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Morphological Variations Of Papillary Muscles In The Human Left Ventricle: A Cadaveric Study

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Abstract:
Background: *Papillary muscles are essential for mitral valve function, with their morphology and the attachment of chordae tendineae influencing valve competence. Understanding their variations is critical for clinical and surgical practice.*
Materials and Methods: *A descriptive cross-sectional study was conducted on 27 formalin-fixed human cadaveric hearts obtained from the Department of Anatomy, RIMS, Imphal. Left ventricles were opened along the left border to expose papillary muscles. The number, shape, and morphological patterns of papillary muscles were recorded.*
Results: *The classical two-muscle pattern was observed in 7 specimens (26%). One papillary muscle was found in 1 specimen (3.7%), three muscles in 7 specimens (26%), four muscles in 4 specimens (14.8%), and five muscles in 8 specimens (29.6%). Observed shapes included conical (51.9%), broad-apexed (37%), pyramidal (22.2%), and fan-shaped (22.2%). The most frequent morphological pattern was a single base with divided apex (29.6%).*
Conclusion: *Papillary muscle anatomy exhibits considerable variation in number, shape, and pattern. Knowledge of these variations is vital for cardiothoracic surgeons, anatomists, and clinicians, as it can influence mitral valve function and outcomes in conditions such as mitral regurgitation or papillary muscle dysfunction.*
Keywords: *Papillary muscles, chordae tendineae, left ventricle, mitral valve anatomy.*

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I. Introduction

The papillary muscles of the left ventricle play a critical role in anchoring the mitral valve leaflets and ensuring proper valvular function. Typically, two muscles—the superoposterior and inferoseptal—arise from the ventricular wall and vary considerably in length, width, and morphology. In some cases, papillary muscles may be bifid or form multiple heads, affecting the attachment of chordae tendineae and, consequently, valve competence.[1,2]

Chordae tendineae generally originate from the apical third of papillary muscles and insert into corresponding areas of the valve leaflets. Some chordae may arise directly from the ventricular wall, while false chordae, which do not connect to the leaflets, are occasionally observed and may influence cardiac conduction.[1,3] True mitral chordae are categorized as interleaflet (commissural), rough zone (including strut chordae), cleft, or basal, and their branching patterns contribute to the mechanical stability of the mitral valve.[1]

The vascular supply of papillary muscles is variable. The anterolateral papillary muscle is usually supplied by branches of the left circumflex artery, whereas the posteromedial muscle may receive blood from the left or right coronary artery depending on coronary dominance.[4,5] Variations in papillary muscle morphology-including fusion, bifurcation, or anomalous insertion-have been associated with valvular dysfunction, such as mitral regurgitation or stenosis, and may contribute to obstructive hypertrophic cardiomyopathy.[7,8]

Understanding the anatomical variations of papillary muscles and their chordal attachments is therefore essential for surgeons, anatomists, and clinicians. Detailed knowledge of these structures aids in surgical planning, interpretation of imaging studies, and management of normal and pathological valvular conditions.[1,2,6,9] The current study aims to evaluate the number, shape, and morphological patterns of papillary muscles in the left ventricle of human cadaveric hearts.

II. Material And Methods

A descriptive cross-sectional study was carried out on 27 formalin-fixed adult human cadaveric hearts obtained from the Department of Anatomy, RIMS, Imphal, between July 2024 and July 2025. The specimens were of unknown age, sex, and race. Hearts with gross morphological anomalies or diseased/fibrosed valves were excluded to ensure analysis of structurally normal left ventricles.

Each heart was cleaned, and the left ventricle was exposed through a longitudinal incision along the left border, extending from the left auricle to the apex. The papillary muscles were carefully examined for number, shape, and morphological pattern. Shapes were categorized as conical, broad-apexed, pyramidal, or fan-shaped, while patterns included single base with divided apex, transverse bridges, small or long muscles, perforated muscles, and chordae arising directly from the ventricular wall. Observations were recorded systematically for all specimens, and the data were analyzed to determine the frequency and distribution of papillary muscle variations.

