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Morphometric Analysis of Medial and Lateral Menisci of the Knee Joint in Adult Human Cadavers

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Abstract:

Background: *The knee joint bears substantial mechanical loads, and the medial and lateral menisci play a crucial role in load transmission, shock absorption, joint stability, lubrication, and proprioception. Alterations in meniscal morphology disrupt normal biomechanics and contribute to pain, functional impairment, and early osteoarthritis. Accurate morphometric data are therefore essential for clinical assessment, surgical planning, and meniscal reconstruction.*

Objective: *To analyse the morphology and morphometric parameters of medial and lateral menisci in adult human cadavers and to assess side-wise variations relevant to clinical practice.*

Materials and Methods: *This descriptive cadaver-based study was conducted in the Department of Anatomy, Mahatma Gandhi Medical College and Research Institute, Puducherry. Thirty-one embalmed adult cadavers were dissected, yielding 62 menisci. Meniscal shape, outer and inner circumferences, regional width and thickness (anterior, middle, and posterior thirds), surface area, menisco–tibial coverage ratios, and weight were measured using standardized techniques. Data were analysed using appropriate descriptive and inferential statistics, with $p < 0.05$ considered significant.*

Results: *Medial menisci predominantly exhibited a normal crescentic shape, while lateral menisci showed greater morphological variability with U-shaped forms being most common. No significant side-wise differences were observed in meniscal shape. Most morphometric parameters—including thickness, surface area, tibial coverage ratios, and weight—were bilaterally symmetrical. However, the lateral meniscus showed a significantly greater outer circumference on the right side, and the medial meniscus demonstrated significantly greater width at the anterior and middle thirds on the right. A significant difference was also noted in a derived medial meniscus ratio.*

Conclusion: *Adult knee menisci show a high degree of bilateral symmetry, with selective regional and composite differences, particularly involving the medial meniscus. These findings provide clinically relevant anatomical reference data that may aid meniscal repair, transplantation, and the design of anatomically compatible meniscal replacements*

Keywords: Knee Joint; Meniscus; Morphometry; Cadaveric study; Menisco-Tibial Anatomy

1. INTRODUCTION

Knee is a complex synovial joint that supports a great mechanical load in the normal day-to-day activities i.e. walking, squatting, and running.[1–3] Medial and lateral menisci are fibrocartilaginous tissues that are present between the tibial plateaus and the feminine condyles and have very significant roles in load transmission, shock absorption, joint stability, lubrication, and proprioception. Demonstrating the close relationships with pain, functional impairment and early onset of osteoarthritis, city or dimensional changes in the menisci disrupt the normal knee biomechanics.[4,5] Therefore, meniscal morphology anatomical information is needed in order to properly carry out the clinical examination and effective surgical decision-making.

Cadaveric morphometric gives the fundamental baseline information of meniscal sizes and regional disparities of normal meniscal. Morphometric analysis typically requires the measurement of the shape and

circumferential length, width, and thickness and spatial correlation between the anterior and posterior horn.[6,7] In order to be biomechanically relevant, each meniscus is conventionally divided into anterior, middle and posterior third because they receive varying loads and are vulnerable to injury in different ways.[8–11] The local treatment is specifically employed because of the fact that meniscal tears; which are mostly degenerative tears tend to affect only a portion of the meniscus and not the whole meniscus.

Generally, there are standard methodologies of cadaveric studies in which dissection of formalin fixed adult knee is performed. The anterior approach is made on the joint and the ligaments on the cruciate and collateral are determined and cut in a way that the meniscus is removed. The length of the outer (peripheral) and inner circumference is established using non-elastic threads and the width and thickness of various predetermined points are measured using either digital or vernier callipers. Most of the Indian and Asian based studies have considered sample sizes of approximately 25-100 knees with most of them giving useful populations morphometric data.[12–14]

Clinical relevance is also enhanced by differences in shape. The medial meniscus is generally crescentic semilunar, and the lateral meniscus is generally C-shaped; discoid morphology is not a common one, particularly in the medial meniscus. These anatomical characteristics influence patterns of injured tissue, arthroscopic repair methods and prognosis of meniscal transplant. Proper morphometric information is therefore vital in surgery planning, allograft sizing and designing of anatomically correct meniscal prostheses.[15]

This morphometric study of adult knee menisci is a cadaver-based study that presents a side-by-side analysis of meniscal shape, circumferential dimensions, region-thickness and width, and surface area, tibial coverage ratios and weight. The aim of the study is to the compare the morphometry of medial and lateral menisci of the knee joint on both sides in human cadavers.

