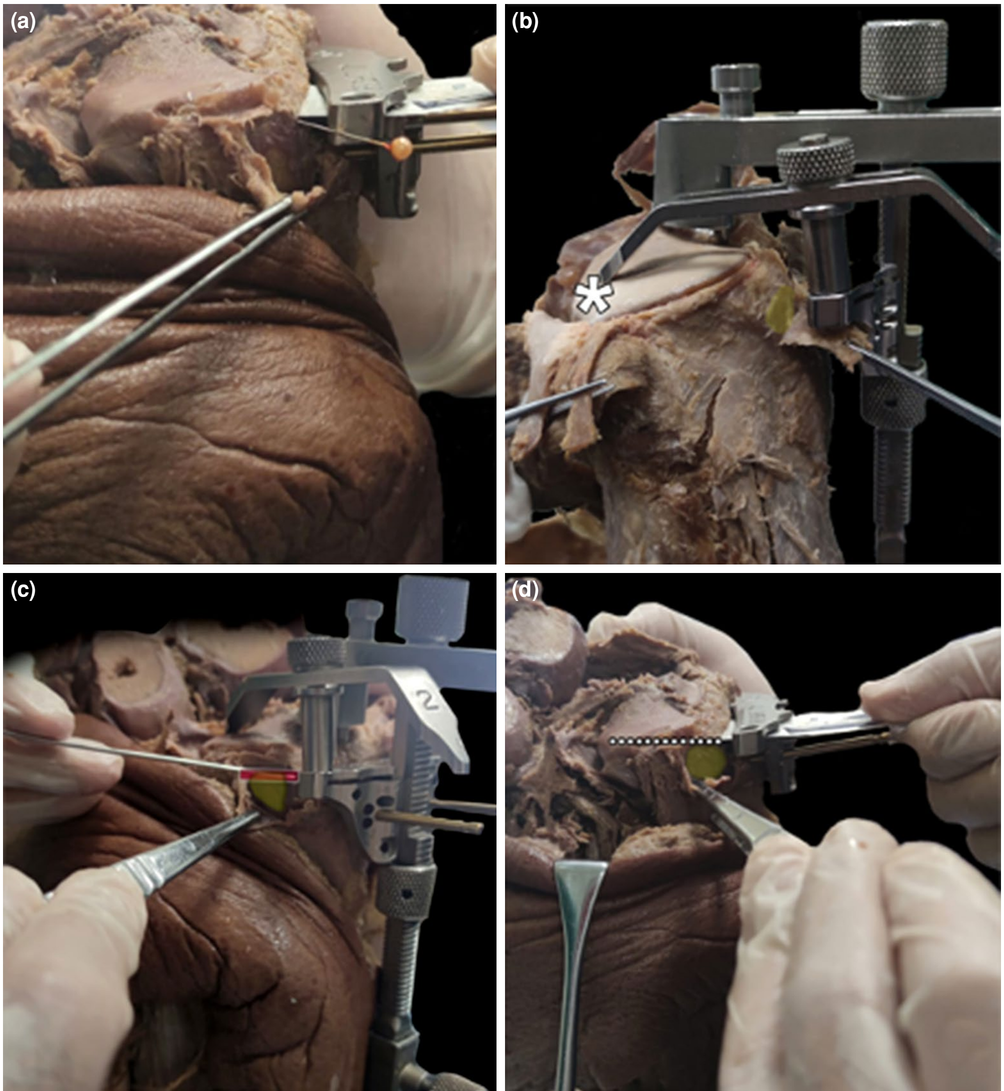

FIGURE 3. Cadaveric examination. **(a)** Gerdy's tubercle, tibia lateral condyle surface and digital caliper. **(b)** External tibial guide, tibia resection guide with 7° slope, 10-mm stylus, posterolateral surface of tibia lateral condyle. **(c)** Gerdy's tubercle superior border (with red line), iliotibial tract. **(d)** Projection of tibial proximal cutting line.

avoiding a 7° slope due to the absence of specific guidance. The vertical distance between these lines and the thickness of the lateral tibial cartilage were measured (Figure 4).

