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Clinical implications of morphometric evaluation of the posterior tibial curvature on the sagittal plane

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MAIN POINTS

- The posterior tibial curvature is significantly greater in the proximal region than in the distal region.
- Understanding tibial curvature is essential for accurate surgical planning and avoiding postoperative complications.
- This study presents a practical morphometric method for evaluating posterior tibial curvature on the sagittal plane.

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ABSTRACT

Aim: This study aimed to morphometrically examine the posterior tibial curvature (PTC) on the sagittal plane in the proximal and distal tibia regions.

Materials and Methods: Forty-eight (21 right, 27 left) dry tibia bones were used. Both linear and angular parameters were measured on ImageJ. Linear measurements: Tibiae were placed on a horizontal surface on their posterior face. Tibiae were photographed from the medial aspect. In the photographs, the distance between the proximal and distal contact points (proximal: C0P, distal: C0D) of the tibia with the horizontal plane was divided into eight equal parts by 7 (C1-C7) landmarks. From each landmark to the tibia, perpendiculars were drawn. The intersections of the perpendiculars with the posterior margin of the tibia were determined (C1'-C7'). The distances between corresponding landmarks were measured (H1-H7). The heights of the tibiae (L) were also measured. Angular measurements: Lines were drawn between each landmark on the proximal tibia and the proximal contact point of the tibia (C0P) for A1 to A3. Similarly, lines were drawn between each landmark on the distal tibia and the distal contact point of the tibia (C0D) for A5 to A7. Angles between these lines and horizontal lines measured (A1-A7).

Results: There were no statistically significant differences between right and left for all parameters. H1, H2 and H3 were statistically greater than the H7, H6 and H5, respectively. A1, A2 and A3 were statistically greater than the A7, A6 and A5, respectively. Sagittal distances and angles in the proximal region were observed to be higher than the distal region.

Conclusion: Tibial morphometry is crucial for treating tibial fractures, planning regional surgeries, assessing surgical outcomes, and preventing complications. We hope that the method proposed in this study will be preferred for evaluating the morphometric characteristics of the posterior curvature of the tibia, particularly in the context of tibial biomechanics or personalized surgical planning.

Keywords: Tibia, Posterior curvature, Morphometry, Anatomy

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INTRODUCTION

The tibia is essential for the lower extremity in carrying body weight of the humans. It helps to distribute body weight properly and keeps the body balanced. Previous studies have included morphological features and curvatures of lower extremity bones [1-7]. Features such as cross-sectional geometry, cortical thickness, trabecular bone architecture, and longitudinal curvature of the diaphysis of long bones are among the morphological features that ultimately affect the mechanical performance of the lower extremities [8]. Curvatures of long bones cause increased tension levels in the bone [1-4]. Studies have shown that curvatures of long bones are associated with activity level and movement, and even these curvatures cannot develop sufficiently without mechanical load [1].

While there are many studies about femoral curvature, studies on the causes and biomechanics of femoral curvature [6, 9] and characteristics of posterior tibial curvature (PTC) are quite limited. According to a study examining tibial curvature among Central European agriculturalists by the historical era, there was a simultaneous decrease in tibial curvature and rigidity seen in the medieval and iron ages compared to prehistoric times. This difference was evident in the middle diaphysis region [5]. In addition, although this study suggests that tibial curvature may be more strongly associated with mobility than body size, it also emphasizes that several complex factors play a role in defining the tibial curvature of the diaphysis and require further study [5].

In rats deprived of mechanical function by unilateral sciatic neurectomy during the growth period, the curvature decreased on the side where the neurectomy was performed, but the length of the tibia was not affected [10]. The distinction between the physiological or pathological curvatures of the tibia is also discussed in the literature. Clinicians need to know the normal range of PTC, especially since curvatures seen in pathological conditions such as genu varum/valgum, rickets, and osteogenesis imperfecta in children require treatment such as osteotomy [11]. A radiographic study found that the depth of sagittal tibia curvature decreases with age in children, establishing age-related average values for physiological tibial curvature [12].

