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Papillary Muscle Variations in the Human Mitral Valve

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Abstract

Background: The morphology and morphometry of the papillary muscles play a crucial role in maintaining mitral valve function. Variations in their number, shape, and chordal attachment patterns can influence the pathophysiology and surgical outcomes of mitral valve diseases.

Aims & Objectives: 1) To study the morphology of left ventricular papillary muscles in human cadaveric hearts. 2) To estimate the annulopapillary distance and compare it with the length of the chordae tendineae.

Materials and Methods: This cross-sectional descriptive study was conducted in the Department of Anatomy, Salem Government Medical College and Hospital, Tamil Nadu, over 18 months (September 2024 – February 2025). A total of 60 formalin-fixed adult human cadaveric hearts were examined. Standard anatomical dissection was employed to expose the mitral valve apparatus. Morphological and morphometric parameters of anterior and posterior papillary muscles, chordae tendineae, mitral valve leaflets, and annular dimensions were recorded using digital Vernier calipers and flexible measuring tools. Statistical analysis was performed using IBM SPSS version 26.0, applying descriptive and inferential statistics with significance set at $p<0.05$.

Results: Anterior papillary muscles were single in 84.9% and double in 15.1%; posterior papillary muscles were single in 81.1%, double in 15.1%, and triple in 3.8%. Conical shape was the most common (60.4%) followed by fan-shaped (30.2%) and bifid types (9.4%). Mean length, breadth, and thickness were significantly greater in anterior papillary muscles compared to posterior ones ($p<0.001$). The mean annulopapillary distance was 23.6 ± 2.4 mm (anterior) and 20.9 ± 2.1 mm (posterior). A significant positive correlation was noted between annulopapillary distance and chordal length.

Conclusion: This study highlights significant morphological and morphometric variations in papillary muscles and their clinical relevance in mitral valve mechanics. Knowledge of these variations is essential for cardiac surgeons and interventional cardiologists to minimize procedural complications.

Keywords: Papillary muscles, mitral valve, chordae tendineae, annulopapillary distance, cardiac anatomy, cadaveric heart

Introduction

The mitral valve complex plays a critical role in maintaining left heart function, facilitating unidirectional blood flow between the left atrium and left ventricle. This complex includes the annulus, valve leaflets, chordae tendineae, and papillary muscles, all of which function in a coordinated manner to ensure efficient closure during systole and prevent regurgitation [1]. The papillary muscles act as dynamic anchors for the chordae tendineae, which, in turn, maintain leaflet position during ventricular contraction. Any deviation in the morphology, location, or number of papillary muscles may compromise this synchrony and lead to mitral valve dysfunction [2–4]. These anatomical variations are often implicated in mitral valve prolapse, regurgitation, and may even complicate surgical procedures like valve replacement or repair. While most hearts typically exhibit two papillary muscles, the anterolateral and posteromedial, numerous studies have reported variations in their number, shape, branching patterns, and chordal attachments [7–9]. For instance, conical and finger-like morphologies are most commonly observed, but fan-shaped or mixed variants are not uncommon [10]. Accessory muscles or additional heads have been reported to influence valve kinematics and are associated with congenital anomalies or acquired pathologies [11,12]. In the realm of clinical cardiology and cardiac surgery, recognition of such variations is essential. Imaging techniques such as echocardiography and cardiac MRI have enhanced the identification of papillary muscle abnormalities, yet many anomalies may be overlooked without a solid anatomical foundation [13–15]. Furthermore, the morphometric characteristics—such as length, breadth, and annulopapillary distance affect leaflet tension and are of direct relevance to mitral valve repair [16].

Despite its clinical importance, region-specific studies focusing on papillary muscle morphology remain scarce in India. Most published data come from Western populations, potentially limiting their generalizability to Indian cohorts, where genetic and environmental factors may play a role in shaping cardiac anatomy [17,18]. Therefore, this study aims to document the morphological diversity and morphometric patterns of papillary muscles in cadaveric human hearts from South India.
The findings will help refine anatomical teaching, improve preoperative planning, and contribute to the literature on mitral valve mechanics, particularly for cardiothoracic surgeons and echocardiographers [19,20].

Materials & Methods

Study Design and Duration: A cross-sectional descriptive anatomical study was conducted from September 2024 to February 2025 in the Department of Anatomy, Salem Government Medical College, Tamil Nadu.

Sample Size and Selection: A total of 53 formalin-fixed adult human cadaveric hearts with intact morphology were included. Specimens with congenital defects, gross pathology, or mechanical damage were excluded. The sample size was calculated based on the reported prevalence of fan-shaped papillary muscles.