Statistical analysis

Statistical analyses were conducted using IBM SPSS Version 28.0 software (IBM Corp., Armonk, NY, USA). The analysis began with the application of descriptive statistics to summarize and present the basic features of the data in our study, including measures such as means, standard deviations, and ranges. To compare the means of two independent groups based on sex for MRI parameters, an independent-sample t-test was utilized, allowing for the determination of statistically significant differences between these means. Due to the nonnormal distribution of measurements on dry bones and cadaveric specimens, Spearman's rho was employed. This nonparametric method measured the strength and direction of association between two ranked variables. For MRI measurements, where the data distribution was appropriate, the Pearson correlation coefficient was utilized. This statistical measure assessed the linear relationship between variables, providing insights into the degree of

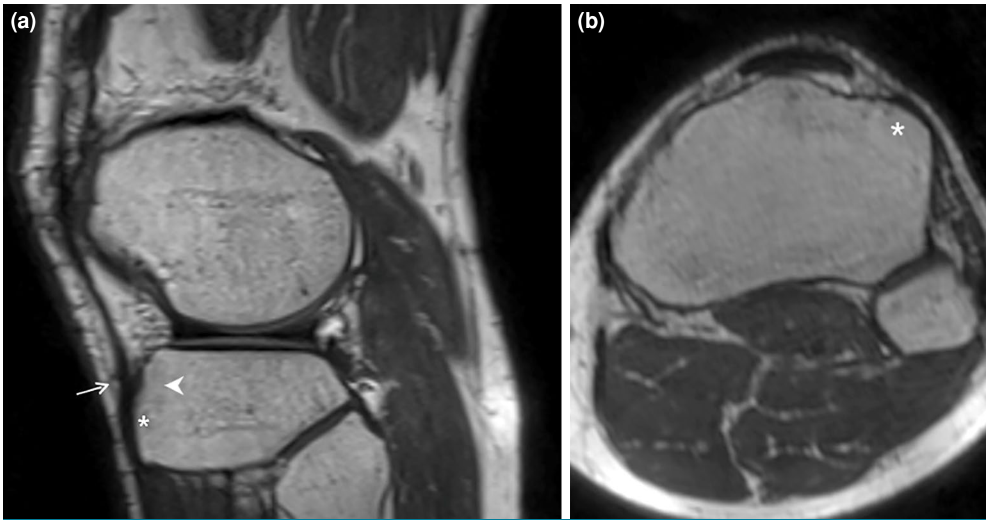

FIGURE 4. MRI examination. **(a)** Three-dimensional T1-weighted sagittal image of 0.6-mm slice thickness showing the iliotibial tract (white arrow) attached to GT (asterisk) and the upper border of GT (arrowhead). **(b)** Three-dimensional T1-weighted axial image showing GT (asterisk).
MRI: Magnetic resonance imaging; GT: Gerdy's tubercle.

correlation. Scatter plots were created to visualize and ascertain the linear correlation between different variables in the study. A *p*-value <0.05 was considered statistically significant.

RESULTS

In the category of the distance from GT's highest point to the shallowest point of the tibial plateau (superior border of GT to posterolateral tibial surface), dry bone specimens exhibited a mean measurement of 8.800±0.600 mm on the right and 8.795±0.654 mm on the left. This contrasted with cadaver specimens, where the mean measurements were slightly higher, at 9.745±0.423 mm on the right and 9.993±0.496 mm on the left (Table I).

Regarding the distance to the shallowest point of the tibia plateau from the tibial tuberosity, dry bone specimens had mean values of 33.255±4.541 mm on the right and 34.589±3.994 mm on the left. In cadaver specimens, these measurements increased slightly to 34.765±3.961 mm) on the right and 36.825±3.902 mm on the left.

For the measurement of the tibia length, defined as the distance from the tip of the medial malleolus to the highest point of the lateral plateau, dry bone specimens showed a mean length of 343.820±23.953 mm on the right and 351.227±24.297 mm on the left. In cadaver specimens, the mean tibia length was greater, with values of 355.645±43.399 mm on the right and 358.065±20.660 mm on the left.