Considering that the bone curvatures are affected by tension on the bone, it is necessary to analyze the morphological characteristics of the tibia well in plaque, screw or prosthesis applications to be placed in the region in surgical interventions to be applied to the patient in cases such as bone fractures or osteoarthritis. Studies emphasize the importance of understanding the details of tibia morphology in surgical interventions such as prostheses and screw applications to be applied on the proximal region of the tibia, especially in knee joint surgery [13]. A comprehensive understanding of tibia morphology may be important for optimizing treatment outcomes and facilitating the healing process in tibial fractures, pathologies, and associated surgical or prosthetic interventions.The aim of this study was to morphometrically investigate the PTC and its associated angles, in the proximal and distal regions of the tibia on the sagittal plane.

MATERIALS AND METHODS

This study was performed on 48 (21 right, 27 left) dry tibia bones in the Anatomy Laboratory of the Izmir Katip Celebi University Faculty of Medicine. The bones with structural deformities that could impact the study's results were excluded. There were no age or gender records of the bones. A match could not be made, indicating whether the right and left tibia bones belong to the same individual. The study was approved by our institutional review board for scientific ethical conduct (Izmir Katip Celebi University Non-Interventional Clinical Research Ethics Committee, Decision No: 0312). Morphometric measurements were evaluated on dry tibia bones and digital image of these bones.

Photograph acquisition

Two digital cameras, Canon EOS 800D and Nikon Coolpix S570, were used to photograph the PTC. A water level gauge ensured that the angle between the digital cameras and the bone surfaces relative to the coronal plane was maintained at 0°. The dry tibia bone was placed horizontally on a table equipped with a water gauge, with the posterior margin facing the table edge, and stabilized using play dough (Figure 1). The first camera was placed superior to the bone to observe the superior articular surface of the tibia. The second camera was placed at level of the table and medial to the bone at a fixed distance and angle. A ruler was placed on the table to calibrate the measurements. To standardize the position of the tibia, the transcondylar axis (parallel to the table) passing through the midpoint of the tibial condyles was aligned with the horizontal grid line using the grid view mode of the first camera. The tibia was then fixed with play dough. The second camera was used to capture medial views of the bone (Figure 1). Measurements were performed on the medical images obtained.

Figure 1. Image of the left dry tibial bone taken from the medial side.

Determination of sagittal neasurements

The measurement points were first identified by examining medial view photographs of dry tibia bones. The tibiae were placed on a horizontal surface on their posterior face to establish these points. The proximal point where the tibia made contact with the horizontal surface was labelled "C0P", and the distal contact point was labelled "C0D" (Figure 2).

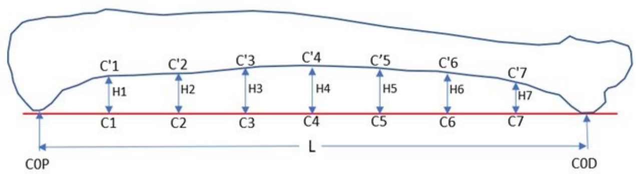

Figure 2. Schematic representation of the sagittal distances between the posterior tibial curvature of left dry tbia bone and the horizontal plane. (C0P: Proximal contact point, C0D: Distal contact point. C1-C7: Landmarks on the horizontal plane, C'1-C'7: Landmarks on the posterior margin of the tibia, H1-H7: Sagittal distances, L: Height of the tibia).

The distance between the proximal and distal contact points (proximal: C0P, distal: C0D) was considered the height (L) tibia with the horizontal plane divided into eight equal parts by 7 (C1-C7) landmarks (Figure 2). From each landmark to the tibia, perpendiculars were drawn. The intersections of the perpendiculars with the posterior margin of the tibia were determined (C1'-C7'). The distances between corresponding landmarks were measured (H1-H7) (Figure 2). The sagittal distances between corresponding landmarks (H1-H7) were measured separately (C1=C1', H1; C2=C2', H2; C3=C3', H3; C4=C4', H4; C5=C5', H5; C6=C6', H6; C7=C7', H7)

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(Figure 2). H1, H2, and H3, representing the sagittal distances were considered proximal region distances. The H4 was classified as the median distance, while H5, H6, and H7 were considered distal region distances.