2. MATERIALS AND METHODS

This is a descriptive cadaver-based anatomical study was conducted in the Department of Anatomy, Mahatma Gandhi Medical College and Research Institute (MGMCRI), Sri Balaji Vidyapeeth (SBV), Puducherry, India.

Study Population and Sample- Thirty-one embalmed adult human cadavers routinely used for undergraduate medical teaching were included. Both knee joints from each cadaver were dissected, yielding a total of 62 menisci (31 medial and 31 lateral) for analysis. All cadavers had been preserved in 10% formaldehyde solution and were of Indian origin. The study was carried out over a period of 18 months, from January 2024 to June 2025.**Inclusion criteria-** consisted of embalmed adult human cadavers with intact knee joints preserved in 10% formaldehyde. **Exclusion criteria-** included knee joints showing gross musculoskeletal abnormalities, macroscopic meniscal tears, evidence of previous knee surgery, fractures or deformities of the tibial plateau, or advanced tissue deterioration that could interfere with accurate measurements.

Ethical Approval: The study was conducted in the Department of Anatomy, after obtaining approval from Institutional Ethics Committee Project Number:(MGMCRI/Res/01/2023/5/IHEC/09) at MGMCRI, Puducherry.

3. Dissection Procedure

A standardized dissection protocol was done as per Cunningham's Manual of Practical Anatomy followed for all specimens. A longitudinal midline incision was made over the anterior aspect of the knee, and the skin and subcutaneous tissues were reflected. The patellar ligament and collateral ligaments were transacted, and the patella was retracted superiorly to expose the joint cavity. Capsular incisions were made along the joint margins, and the capsule was reflected inferiorly. The cruciate ligaments were sectioned, and intra-articular connective tissue was cleared to visualize the menisci. The medial and lateral menisci were examined *in situ* for gross morphology and subsequently excised carefully to preserve their native contours. Excised specimens were stored in 10% formaldehyde until further analysis.

4. Morphometric Measurements

Morphometric assessment was performed for both medial and lateral menisci. Shape was recorded macroscopically and categorized as crescentic, C-shaped, discoid, or other variants. The outer (peripheral) and inner circumferential lengths were measured using a non-elastic thread secured with metallic pins along the respective margins, and the thread length was measured with a digital vernier calliper. Each meniscus was divided into anterior, middle, and posterior one third, and width and thickness at each segment were measured using a digital vernier calliper. Surface area was determined by tracing the meniscal outline on

graph paper and calculating the enclosed area. The ratio of meniscal area to tibial plateau area was derived using corresponding surface tracings. Meniscal weight was measured using an electronic weighing balance after gently blotting excess preservative fluid.

5. Study Instruments

Measurements and analyses were performed using digital vernier callipers, non-elastic thread, metallic pins, measuring tape, electronic weighing balance, graph paper, Linear scale, scalpel, toothed forceps, standard dissection instruments.

6. Statistical Analysis

Data were entered into Microsoft Excel and analysed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequencies and percentages. Continuous variables were expressed as mean ± standard deviation for normally distributed data or as median with interquartile range for non-normally distributed data. Normality was assessed using the Kolmogorov–Smirnov test, Shapiro–Wilk test, and Q–Q plots. Comparisons between groups were performed using the chi-square or Fisher's exact test for categorical variables, independent *t*-test or ANOVA for normally distributed continuous variables, and Mann–Whitney U or Kruskal–Wallis tests for non-parametric data. A p-value < 0.05 was considered statistically significant.