The measurements in cadaver specimens were generally slightly higher than those in dry bones (Table I). These variations could be attributed to the

TABLE I
Descriptive statistics based on the side for dry bones and cadavers

	Dry bone (n=100)		Cadaver (n=10)	
	Right (n=50)	Left (n=50)	Right (n=6)	Left (n=4)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD
GTSB-PLTS	8.800±0.600	8.795±0.654	9.745±0.423	9.993±0.496
Length of the tibia	15.128±2.207	15.973±2.805	15.505±0.872	16.350±1.746
TT-LPTP	33.255±4.541	34.589±3.994	34.765±3.961	36.825±3.902

SD: Standard deviation; GTSB-PLTS: Gerdy's tubercle-posterolateral tibial surface; TT-LPTP: Tuberositas tibia-lowest point of tibia plateau

TABLE II
Descriptive statistics for the MRI study (n=48)

MRI	Min	Max	Min	Max
Distance of Gerdy superior border and tibia posterolateral surface	7.400	9.100	8.321	0.388
Cartilage thickness	1.600	2.800	2.198	0.241
Total distance	9.800	11.200	10.477	0.376

MRI: Magnetic resonance imaging.

different conditions and preservation states of dry and cadaveric bones and due to the presence of the cartilage. Additionally, the consistent differences between the right and left sides in both types of specimens underscore the inherent anatomical asymmetries.

The Shapiro-Wilk test, used for assessing the normality of the data, indicated nonnormal distribution for the distance from the highest point of GT to the lowest point of the tibial plateau (p=0.003). However, other measurements, including the distance from the tuberositas tibia to the lowest point of the tibial plateau, the length of the tibia from the medial malleolus to the highest point of the lateral plateau, the width, and the length of the specimens, demonstrated a normal distribution (p>0.05).

Spearman's rho correlation analysis revealed several significant relationships among the variables. A moderate positive correlation was found between the tibia length (from the tip of the medial malleolus to the highest point of the lateral plateau) and both the width (r=0.468, p<0.001) and the length of the specimens (r=0.510, p<0.001). Additionally, a significant positive correlation was observed between the distance to the lowest point of the tibia plateau from the tibial tubercle and the tibia length (r=0.352, p<0.001). The width and length of the specimens also showed a strong positive correlation (r=0.609, p<0.001). Other correlations, including those involving the distance of GT's highest point to the lowest point of the tibial plateau, were not statistically significant.

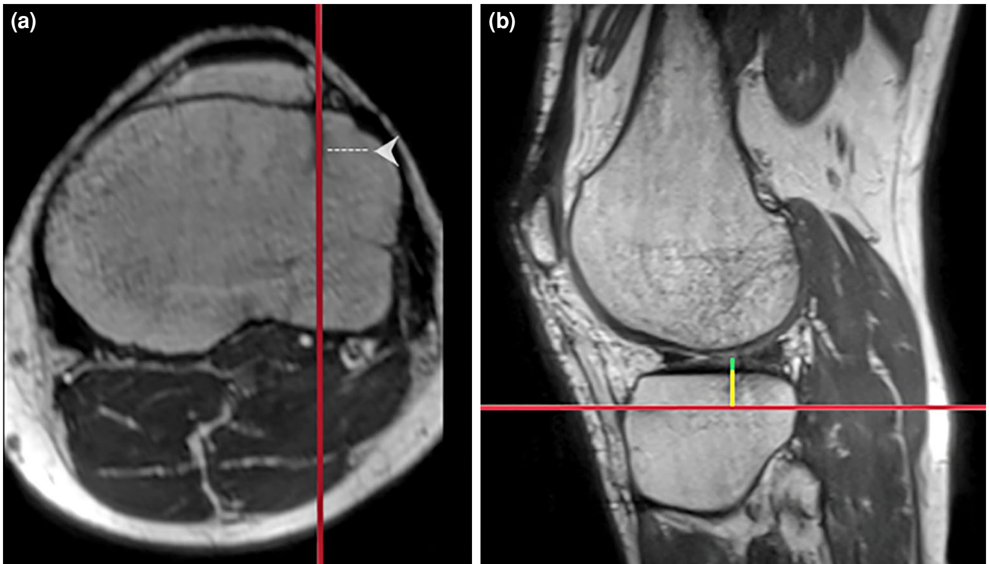

FIGURE 5 MRI examination. **(a)** A line (red line) parallel to the tibial plateau's least degenerated part; the line was drawn from the medial projection of the GT's upper border (arrowhead). **(b)** The craniocaudal (vertical) distance between red line and the cortex of the proximal lateral tibial condyle was measured (yellow line). At this level, the thickness of the lateral tibial cartilage (green line) was also measured.