Determination of angular parameters

Lines were drawn from each proximal landmark (C1'-C3') to the proximal contact point (C0P) to form the proximal region angles A1-A3 (Figure 3). Similarly, lines were drawn from each distal landmark (C5'-C7') to the distal contact point (C0D) to form the distal region angles A5-A7 (Figure 3). The angle between C4' and the C0P/C0D points was symmetrical, and these angles were considered equal (Figure 3). The angles between these lines and the horizontal plane were measured (A1-A7).

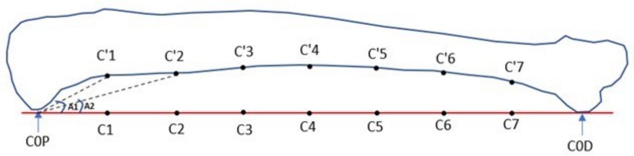

Figure 3. Schematic representation of the A1-A7 angles between the posterior tibial curvature of left dry tbia bone and the horizontal plane. (C0P: Proximal contact point, C0D: Distal contact point. C1-C7: Landmarks on the horizontal plane, C'1-C'7: Landmarks on the posterior margin of the tibia, A1: The angle between three points (C'1-C0P-C0D), A2: The angle between three points (C'2-C0P-C0D)).

The Image J program (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA, https://imagej.nih.gov/ij/, 1997-2018) was used to perform the angular and sagittal measurements. Two researchers independently repeated these measurements, ensuring no intra- or inter-observer variability. In addition, intra-observer and inter-observer correlation coefficients were calculated to assess observer consistency. The measurements were performed separately by the researchers. There were no significant differences in intra-observer and inter-observer measurements.

Statistical analysis

The data were analyzed using statistical software package for social sciences version 25 (SPSS 25.0) (IBM Corp., Armonk, New York, USA). Descriptive statistics for the variables were presented as the number of observations, minimum and maximum values, and median (IQR). The normality of the data was assessed using the Shapiro-Wilk test. An independent samples T-test was used to compare side and proximal-distal measurements for data with a normal distribution, while the Mann-Whitney U test was applied for non-normally distributed data. Any p value < 0.05 was considered as statistical significance. The analyses were performed using 95% confidence interval.

RESULTS

In this study, a total of 48 dry tibia bones were used, consisting of 21 right and 27 left tibias. No significant difference was found between right and left side in terms of tibial height (L) as defined in our study ($p > 0.05$). The median tibial height was 301,25 mm (Table 1). The median (interquartile range, IQR), and range (minimum-maximum) of the sagittal distances (H1-H7) and angular parameters (A1-A7), categorized by side (right/left) and tibial region (proximal/median/distal), are presented in Table 1 and Table 2, respectively. All parameters had no statistically significant differences between right and left side ($p > 0.05$).

There was a significant difference in the comparison of the H1-H7, H2-H6, and H3-H5 parameters between the proximal and distal sagittal distances on both the right and left sides ($p<0.001$, Table 2). H4 is a median distance, and median (IQR) result is 19,35 (4,41) mm (Table 1). There was a significant difference in the comparison of the A1-A7, A2-A6, and A3-A5 parameters between the proximal and distal sagittal distances on both the right and left sides ($p<0.001$, Table 2). Sagittal distances and angles in the proximal region were observed to be higher than the distal region.

DISCUSSION

The tibia is one of the bones that is essential for carrying the human body weight. It maintains the balance of the body by distributing its weight evenly in the lower extremity. However, studies have shown that the curvatures of long bones develop with activity level, movement and mechanical loading [1]. Studies on posterior tibial curvature seen in the tibia are quite limited. In our study, it was aimed to examine the PTC and related angles morphometrically in the proximal and distal regions of the tibia in the sagittal plane in the limited number of tibial bones in our laboratory. We performed a preliminary evaluation of the data regarding posterior tibial curvature obtained in our study.

The results showed no significant difference between the right and left sides in tibial height (L) or the sagittal distances (H1-H7), but the sagittal distances on the right side were greater than on the left side (Table 1). A similar pattern was observed in the angular measurements (A1-A7), where the angles on the right side were greater than those on the left (Table 2). These quantitative differences may be attributed to the small sample size or the fact that the dry bones from each side did not belong to the same individual. Additionally, the greater sagittal distances and angles observed on the right side may indicate that the dominant limb is subjected to different biomechanical forces, influencing bone curvature.