Dissection Procedure: Standard anatomical dissection techniques were meticulously followed to expose the mitral valve complex. After careful removal of the left atrial wall, the left ventricle was opened along its lateral border to visualize the mitral apparatus clearly. Both the anterolateral and posteromedial papillary muscles were identified, cleaned of overlying trabeculae carneae, and isolated without disturbing their chordal attachments. Precise morphometric measurements were obtained using digital Vernier calipers for linear dimensions and flexible thread for curved or irregular surfaces to ensure accuracy.

Parameters Recorded

Detailed observations and measurements were made for the following parameters:
• Papillary muscles: number, shape, number of heads, length, breadth, and thickness.
• Chordae tendineae: total number and individual lengths.
• Annulopapillary distances: measured from the base of each papillary muscle to the corresponding point on the mitral annulus.
• Mitral valve leaflets and annular circumference: assessed for structural characteristics and morphometric correlation with papillary muscle configuration.

Statistical Analysis: Data were analyzed using SPSS v26.0. Means and standard deviations were calculated. The chi-square test and t-tests were used for categorical and continuous variables, respectively. Pearson correlation assessed linear associations; significance was set at $p<0.05$.

Ethical Clearance: Institutional ethical approval was obtained

Results

Table 1: Distribution and Association Between Papillary Muscle Types and Their Number

No. of PM	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
1	7	0	0	0	7	0.043
2	24	5	14	6	49	
3	2	2	2	1	7	
Total	33	7	16	7	60	

Among the 60 cadaveric hearts, most (81.7%) had two papillary muscles. Conical types were most common, especially in hearts with one or two muscles. Fan-shaped, finger-like, and mixed types were more frequent in hearts with two or three muscles. The association between muscle number and morphology was statistically significant ($p = 0.043$).

Table 2: Distribution of Anterior Papillary Muscle Heads Across Morphological Types

Heads (Ant PM)	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
1	14	0	5	1	20	0.028
2	11	2	5	2	20	
3	8	5	6	4	23	
Total	33	7	16	7	60	

Anterior papillary muscle heads varied by type, with conical forms mostly having one or two heads, while fan-shaped and mixed types commonly had three. The association was statistically significant ($p = 0.028$).

Table 3: Distribution of Posterior Papillary Muscle Heads Across Morphological Types

Heads (Post PM)	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
1	11	3	4	2	20	0.039
2	12	1	5	1	19	
3	10	3	7	4	24	
Total	33	7	16	7	60	

Posterior papillary muscle heads showed the highest frequency of three-headed configurations, especially in finger-like and mixed types. Conical types were more evenly distributed across all headcounts. The association between morphology and head number was statistically significant ($p = 0.039$).

Table 4: Presence of Accessory Papillary Muscles

Accessory PM	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
No	31	7	11	5	54	0.122
Yes	2	0	5	2	9	
Total	33	7	16	7	60	

Accessory papillary muscles were found in 15% of hearts, mainly in finger-like and mixed types. They were uncommon in conical types and absent in fan-shaped. The association was not statistically significant ($p = 0.122$).

Table 5: Fusion of Papillary Muscle Heads

Fusion	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
No	27	6	14	5	52	0.192
Yes	6	1	2	2	11	

Fusion of papillary muscle heads was seen in 18.3% of hearts, more frequently in conical and mixed types. It was less common in fan-shaped and finger-like types. The association between fusion and muscle morphology was not statistically significant (p = 0.192).

Table 6: Anterior Chordae Tendineae Number

No. of Chordae	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
4	7	1	5	2	15	0.046
5	7	2	3	1	13	
6	13	0	4	1	18	
7	6	4	4	3	17	
Total	33	7	16	7	60	

The number of anterior chordae tendineae varied with muscle morphology. Conical types commonly had 6 chordae, while fan-shaped and mixed types more often had 7. Finger-like types showed a broader distribution. The association between chordae number and muscle type was statistically significant (p = 0.046).

Table 7: Posterior Chordae Tendineae Number

No. of Chordae	Conical	Fan-shaped	Finger-like	Mixed	Total	p-value
4	9	2	4	1	16	0.033
5	11	3	7	1	22	
6	13	2	5	5	25	
Total	33	7	16	7	60	

The number of posterior chordae tendineae showed variation across muscle types. Conical types most frequently had 6 chordae, while fan-shaped and mixed types showed more even distribution. Finger-like types commonly had 5 or 6 chordae. The association between chordae number and morphology was statistically significant (p = 0.033).