III. Result

In this study, the classical two-papillary muscle pattern (single or common base) was observed in 7 of 27 hearts (25.9%). Variations in the number of papillary muscles included one muscle in 1 specimen (3.7%), three muscles in 7 specimens (25.9%), four muscles in 4 specimens (14.8%), and five muscles in 8 specimens (29.6%) (Table 1).

Table 1. Variations in the number of papillary muscles (N = 27)

No. of Papillary Muscles	Number of Specimens	Percentage (%)
One (fig:1)	1	3.7
Two (classical pattern) (fig:2)	7	25.9
Three (fig:3)	7	25.9
Four (fig:4)	4	14.8
Five (fig:5)	8	29.6

Papillary muscle shapes showed considerable variation. Conical muscles were most common (14 specimens, 51.9%), followed by broad-apexed (10 specimens, 37%), pyramidal (6 specimens, 22.2%), and fan-shaped (6 specimens, 22.2%) forms (Table 2).

Table 2. Distribution of papillary muscle shapes (N = 27)

Shape	Number of Specimens	Percentage (%)
Conical (fig:2)	14	51.9
Broad-apexed (fig::3)	10	37.0
Pyramidal (fig: 11)	6	22.2
Fan-shaped (fig:12)	6	22.2

Morphological patterns were also diverse. The most frequent pattern was a single base with divided apex (bifid), observed in 8 specimens (29.6%). Other patterns included two papillary muscles interconnected by a transverse bridge (H-shaped, 6 specimens, 22.2%), small muscles (6 specimens, 22.2%), long muscles (6 specimens, 22.2%), perforated muscles (4 specimens, 14.8%), chordae arising directly from the ventricular wall (4 specimens, 14.8%), and long, broad, wide papillary muscles (2 specimens, 7.4%) (Table 3).

Table 3. Morphological patterns of papillary muscles (N = 27)

Pattern Description	Number of Specimens	Percentage (%)
Single base with divided apex (bifid) (fig:8)	8	29.6
Two muscles interconnected by transverse bridge (H) (fig:7)	6	22.2
Small papillary muscles (fig:1)	6	22.2
Long papillary muscles (fig: 9)	6	22.2

Pattern Description	Number of Specimens	Percentage (%)
Perforated papillary muscles (fig:10)	4	14.8
Chordae tendineae arising directly from ventricular wall (fig:6)	4	14.8
Long, broad, wide papillary muscles (fig: 12)	2	7.4

These results highlight the wide anatomical variability of papillary muscles in terms of number, shape, and morphological pattern within the left ventricle.