Macintosh et al. [5] comparatively examined the curvature of farmers' dry tibia bones at different ages in Central Europe. Using a 3D modelling method, they reported that tibial curvature in the middle diaphyseal region decreased from the Neolithic age to the middle age. They also found that this change was not affected by body size and tibia height. Their study

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Table 1. Median (Interquartile Range (IQR)) and minimum--maximum (min--max) values for sagittal distances (H) in the proximal, median, and distal tibia regions of the right and left tibia (mm).

		Tibial Height (L)	Tibia Regions						
				Proximal**		Median***		Distal**	
			H1	H2	H3	H4	H5	H6	H7
Right* (R)	Median (IQR)	294.10 (37.58)	16.82 (2.43)	18.58 (4.63)	20.74 (4.52)	20.44 (3.56)	18.60 (2.81)	16.51 (2.79)	12.83 (3.28)
N=21	Min-max	271.57-349.27	8.32-22.97	7.99-25.14	9.32-26.62	9.66-25.88	8.99-25.52	7.66-22.92	5.33-18.49
Left* (L)	Median (IQR)	307.53 (42.59)	15.29 (5.81)	17.11 (3.69)	18.24 (4.53)	18.57 (4.26)	16.74 (3.89)	14.03 (4.00)	10.69 (3.46)
N=27	Min-max	186.42-352.24	10.23-22.99	10.42-23.99	10.42-24.59	11.18-26.28	9.62-24.89	8.02-21.14	8.02-21.14
Total	Median (IQR)	301.25 (36.52)	16.44 (4.27)	17.63 (4.55)	19.03 (5.12)	19.35 (4.41)	17.94 (3.95)	15.07 (3.53)	11.48 (3.50)
N=48	Min-max	186.42-352.24	8.32-22.99	7.99-25.14	9.32-26.62	9.32-26.62	8.99-25.52	7.66-22.92	5.06-23.55

**p>0.05: Comparison of sagittal distances (H1-H7) between right and left tibiae. **p<0.001: There was a significant difference in the comparison of the H1-H7, H2-H6, and H3-H5 parameters between the proximal and distal sagittal distances on both the right and left sides. *** p>0.05: There was no difference in the H4 sagittal distance measured from the median region on both the right and left sides.*

Table 2. Median (Interquartile Range (IQR)) and minimum--maximum (min--max) values for sagittal distances (H) in the proximal, median, and distal tibia regions of the right and left tibia (mm). for angles in the proximal, median, and distal tibia regions of the right and left tibia (mm).

		Tibia Regions						
			Proximal**		Median		Distal**	
		A1	A2	A3	A4	A5	A6	A7
Right* (R)	Median (IQR)	23.07 (4.91)	12.74 (3.61)	10.60 (2.88)	7.75 (2.14)	9.50 (2.03)	12.13 (3.20)	18.98 (5.01)
N=21	Min-max	14.04-31.78	6.37-20.11	5.15-14.24	4.11-10.86	5.13-13.89	6.57-18.81	10.59-29.27
Left* (L)	Median (IQR)	23.96 (5.32)	12.74 (3.61)	9.37 (2.21)	7.01 (2.00)	8.63 (2.76)	10.45 (3.72)	16.16 (5.29)
N=27	Min-max	8.66-31.14	5.94-17.71	4.82-11.94	4.79-9.59	6.31-12.04	8.09-15.43	11.1021.65
Total	Median (IQR)	23.49 (5.12)	13.48 (3.69)	9.86 (2.76)	7.20 (1.99)	8.86 (2.25)	11.19 (3.01)	17.17 (4.76)
N=48	Min-max	8.66-31.78	5.93-20.10	4.81-14.24	4.11-10.86	5.13-13.88	6.57-18.81	10.58-29.26

**p>0.05: Comparison of angles (A1-A7) between right and left tibiae **p<0.001: There was a significant difference in the comparison of the A1-A7, A2-A6, and A3-A5 parameters between the proximal and distal sagittal distances on both the right and left sides.*

does not provide detailed data on PTC [5]. In our study, the sagittal distances and angles of the posterior surface of the tibia are detailed for the proximal, median, and distal regions of the tibia.