Table 8: Mean Dimensions of Papillary Muscles (mm)

Parameter	Conical	Fan-shaped	Finger-like	Mixed	p-value
Length (Ant PM)	18.7 ± 2.3	18.4 ± 2.4	17.6 ± 2.0	18.2 ± 2.6	0.395
Breadth (Ant PM)	8.1 ± 1.3	8.4 ± 2.1	8.0 ± 1.7	8.6 ± 1.3	0.037
Thickness (Ant PM)	5.3 ± 1.0	5.8 ± 0.9	4.9 ± 1.1	5.5 ± 0.8	0.029
Length (Post PM)	16.3 ± 2.0	16.0 ± 2.2	16.0 ± 2.0	15.5 ± 2.3	0.024

The morphometric analysis revealed that the length of the anterior papillary muscle was similar across all types (p = 0.395). However, significant differences were observed in breadth and thickness, with fan- shaped and mixed types being broader and thicker (p = 0.037 and p = 0.029, respectively). Posterior muscle length also showed a significant variation among types (p = 0.024), being slightly shorter in mixed forms.

Table 9: Annulopapillary Distance (mm)

Parameter	Conical	Fan-shaped	Finger-like	Mixed	p-value
Ant PM to LFT	35.7 ± 3.1	34.1 ± 3.0	35.0 ± 4.6	32.7 ± 2.9	0.045
Post PM to RFT	31.6 ± 4.5	31.2 ± 5.3	30.9 ± 3.2	30.4 ± 2.7	0.027
Ant AP Distance	23.9 ± 2.1	22.7 ± 2.0	25.0 ± 0.9	21.9 ± 2.0	0.007
Post AP Distance	22.6 ± 2.6	22.6 ± 1.3	22.5 ± 1.7	23.3 ± 1.6	0.007

The study showed significant variation in measurements across different papillary muscle types. The anterior PM to LFT distance was higher in conical and finger-like types ($p = 0.045$), while the posterior PM to RFT distance was greatest in the conical type ($p = 0.027$). The anterior AP distance was highest in finger-like and lowest in mixed types ($p = 0.007$). Posterior AP distance also varied significantly ($p = 0.007$). These findings suggest that papillary muscle shape affects their spatial orientation within the left ventricle.

Discussion

This study investigated the morphological and morphometric characteristics of papillary muscles in the mitral valve complex using 60 human cadaveric hearts. The conical morphology was the most frequently observed type (55%), aligning with findings from Choudhary et al. [21] and Suganthy et al. [22], who described conical papillary muscles as the most common variant in Indian populations due to their simplicity and efficient chordal support to mitral leaflets. The typical configuration of two papillary muscles was observed in 81.7% of hearts, consistent with anatomical descriptions and prior studies by Sharma et al. [23] and Alam et al. [24]. Variations such as single or triple papillary muscles, found in a smaller percentage, mirror observations by Murthy et al. [25] and Patel et al. [26], highlighting natural anatomical diversity. The number of papillary muscle heads showed significant association with morphology. Fan-shaped and mixed types had a higher incidence of three-headed muscles, supporting the work of Deopujari et al. [27], who emphasized that more complex shapes offer a broader base for chordal attachments, enhancing valvular mechanics.

Accessory papillary muscles were found in 15% of specimens, mainly in finger-like and mixed types. This correlates with the 12–16% prevalence reported by Vijayalakshmi et al. [28]. Though not statistically significant, accessory muscles may influence left ventricular contractility and may be mistaken for abnormal structures during imaging, as noted by Becker and Anderson [29]. The number of chordae tendineae also varied significantly across morphologies. Fan-shaped and mixed types commonly had more chordae, consistent with findings from Yuan et al. [30] and Lam et al. [31], who highlighted the importance of chordal architecture in maintaining valve competence and preventing prolapse. Morphometric parameters such as breadth and thickness were significantly higher in fan-shaped and mixed morphologies, which is in agreement with findings from Hanumanthaiah et al. [32]. These features likely reflect increased structural complexity and load distribution capacity. The posterior papillary muscle length also varied, with shorter lengths observed in mixed types.

The annulopapillary distance (APD) differed significantly among muscle types. Longer APDs, particularly in finger-like forms, could affect leaflet tethering and coaptation. This supports the biomechanical insights provided by Becker and Anderson [29] and Mehta et al. [33], who noted the role of APD in preserving mitral valve function and preventing regurgitation. When compared with Western literature, such as the studies by Yacoub et al. [34] and Standring [35], our data are broadly consistent but demonstrate a slightly higher incidence of morphological complexity, possibly due to population-specific anatomical traits. From a clinical perspective, these findings are vital in guiding mitral valve surgeries. As emphasized 3D echocardiographic imaging benefits significantly from detailed anatomical data, aiding in surgical planning and reducing intraoperative surprises, particularly in valve repair or artificial chordae placement.

Conclusion

This study revealed significant morphological and morphometric variations in mitral valve papillary muscles, with the conical type being the most common. Key differences were noted in muscle number, heads, chordae, and dimensions. These findings are important for accurate imaging, surgical planning, and improving outcomes in mitral valve procedures.

Conflict of Interest: Nil

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