MRI: Magnetic resonance imaging; GT: Gerdy's tubercle.

TABLE III
Comparative analysis of tibial measurements using MRI by sex (n=48)

	n	Mean±SD	*p*	Mean difference	95% CI of difference
Distance of Gerdy superior border and tibia posterolateral surface					
Male	28	8.421±0.393	0.016*	0.241	0.022.461
Female	20	8.18±0.343			0.026.456
Cartilage thickness					
Male	28	2.186±0.194	0.341	0.029	– 0.173.114
Female	20	2.215±0.299			– 0.185 .127
Total distance					
Male	28	10.564±0.371	0.028*	0.209	– 0.006 .424
Female	20	10.355±0.356			– 0.005. 424

SD: Standard deviation; * p<05.

The MRI analysis of 48 participants revealed the following measurements. The distance between GT's superior border and the tibia's posterolateral surface ranged from 7.400 to 9.100 mm, with a mean of 8.321±0.388 mm. The thickness of the cartilage varied between 1.600 and 2.800 mm, with a mean value of 2.198±0.241 mm. The total distance, presumably combining the above measurements, ranged from 9.800 to 11.200 mm, with a mean of 10.477±0.376 mm. These results indicate a relatively narrow range of variation in these measurements among the study participants, suggesting consistency in the anatomical features being examined (Table II, Figure 5). The data for the distance from GT to the posterolateral corner, cartilage thickness, and total distance demonstrated a normal distribution in the study sample (p>0.05).

The independent-sample t-test conducted to assess MRI data from 48 participants revealed significant sex differences in certain measurements. Specifically, the distance between GT's superior border and the tibia's posterolateral surface differed significantly between sexes (p=0.016). Males (n=28) had a higher mean value of 8.421±0.393 mm compared to females (n=20) with a mean of 8.180±0.343 mm, indicating a mean difference of 0.241 mm with a 95% confidence interval ranging from 0.022 to 0.461 (Table III).

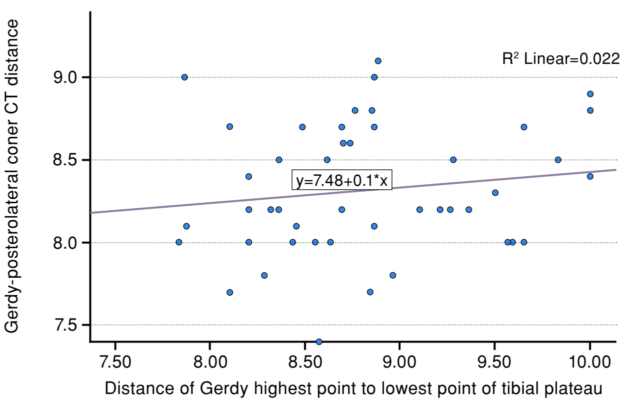

FIGURE 6. A scatter plot diagram showing the relationship between the distance between GT and the posterolateral corner (MRI) and the distance between the highest point of GT to the lowest point of the tibial plateau (dry bones).
GT: Gerdy's tubercle; MRI: Magnetic resonance imaging; CT: Computed tomography.