7. RESULTS

The study sample demonstrated the sex and laterality distribution of the cadaveric knee samples (N = 62). Female specimens constituted 61.2% (n = 38) of the sample, while male specimens accounted for 38.8% (n = 24). The distribution of sides was equal, with left and right knees each contributing 31 specimens (50.0%), indicating balanced laterality in the study sample for morphometric comparisons. **Table 1**

Table 1. Sex and Laterality Distribution of Cadaveric Knee Samples (N = 62)

Variable	Category	Count	Percentage (%)
Gender	Female	38	61.2
	Male	24	38.8
Side	Left	31	50.0
	Right	31	50.0

Table 2 Summarizes meniscal shape variants in medial and lateral menisci by side. In the medial meniscus, the Cresent shape was the most common variant, observed in 74.2% of left knees and 83.9% of right knees. U-shaped medial menisci were more frequent on the left side (16.1%) compared to the right (3.2%), while C-shaped and sickle-shaped variants together accounted for less than 10% on either side. For the lateral meniscus, U-shaped morphology predominated, seen in 51.6% of left and 61.3% of right knees, followed by normal morphology in 25.8% and 29.0%, respectively. Complete lateral meniscus was uncommon, observed in 6.5% of left and 3.2% of right knees. No statistically significant side-wise differences were observed for medial ($\chi^2 = 4.065$, $p = 0.255$) or lateral meniscal shapes ($\chi^2 = 3.301$, $p = 0.509$). suggesting that gross meniscal morphology is largely bilaterally symmetrical. (Figure 1)

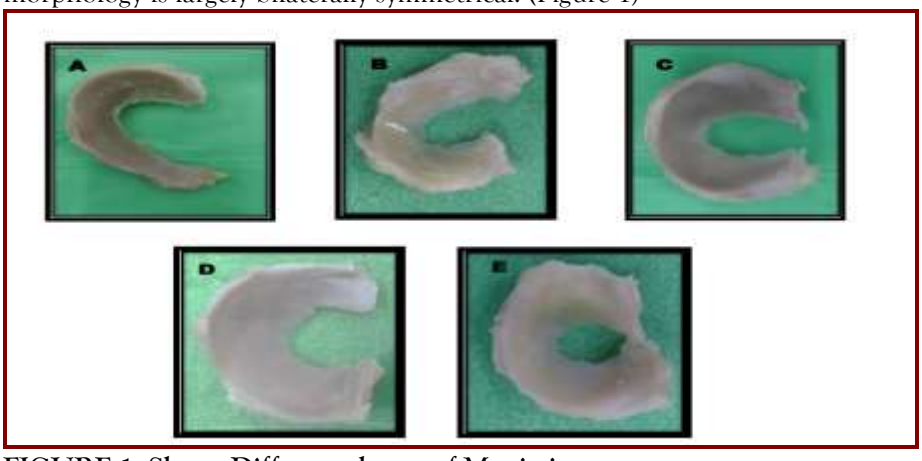

FIGURE 1. Shows Different shapes of Menisci

(A) Cresent shape (B) Sickle shape (C) U- shape (D) C- shape (E) Complete shape

Table 2. Meniscal Shape Variants in Medial and Lateral Menisci by Side (Left vs Right)

Meniscus	Shape Type	Left n (%)	Right n (%)	χ^2 (df), p
Medial	0 – Crescent	23 (74.2)	26 (83.9)	4.065 (3), 0.255
	1 – U shaped	5 (16.1)	1 (3.2)	
	2 – C shape	2 (6.5)	1 (3.2)	
	3 – Sickle	1 (3.2)	3 (9.7)	
Lateral	0 – Crescent	8 (25.8)	9 (29.0)	3.301 (4), 0.509
	1 – U shaped	16 (51.6)	19 (61.3)	
	2 – C shape	3 (9.7)	2 (6.5)	
	3 – Sickle	2 (6.5)	0 (0.0)	
	4 – Complete	2 (6.5)	1 (3.2)	

Circumferential analysis **Table 3** further supports this symmetry for the medial meniscus, as both outer and inner circumferences did not differ significantly between sides. In contrast, the compares circumferential measurements of menisci by side. The outer circumference of the lateral meniscus was significantly greater on the right side (9.61 ± 1.23 cm) compared to the left (8.63 ± 1.53 cm; p = 0.007). No significant side-wise differences were noted for medial outer circumference or for inner circumferences of either meniscus (p > 0.05) indicating a localized peripheral asymmetry rather than a global difference in meniscal size.