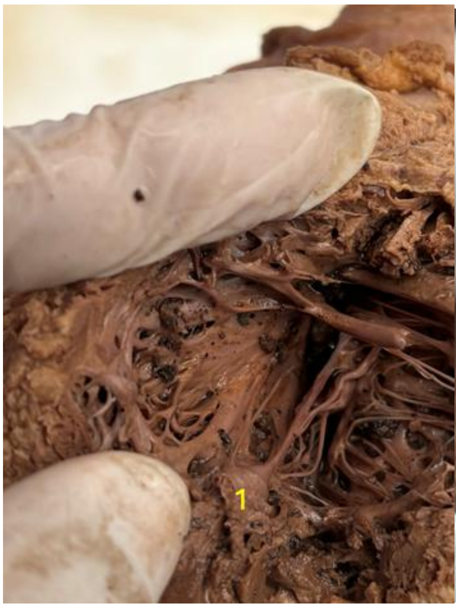

Figure: 1

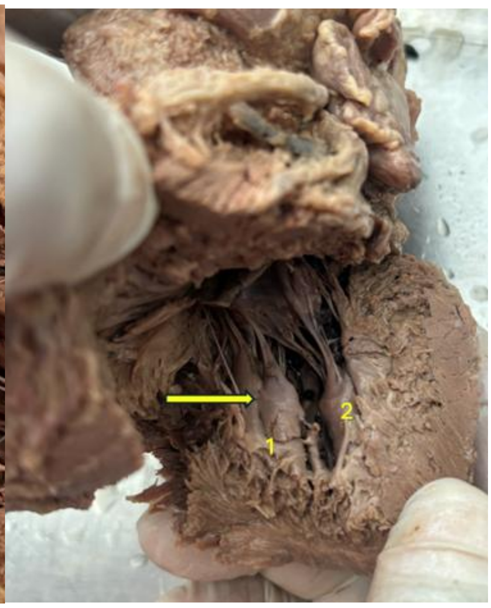

Figure: 2

FIG 3,4

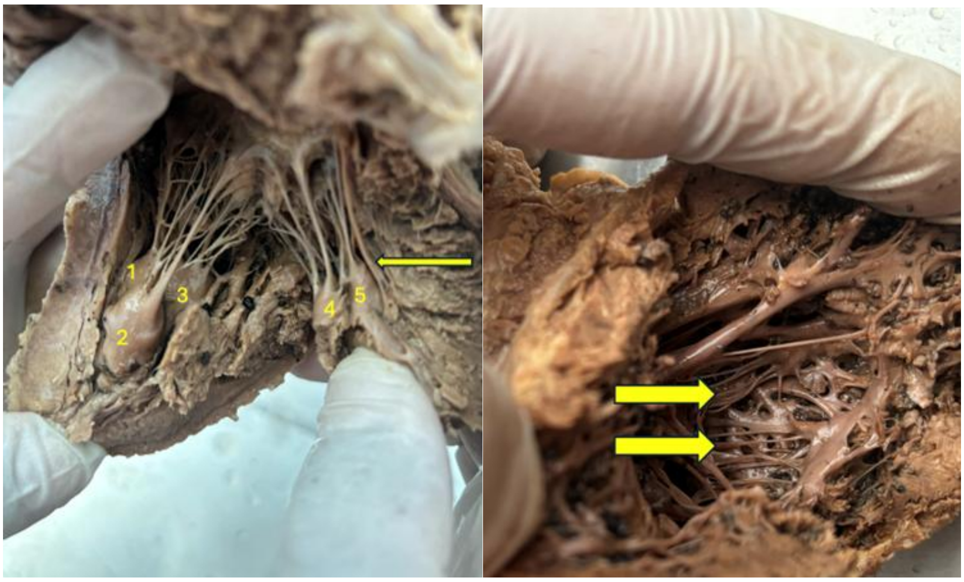

FIG 5,6

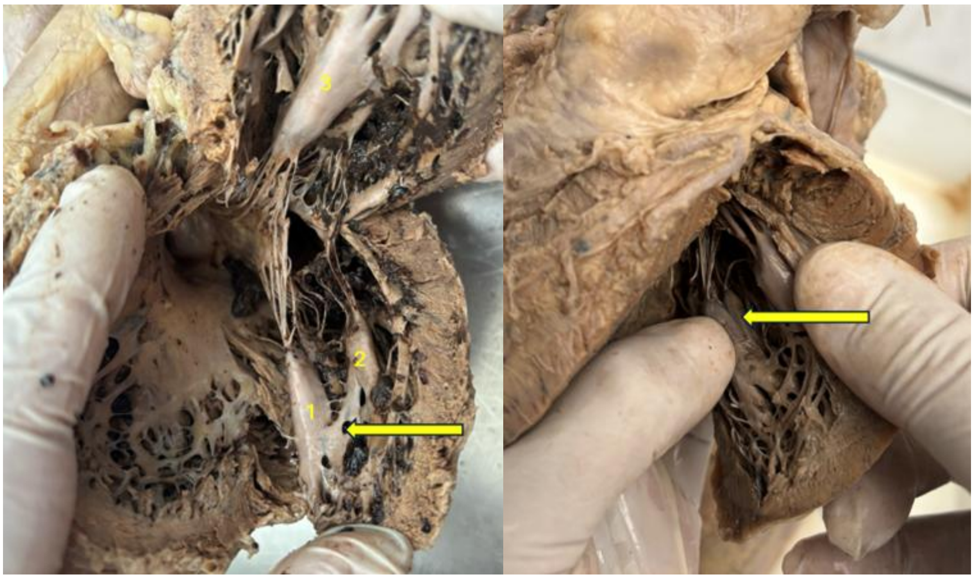

FIG 7,8

FIG 9,10

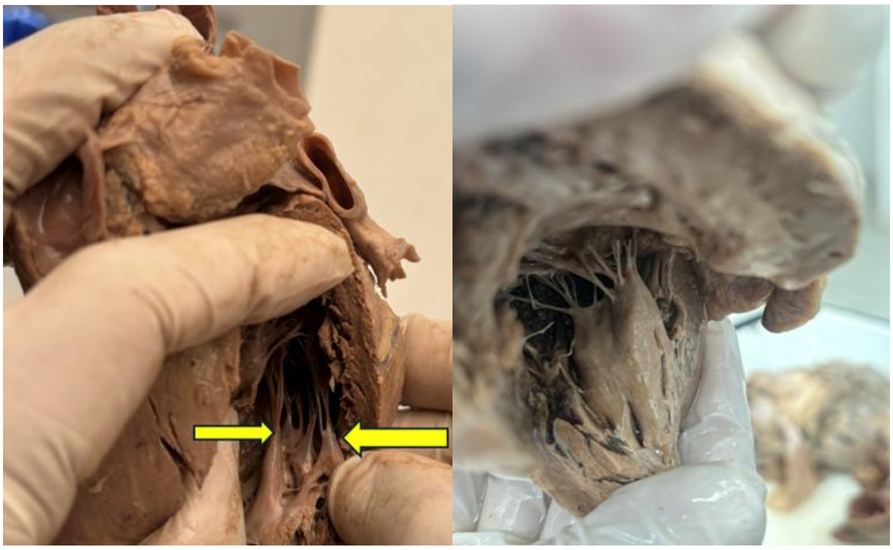

FIG 11,12

FIG 13

IV. Discussion

Classically, Gray's Anatomy describes two papillary muscles in the left ventricle: the superoposterior and the inferoseptal muscles, which may vary in length, breadth, and occasionally present as bifid structures.[1] However, our study demonstrates significant variability in both the number and morphology of papillary muscles. Recent reviews and clinical anatomy studies report wide anatomical and functional variation of papillary muscles, emphasizing their role not only in structural morphology but also in arrhythmogenesis and mitral valve mechanics.[3]

Roberts and Cohen identified the most common congenital anomaly of the left ventricular papillary muscles as the presence of a single papillary muscle. This condition, termed parachute mitral valve, is characterized by the attachment of all mitral chordae tendineae to a solitary papillary muscle. It most commonly results in mitral stenosis, although valvular incompetence or normal function may also occur. The anomaly is frequently associated with additional cardiac defects, including supramitral ring, diffuse subaortic stenosis, and coarctation of the aorta.[5]

Oosthoek et al. described a case in which a third papillary muscle was present alongside the anterolateral and posteromedial muscles. This accessory muscle was attached to the left ventricular lateral wall at a site where myocardial connections normally regress. Its presence in the adult heart likely reflects persistence of embryonic trabecular condensation, a process typical of early cardiac development.[10]