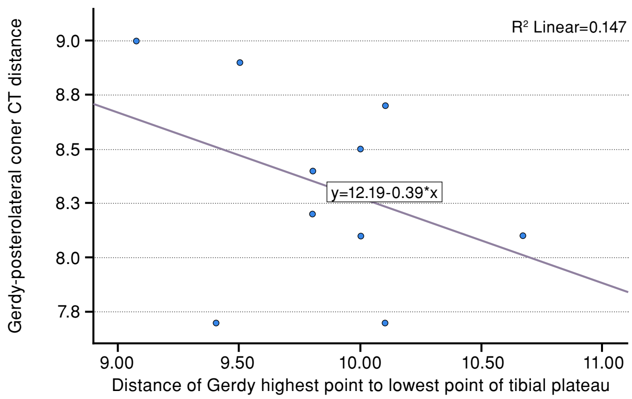

FIGURE 7. A scatter plot diagram showing the relationship between the measurements between the GT and the posterolateral corner (MRI) and the distance between the highest point of GT to the lowest point of the tibial plateau (cadaver).
GT: Gerdy's tubercle; MRI: Magnetic resonance imaging; CT: Computed tomography.

Scatter plot clearly shows that there is no linear relationship between the Gerdy-Posterolateral Coner KK Distance (MR) Distance of Gerdy Highest Point to Lowest Point of Tibial Plateau in dry bones. Based on correlation coefficient there is no statistically significant correlation (r=0.180 and p=0.222) at 005 level. Furthermore, when determination coefficient R^2 (R-square) is examined, it can be interpreted that there is no successful variance explaining rate between the measurements (Figure 6). Similarly, it can also be said that there is no linear relationship between Gerdy-Posterolateral Coner KK Distance (MR) and Distance of Gerdy Highest Point to Lowest Point of Tibial Plateau for cadever specimen measurements (Figure 7).

Regarding the cartilage thickness, although males had a slightly lower mean value (2.186±0.194 mm) than females (2.215±0.299 mm), this difference was not statistically significant (p=0.341), with a mean difference of 0.029 mm and a 95% confidence interval between –0.173 and 0.114.

The total distance measured also showed a significant sex difference (p=0.028). Males exhibited a higher mean total distance of 10.564±0.371 mm compared to females, who had a mean of 10.355±0.356 mm. The mean difference was 0.209 mm, with a 95% confidence interval ranging from –0.006 to 0.424.

Based on the provided Pearson correlation results, there was a significant negative correlation between the distance from GT to the posterolateral corner and cartilage thickness (r=–0.302, p=0.037).

DISCUSSION

The results of our study, focusing on the anatomical characteristics of GT and their implications for TKA, align with and extend the findings of recent research in this field. A study that analyzed the morphometry of the proximal tibia, including measurements of GT, highlighted the importance of these anatomical features for surgeons during TKA, particularly in designing tibial components of knee prostheses for specific populations.[14]

In cases in which intra-articular landmarks on the tibial plateau are not obvious, resection with the aid of stylus may be inappropriate. For example, in rheumatoid arthritis and severely deformed osteoarthritic knees, the classical tibial bone resection technique with an extramedullary system with the use of stylus may resect an inadequate amount of bone. Therefore, a landmark is needed for designating the horizontal tibial osteotomy level.[7] This is in line with our findings that suggest the need for detailed anatomical understanding, particularly in cases with significant anatomical variations.

Our research on the effectiveness of using GT as a landmark in TKA is supported by a study that investigated the clinical efficacy of a lateral parapatellar approach with iliotibial band dissection from the GT for TKA in valgus knees.[15] This approach showed significant improvements in pain and function without deviation of the lower limb mechanical axis or prosthesis position, underscoring the practical utility of focusing on GT in TKA procedures.

Another study by Mahmood et al.[16] introduced a new landmark for measuring tibial component rotation after TKA. This research underscores the importance of identifying reliable anatomical landmarks for component placement, a key aspect that aligns with our study's focus on the detailed measurements of GT. The identification of such landmarks is crucial for the precise alignment of TKA components, which our study also emphasizes.

The significant sex differences found in certain measurements, particularly the distance between GT’s superior border and the tibia's posterolateral surface, suggest that male and female knees may require different surgical approaches or implant sizes in TKA. For example, research on the posterior cortical axis as an alternative reference for femoral component placement in TKA revealed sex-based differences in rotational alignment.[17] This finding underscores the need for sex-specific preoperative planning to achieve optimal outcomes.