Table 3. Meniscal Circumferential Measurements (Right vs Left)

Parameter	Right(Mean±SD)	Left (Mean ± SD)	t(df)	p-value
Outer Circumference –MM	9.86 ± 0.99	9.75 ± 1.38	0.336 (61)	0.738
Outer Circumference – LM	9.61 ± 1.23	8.63 ± 1.53	2.773 (61)	**0.007**
Inner Circumference – MM	5.67 ± 1.02	5.84 ± 1.34	-0.552 (61)	0.583
Inner Circumference – LM	4.80 ± 1.01	4.57 ± 0.92	0.961 (61)	0.341

Regional assessment of thickness and width **Table 4** Revealed no significant side-related differences in thickness across anterior1/3rd, middle1/3rd, and posterior1/3rd of either meniscus, suggesting uniform vertical meniscal architecture bilaterally. However, the medial meniscus showed significantly greater width on the right side at the anterior1/3rd and middle1/3rd, while the posterior1/3rd remained comparable, highlighting region-specific asymmetry in mediolateral expansion. The lateral meniscus exhibited no significant side-wise differences in either thickness or width across all regions, consistent with its known biomechanical mobility and adaptability.

Table 4. Meniscal Thickness and Width by Thirds (Right vs Left)

Region	Thickness Right (Mean±SD)	Thickness Left (Mean±SD)	p	Width Right (Mean±SD)	Width Left (Mean±SD)	p
Anterior 1/3rd MM	3.74 ± 1.12	3.65 ± 1.12	0.742	7.61 ± 1.32	6.83 ± 1.42	**0.034**
Middle 1/3rd MM	5.43 ± 1.65	4.84 ± 1.55	0.149	8.37 ± 2.00	7.33 ± 1.44	**0.030**
Posterior 1/3rd MM	5.08 ± 1.35	4.77 ± 1.28	0.353	10.86 ± 2.92	10.83 ± 2.72	0.887
Anterior 1/3rd LM	3.45 ± 1.24	3.47 ± 1.29	0.800	8.22 ± 2.23	8.63 ± 2.03	0.374
Middle 1/3rd LM	4.73 ± 0.90	4.89 ± 1.04	0.405	8.13 ± 1.60	8.42 ± 1.63	0.411
Posterior 1/3rd LM	4.55 ± 1.30	4.48 ± 1.16	0.745	9.20 ± 2.02	9.38 ± 1.92	0.634

Abbreviations: MM – Medial menisci, LM – Lateral menisci

As presented in **Table 5**, shows that area of menisci, area of tibial coverage, ratios of menisci, and weights were comparable between sides (p > 0.05). A significant difference was noted only in the medial meniscus ratio, which was higher on the left side (68.23 ± 9.20) compared to the right (63.40 ± 6.84; p = 0.023). meniscal surface area, tibial coverage ratios, and meniscal weight did not differ significantly between sides for both medial and lateral menisci, reinforcing overall bilateral symmetry in meniscal mass and menisco- tibial + articulation. Notably, a significant difference was observed only in the medial meniscus ratio, with higher

values on the left side, suggesting that composite morphometric indices may capture subtle anatomical variations not evident in individual linear or area measurements. Collectively, these findings indicate that while adult knee menisci are largely symmetrical between sides, selective regional and composite differences particularly involving the medial meniscus may have biomechanical and clinical relevance.

Table 5. Area of menisci, Area of Tibial plateau, Morphometric Ratios, and Weight (Right vs Left)