Several cadaveric studies support these observations. Hosapatna et al. reported that among 15 cadaveric hearts, cases of double anterior and posterior papillary muscles were observed. They also noted that left ventricular papillary muscles were significantly longer than those in the right ventricle. In the left ventricle, all papillary muscles were cone-shaped, with the majority of the moderator bands attaching to the lower third of the papillary muscles.[2]

Ballesteros-Acuña et al. examined 82 male autopsy hearts and observed a single anterior papillary muscle in 90.2% of specimens and a single posterior papillary muscle in 58.5%. Truncated apical shapes were the most common for both anterior (50%) and posterior (45.1%) muscles, followed by flat-topped and bifurcated variants.[6]

Gunnal et al. documented wide anatomical variability: among their specimens, classical two-muscle configurations were seen in only 3.44% of hearts, whereas two, three, and four groups were present in 43.11%, 31.90%, and 21.55%, respectively. Shapes varied from conical to broad-apexed, pyramidal, and fan-shaped, while patterns included separate bases with fused apex, bifid apices, long muscles, perforated muscles, and transverse bridges [9]. Ozan et al. observed three distinct groups of left ventricular papillary muscles in 60 cardiac specimens; group I (43.3%)- the basal part and the apex of the muscle were undivided, group II (30%) - two heads, and group III (26.7%)- three heads.[11]