A study comparing the curvature of the fibula diaphysis between the Jomon population, who were hunter-gatherers, and the modern Japanese population found that the fibula in modern individuals is significantly flatter [7]. This suggests that bone curvature is influenced by mechanical loading associated with daily activities.

Curvatures in long bones play a crucial role in managing bone stress and stiffness during skeletal loading. The axial forces and ground reaction forces from the muscles act around the longitudinal curvature of the bone, generating multidirectional bending moments [14]. It may be thought that the difference in curvature between the proximal and distal regions of the tibia may be due to the fact that the muscle insertions in the proximal region are more than those in the distal region, and the weight force components loaded on the bone are reflected more in the proximal region. Interventions involving the proximal tibia region can lead to misalignment, which may result in clinical problems due to tension on muscle tendons [14,15]. Misalignment can increase mechanical stress on the bone and lead to postoperative complications. Research on tibial morphology and curvature highlights the importance of accounting for proximal and distal variations during surgeries like total knee arthroplasty and intramedullary nailing to avoid complications such as cortical impingement and postoperative osteoarthritis [16]. Also, in total knee arthroplasty, selecting the correct entry point for the tibial alignment system is crucial because the tibial curvature and the axis of the intramedullary canal influence this entry point [17]. Therefore, we consider a thorough understanding of tibial morphometry essential for achieving optimal surgical outcomes.

In addition, the proper design of tibial prostheses, including alignment and stem insertion points, is essential for reducing stress on the bone and preventing complications like bone remodeling or implant loosening. Specifically, stem design for knee prostheses must consider tibial curvature and load distribution to avoid issues like strain shielding in the proximal tibia, which can affect postoperative outcomes [18]. For this reason, prostheses should also be designed by calculating these stresses. Accurate knowledge of tibial curvature and morphometry helps in selecting appropriate prosthetic designs that accommodate the natural biomechanics of the

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tibia [19].

Our study could not be directly compared with previous studies due to differences in measurement methods and variables related to tibial curvature. Therefore, our data were evaluated independently. The main distinction of our study from others is the identification of regional variations in tibial curvature.

There are some limitations of this study. The number of bones available in our laboratory is limited; however, the aim of our study was to determine the difference in the curvature of the posterior border of the tibia in the proximal and distal regions as a preliminary study. The bones analyzed do not belong to the same individuals, and the lack of information on age and gender may affect the generalizability of the results.

CONCLUSION

In conclusion, this study highlights the importance of understanding tibial morphology and curvature when performing surgical procedures such as total knee arthroplasty and intramedullary nailing. Our findings demonstrate significant variations in PTC between the proximal and distal regions, which can influence the success of surgical outcomes. These variations, likely related to muscle insertions and biomechanical forces, underscore the need to account for tibial curvature when selecting prosthetic designs and surgical entry points. Future studies should aim to refine tibial morphometric data further to improve surgical precision and reduce postoperative complications.

Large-scale radiological studies are required to confirm the differences in posterior tibial curvature across genders, age groups, and populations, offering critical insights into its biomechanical and clinical implications.

Ethics Committee Approval: The study was approved by Izmir Katip Çelebi University Non-Interventional Clinical Research Ethics Committee (Decision No: 0312).

Informed Consent: As the study involved anonymized human skeletal remains with no associated personal data, informed consent was not applicable.

Peer-review: Externally peer-reviewed.