Parameter	Right (Mean ± SD)	Left (Mean ± SD)	t(df)	p-value
Area of Medial menisci (mm²)	788.7 ± 125.2	803.3 ± 176.2	-0.376 (60)	0.708
Area of Lateral menisci (mm²)	743.3 ± 179.6	700.4 ± 159.8	0.994 (60)	0.324
MM: Area of Tibial plateau	1257.7 ± 242.8	1201.4 ± 325.5	0.771 (60)	0.444
LM: Area of Tibial plateau	910.7 ± 220.9	846.1 ± 191.4	1.230 (60)	0.224
Ratio of MM	63.40 ± 6.84	68.23 ± 9.20	-2.335 (60)	**0.023**
Ratio of LM	81.91 ± 6.77	83.12 ± 7.40	-0.673 (60)	0.504
Weight – MM (g)	3.32 ± 0.83	3.45 ± 1.26	-0.760 (60)	0.636
Weight – LM (g)	2.94 ± 1.00	2.77 ± 0.88	0.674 (60)	0.503

8. DISCUSSION

In this cadaver-based morphometric study of adult knee menisci, we provide a side-specific evaluation of meniscal shape, circumferential dimensions, regional thickness and width, surface area, tibial coverage ratios, and weight. The key findings were that meniscal shape variants showed no significant laterality, most morphometric parameters were bilaterally symmetrical, and only selective side-related differences were observed—particularly involving the lateral meniscal outer circumference, medial meniscal regional width, and a derived medial meniscus ratio.

In terms of meniscal morphology, our series of crescentic medial menisci and U-shaped lateral menisci are in agreement with previous cadaver studies by Gupta et al., and Ashwini et al. which also reported crescentic medial menisci as dominant and a high morphological variability in the lateral meniscus. In terms of meniscal morphology, the lack of significant side-wise variance in the shape distribution is in agreement with prior cadaveric studies by Gupta et al., and Ashwini et.[16,17]

The circumferential measurements revealed no significant right to left disparities in the outer or inner circumference of the medial meniscus, as compared to the results of Murlimanju et al and Kaur et al [4,12] but the lateral meniscus had a significantly larger outer circumference on the right side. Though of minor scale, other subtle asymmetries of this type have been sometimes observed, even in population studies by Semindei et al., which indicates that not extreme bilateral symmetry can always be assumed, especially with respect to peripheral dimensions of interest in load transfer.[18] Although such functional associations cannot be investigated in cadaveric material, the result indicates that perfect bilateral symmetry cannot always be expected, even in dimensions of interest in population studies.

The patterns of determined biomechanical relevance were observed as regional analysis of thickness and width. The medial meniscus was found to be thicker at the middle and posterior third like Ashwini et al., and Subramanian et al. had noted, and the areas are often the ones involved in degenerative tear, which is also anatomically supported.[17,19] It is interesting to note that, the medial meniscus was much wider on the right side at the anterior third and the middle third and the widest of all at the posterior third. This local imbalance can have effects on local tensile distribution and might be one of the factors contributing to the variability in tear patterns observed in clinical series.

Conversely, relative uniformity of the lateral meniscus in terms of thickness and width between regions and sides was observed as compared to the medial meniscus, which can be attributed to the increased mobility and adaptability of the lateral meniscus itself over the medial one and could be a contributing factor to its reduced vulnerability to degenerative injury.

Lastly, medial meniscus ratio, tibial coverage ratios, and weight did not differ significantly across sides, which is consistent with the results of Immonen et al. and Subramanian et al. and the fact that composite morphometric indexes could reflect small anatomical differences missed by linear measures alone, and would be more valuable to understand the biomechanical effects of the meniscus.[15,19,20]

9. Strengths And Limitations

The strengths of this study include a standardised dissection protocol, comprehensive morphometric assessment, and simultaneous evaluation of multiple clinically relevant parameters in both menisci. Nonetheless, several limitations merit consideration. The use of embalmed cadavers may introduce minor dimensional alterations due to fixation. Information regarding age, occupation, limb dominance, and premorbid joint pathology was unavailable, limiting causal inference. Additionally, the sample size, while adequate for descriptive anatomy, may not capture rarer morphological variants.

10.Conclusion

This cadaveric study demonstrates that adult knee menisci exhibit a high degree of bilateral symmetry in shape, thickness, surface area, tibial coverage, and weight. However, selective side-related differences in medial meniscal width and lateral meniscal outer circumference highlight subtle regional variations. These findings provide clinically relevant anatomical reference data that may aid in meniscal repair, transplantation, and the design of anatomically matched meniscal substitutes.

CONFLICT OF INTEREST: Nil

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