Advanced imaging studies have reinforced the clinical relevance of these variations. Rajiah et al. emphasized the utility of cardiovascular magnetic resonance (CMR) in evaluating papillary muscle morphology and function, noting variations ranging from asymptomatic anomalies to obstructive features in hypertrophic cardiomyopathy. Congenital anomalies such as parachute mitral valve, ischemic dysfunction, papillary muscle rupture post-myocardial infarction, and papillary neoplasms further highlight the importance of detailed morphological assessment.[7,8]

Saha and Roy observed that among 52 specimens, classical two-muscle patterns were present in only 25%, with extra papillary muscles seen in 34.61% and 71.15% in superolateral and inferoseptal group respectively. Shapes and patterns were variable, with conical and truncated forms predominating.[12] Victor and Nayak corroborated these findings in 100 autopsy hearts, documenting multiple bellies and diverse configurations, emphasizing that the fan-like arrangement of chordae is unique to each heart.[13]

Li et al. highlighted the role of multimodal imaging, including echocardiography, CT, and CMR, in assessing both structural and functional aspects of papillary muscles. Their study demonstrated that variations in papillary muscle morphology can influence valve dynamics, risk of mitral regurgitation, and outcomes in surgical planning.[14]

Eötvös et al. investigated the integrated electrical and mechanical dynamics of the left ventricular papillary muscles. They showed that papillary muscle structure can affect both conduction pathways and mechanical synchronization, which has direct implications for arrhythmogenesis, post-infarction complications, and surgical interventions.[3]

Maron et al. highlighted the clinical relevance of papillary muscle variations in two patients with obstructive hypertrophic cardiomyopathy, where anomalous insertion of papillary muscles into the anterior mitral leaflet caused midcavity obstruction.[7]

Another possible cause of severe systolic anterior motion of the mitral valve and left ventricular outflow tract obstruction is the orientation of the papillary muscles and their attachment in relation to the left ventricular outflow tract, according to Bryant R III et al. Up to 20% of individuals receiving surgery for hypertrophic obstructive cardiomyopathy have been found to have mitral valve abnormalities.[15]

In our study, classical papillary muscles (single or common base) were present in 25.9% of specimens. One papillary muscle was observed in 3.7%, three muscles in 25.9%, four muscles in 14.8%, and five muscles in 29.6% of hearts. Conical muscles predominated (51.9%), followed by broad-apexed (37%), pyramidal (22.2%), and fan-shaped (22.2%). Patterns included bifid apices, transverse bridge interconnections (H-shaped), small muscles, perforated muscles, and chordae originating directly from the ventricular wall (Tables 1–3).

Comparative studies reinforce these trends. Hosapatna et al. reported conical shapes as most frequent,[2] while Xalxo et al. found broad-based shapes predominant constituting 55.26% on sternocostal and 44.73% on diaphragmatic surfaces of the left ventricle, respectively.[16] These findings highlight the wide anatomical variability beyond classical descriptions in Gray's Anatomy.[1,11,12] Gunnal et al stated that broad-apex was most common shaped observed in 50.48%, other shaped observed were conical (45.51%), pyramidal (50.48%) and fan-shaped (12.93%).[9] Victor S et al stated that out of 100 human autopsy hearts, conical-shaped was most common shaped observed in 32 specimens in anterolateral group and 12 specimens in posteromedial group.[13]

V. Conclusion

Analyzing the papillary muscle, we have found considerable variations in number, shape, pattern, and position of papillary muscles in the present study. These findings are particularly important for anatomists, as they provide a detailed framework for understanding structural diversity within the left ventricle, informing both teaching and research on cardiac anatomy. For clinicians, including cardiologists and cardiothoracic surgeons, awareness of these variations is critical for accurate interpretation of imaging, planning surgical interventions, and managing valvular dysfunctions such as mitral regurgitation or stenosis. Knowledge of papillary muscle morphology can guide individualized patient care, minimize surgical complications, and improve outcomes in procedures involving the mitral apparatus.

Overall, detailed anatomical and functional understanding of papillary muscles bridges the gap between basic anatomy and clinical practice, reinforcing the need for careful evaluation of cardiac structures in both educational and medical settings.

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