Nishikawa et al.'s[18] research focused on the accuracy of proximal tibial bone cuts in TKA using the anterior border of the tibia as a bony landmark. Their findings indicated significant improvements in the coronal alignment of the tibial component when using this specific landmark, suggesting the anterior tibial border is a reliable guide in clinical practice. Our focus on GT similarly aims to improve the accuracy of proximal tibial cuts, particularly in complex cases such as over-degenerated knees, by providing a potentially reliable and consistent anatomical reference point.[19]

Another study on case-related factors affecting cutting errors of the proximal tibia in TKA revealed that preoperative varus alignment and male sex were significantly associated with varus tibial cutting errors.[20] Our study, which focuses on the utilization of GT as a novel anatomical landmark, aligns with these findings by suggesting an alternative approach that could potentially mitigate such cutting errors, particularly in anatomically complex or varied cases.

All of the dry bones examined for this study had intact greater trochanters, even if they had degenerative or missing bony parts. Furthermore, in cadavers, the iliotibial band was firmly attached to the greater trochanter and could not be easily separated from the bone. Additionally, in cadavers, the iliotibial band was separated from the greater trochanter, revealing the exact shape of the trochanter and its superior border. This confirmed the physical examination, which identified the depression over the tip of the tubercle as the superior border. Thus, the superior border of the greater trochanter was accurately determined in our specimens.

During surgery, intact cartilage on the posterolateral side of the lateral plateau is commonly referenced. However, it is important to note that the measurements were performed on dry bones that do not have cartilage on the surface. To address this weakness, the present study utilized cadaveric dissections and radiological evaluations to support the measurements.

The inclusion of soft tissue allowed for an additional distance of over 1 mm for tibia cuts. In cadavers, the mean distance between the superior border of the GT and the lowest point of the lateral tibial plateau was 9.84 mm, while it was 8.48 mm in dry bones. Furthermore, radiological evaluations showed distances greater than 8 mm. The study demonstrates that TKA operations utilizing the lateral tibial condyle and classical 8- to 10-mm cuts can safely use GT as an inferior osteotomy level, particularly in degenerated knees. Furthermore, there were no observed differences between the left and right specimens. The distance of the GT from other structures is not related to the length of the tibia, indicating that the GT is a reliable landmark regardless of side and length differences.

The limitations of the present study were the low numbers of cadaveric specimens and radiological data. Even with our high numbers of dry bones, further studies including radiological and cadaveric data should be conducted.

In conclusion, proper alignment in the coronal, sagittal, and horizontal planes is necessary for successful TKA. However, finding an extra-articular anatomic landmark for horizontal tibial resection proves challenging. While articular landmarks from either side of the tibial plateau have been identified, restoring joint line levels in severely arthritic knees remains difficult. This study contributes to the ongoing discourse in orthopedic surgery regarding the importance of precise anatomical landmarks in TKA. The exploration of GT as a landmark offers a potentially more reliable reference point, which could enhance surgical accuracy, particularly in cases with significant degenerative changes. This approach may lead to better alignment of the prosthetic components, potentially improving surgical outcomes in TKA. The findings encourage further research and clinical trials to validate these results and explore their implications in diverse patient populations and complex clinical scenarios.

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Ethics Committee Approval: The study protocol was approved by the Gazi University Clinical Research Ethics Committee (date: 22.05.2023, no: 437). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Conceived and designed the study, provided research supervision, and critically reviewed the manuscript for important intellectual content: H.Ö.; Participated in the study design, was involved in data collection and processing, conducted the literature review, wrote the initial draft of the manuscript, and contributed to subsequent revisions: F.A., A.A.; Assisted in designing the study, collected and processed data, reviewed the relevant literature, and contributed to writing and revising the manuscript: N.P.C.Y.; Helped in the study design, was responsible for data collection and processing, analyzed and interpreted the data, reviewed the literature, and participated in writing the manuscript, also contributed to the critical revision of the manuscript: A.A.; Oversaw the study control and supervision, and was involved in sourcing the materials necessary for the research: A.C.; Critically reviewed the manuscript to enhance its intellectual content and provided necessary materials for the study. NT and SNT were additionally responsible for performing the radiological measurements and handling the related data: Y.G., N.T., M.Y.; Also contributed to the radiological data collection and analysis: S.N.T.

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