DOI: http://doi.org/10.4038/jmj.v33i2.136

Original Article

Morphological variations and morphometry of the papillary muscles of the mitral valve – a cadaveric study

Sivananthini Udhayakumar [1] **, *Yasawardene S G*** [2]

[1]*Department of Anatomy, Faculty of Medicine, University of Jaffna, Sri Lanka*

[2]*Department of Anatomy, Faculty of Medical Sciences, University of Sri Jayewardenepura, Sri Lanka*

Abstract

Recent advances and refinements in mitral valve surgery as well as interventional procedures have revived the interest in disparity in the morphology and morphometry of papillary muscles of the mitral valve. Study was taken up with an effort to extend the concepts previously presented on papillary muscles of mitral valve.

Papillary muscles were studied in 320 fresh autopsied adult normal hearts. With varying number of muscle bellies.

Anterolateral (ALPM) and posteromedial (PMPM) groups of papillary muscles were found. In two hearts, the ALPM and PMPM were connected by muscle tissue. According to the number of separate muscle bellies, 4 groups were categorized with increasing complexity. Single belly was the commonest form in the ALPM (73 %) and two bellies were the commonest form in the PMPM (40 %). The papillary muscles show a great variability on the nature of attachment to the ventricular wall. More than half of the hearts studied had a mixed type of papillary muscles (partly tethered and partly protruding in ALPM and PMPM groups. The mean distance separating the mitral annulus from the apex of the ALPM was 19.38 mm ± 3 SD (range 5 – 26) and from the apex of the PMPM was 20.36 mm ± 3.7 SD (range 10 – 32). The average length of ALPM was 32.24 mm ± 4.8 SD (range 20 - 45) and that of the PMPM was 29.92 mm ± 4.9 SD (range 16 - 44).

The documented classical view of two papillary muscles should be adapted with 4 types of variations in morphology with increasing complexity.

Key words

Mitral valve, papillary muscle, morphology, morphometry

Background

The mitral valve apparatus consists of valvular leaflets with commissures and subvalvular apparatus. The papillary muscles and the chordae tendinae complex are identified as subvalvular apparatus and they play an integral part in function of the valve by Lam et al. [1] Imaging of subvalvular apparatus, reconstructive procedures and replacement of valve with homograft necessitates a detailed anatomy of this region. Morphology of papillary muscle is described in text book using the simple classification made by as two papillary muscles; anterolateral (ALPM) and posteromedial (PMPM) lying beneath the commissiral regions of the leaflets. [2] This arrangement ensures a chordal attachment to both leaflets from both muscles. [5] Recent works show a spectrum of normality in the morphology of papillary muscles of mitral valve. [3 - 10] Berdajs et al pointed out that mitral valve homograft is not widely used partly due to lack of information about the three-dimensional geometry of the mitral apparatus. This make it clear that thorough understanding of the structure becomes a prerequisite for a successful surgery. Therefore, a study was undertaken to establish a nominal data base of the normal variations in the papillary muscle. [6]

Corresponding author: Nanthini , email-Nanthini@univ.jfn.ac.lk, https://orcid.org/0000-0002-7991-0634,
Submitted June 2021 Accepted November 2021

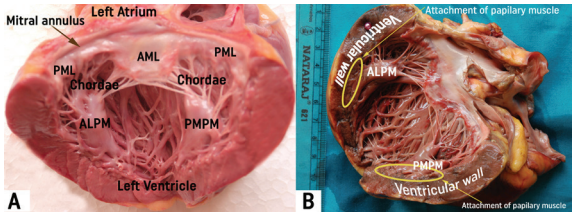
Methods

Three hundred and twenty fresh autopsied healthy adult Sri Lankan hearts were obtained from judicial postmortem office, Colombo. At autopsy, the heart was washed and left atrium was excised just above the left atrioventricular groove to allow visualization of the mitral valve apparatus. Ventriculotomy was done by dividing the posterior leaflet between its two chordopapillary muscles groups to expose the mitral valve complex (adopted the method of Victor and Nayak. [3] Two groups of papillary muscles were studied with regard to the number of bellies in each group, extent of attachment of muscle to the ventricular wall, configuration, relationship between the heads and chordal distribution to the leaflets, greatest length of muscle and distance between the apex of the papillary muscle and the annulus. For measurement Vernier calliper was used. Photographs were taken to substantiate and illustrate the findings. Ethical clearance was obtained from Ethics Review committee, Faculty of Medicine, University of Colombo

Results

Morphological findings

We could distinguish two groups of papillary muscles: anterolateral (ALPM) and posteromedial (PMPM) in all specimens (Fig. 1).