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REFERENCES

1. Bertram JE, Biewener AA. Bone curvature: sacrificing strength for load predictability? *J. Theor. Biol.* 1988;131(1):75-92. doi: 10.1016/s0022-5193(88)80122-x.
2. Shackelford LL, Trinkaus E. Late pleistocene human femoral diaphyseal curvature. *Am J Phys Anthropol.* 2002;118(4):359-70. doi: 10.1002/ajpa.10093.
3. Groote D, Elisabeth I, Maria P. A comprehensive analysis of long bone curvature in Neanderthals and modern humans using 3D morphometrics: University of London, University College London (United Kingdom); 2008.
4. De Groote I. Femoral curvature in Neanderthals and modern humans: a 3D geometric morphometric analysis. *J Hum Evol.* 2011;60(5):540-8. doi: 10.1016/j.jhevol.2010.09.009.
5. Macintosh AA, Davies TG, Pinhasi R, Stock JT. Declining tibial curvature parallels ∼6150 years of decreasing mobility in Central European agriculturalists. *Am J Phys Anthropol.* 2015;157(2):260-75. doi: 10.1002/ajpa.22710.
6. Tagomori H, Kaku N, Shimada T, Tsumura H. Effect of age and sex on femoral curvature in the Japanese population: three-dimensional computed tomography findings. *Anat Sci Int.* 2021;96(3):411-21. doi: 10.1007/s12565-021-00606-x.
7. Hagihara Y. Fibular diaphyseal curvature of the Jomon population. *Anat Sci Int.* 2023;98(4):548-57. doi: 10.1007/s12565-023-00722-w.
8. Lanyon LE. Functional strain in bone tissue as an objective, and controlling stimulus for adaptive bone remodelling. *J Biomech.* 1987;20(11-12):1083-93. doi: 10.1016/0021-9290(87)90026-1.
9. Imamura T, Ogami-Takamura K, Saiki K, Hamamoto A, Endo D, Murai K, et al. Morphological divergence in the curvature of human femoral diaphyses: Tracing the central mass distributions of cross-sections. *J Anat.* 2021;239(1):46-58. doi: 10.1111/joa.13399.
10. Lanyon L. The influence of function on the development of bone curvature. An experimental study on the rat tibia. *Journal of Zoology.* 1980;192(4):457-66. doi: 10.1111/j.1469-7998.1980.tb04243.x.
11. Cheema JI, Grissom LE, Harcke HT. Radiographic characteristics of lower-extremity bowing in children. Radiographics : a review publication of the Radiological Society of North America, Inc. *Radiographics.* 2003;23(4):871-80. doi: 10.1148/rg.234025149.
12. Zbinden I, Rutz E, Jacobson JA, Magerkurth O. Tibial bowing in children - what is normal? A radiographic study. *Eur Radiol.* 2015;25(12):3459-71. doi: 10.1007/s00330-015-3785-1.
13. Valcarenghi J, Vittone G, Mouton C, Coelho Leal A, Ibañez M, Hoffmann A, et al. A systematic approach to managing complications after proximal tibial osteotomies of the knee. *J Exp Orthop.* 2023;10(1):131. doi: 10.1186/s40634-023-00708-7.
14. Akdemir Aktaş H, Ülkir M, Günenç Beşer C, Demiryürek D. Reappraisal of the proximal tibia anatomy in Turkish population. *Surg Radiol Anat.* 2023;45(3):263-70. doi: 10.1007/s00276-023-03094-y.
15. Charng J-R, Chen AC-Y, Chan Y-S, Hsu KY, Wu C-T. Proximal tibial morphology and risk of posterior tibial cortex impingement in patients with AA-sized Oxford unicompartmental knee arthroplasty tibial implants. *J Orthop Surg Res.* 2020;15(1):380. doi: 10.1186/s13018-020-01900-6.
16. Biewener, A A. Locomotory stresses in the limb bones of two small mammals: the ground squirrel and chipmunk. *J Exp Biol.* 1983;103(1):131-54. doi: 10.1242/jeb.103.1.131.
17. Kwak DS, Han CW, Han SH. Tibial intramedullary canal axis and its influence on the intramedullary alignment system entry point in Koreans. *Anat Cell Biol.* 2010;43(3):260-7. doi: 10.5115/acb.2010.43.3.260.
18. Cawley DT, Kelly N, Simpkin A, Shannon FJ, McGarry JP. Full and surface tibial cementation in total knee arthroplasty: a biomechanical investigation of stress distribution and remodeling in the tibia. *Clin Biomech (Bristol).* 2012;27(4):390-7. doi: 10.1016/j.clinbiomech.2011.10.011.
19. Scott C, Biant L. The role of the design of tibial components and stems in knee replacement. *J Bone Joint Surg Br.* 2012;94(8):1009-15. doi: 10.1302/0301-620X.94B8.28289.

https://doi.org/10.5455/annalsmedres.2024.12.261