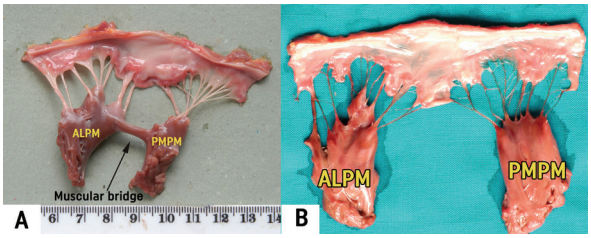


A- Heart having finger like single bellied papillary muscles

B-Heart having equally sessile and equally protruding single bellied papillary muscles

Fig 1 : Opened Mitral valve in situ showing its components

The 2 groups had varied number of muscle bellies (Fig 1 – 5). The muscle bellies within each group were connected by fibrous or muscle tissue (Fig. 3). In two hearts, the ALPM and PMPM were connected by muscle tissue (Fig 2).



A - ALPM & PMPM are connected by muscular ridge

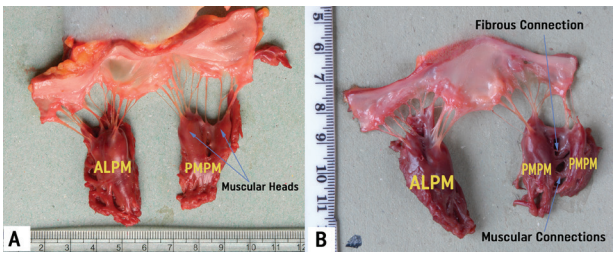
B - Sloping ALPM & Broad apex PMPM

Fig 2 : Group 1- Mitral valve with single bellied papillary muscles

Authors try to classify the papillary muscles considering the number of bellies in a group and relationship between papillary muscle-chordae-leaflet unit. Accordingly, papillary muscles were categorized into four groups. This categorization is a modified form of what described by Ramsheyi et al. [4] and Berdajs et al. [6]

Group 1 : Single bellied muscle (Fig. 1 , 2) gave rice to chordae tendinae which fanned out to the corresponding hemi valve leaflet. Shape of the papillary muscles varied; conical, broad flat topped, sloping apices etc (Fig. 1 -5). In some single bellied muscles the apex of the muscle divided into nipple like projections (Mamillated) (Fig. 3A & 4A**).** Commonly, the chordae to the commissural area arose from the highest point/ summit of the papillary muscle.

Group 2 : Papillary muscles with two separate bellies (Fig. 3B). The 2 bellies were either present in sagittal plane or coronal plane

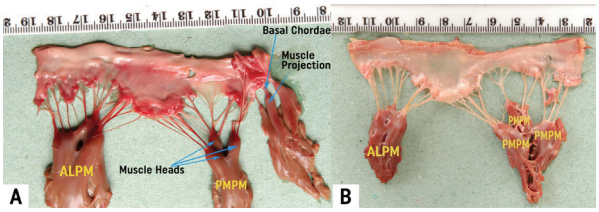


A - Single bellied PMPM with 2 heads

B - 2 bellied PMPM

Fig 3 : Group 2 - Mitral valve with 2 bellied posteromedial papillary muscle

Group 3 : Papillary muscle with three separate muscle bellies (Fig. 4B). In this type one belly gave rise to the chordae of the posterior leaflet, another belly gave rise chordae of the anterior leaflet and the third belly to the commissural region.

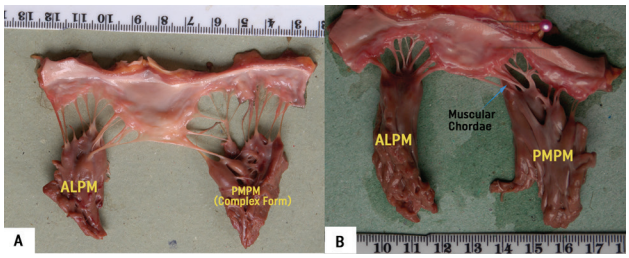


A - Single bellied PMPM with 3 heads, note the basal chordae originating from separate muscle projections from ventricular wall

B – 3 bellied PMPM

Fig 4 : Group 3 - Mitral valve with 3 bellied posteromedial papillary muscle

Group 4 : Complex form of papillary muscle (Fig. 5). In this type there were multiple muscle bellies, chordae from each muscle belly radiated to the leaflets in varied patterns . This made the categorization difficult. In complex form, direct insertion of papillary muscle into the leaflet without an intervening chordae tendinae was noted Fig. 5).



A & B - Note the shape of ALPM

Fig 5 : Group 4 - Mitral valve with complex form of posteromedial papillary muscle

Single belly is the most common form found in the ALPM group (73 %) followed by two bellies (22 %), three bellies (4 %) and complex form (1 %). Two bellies; the most common form found in the PMPM group (40 %) followed by single belly (33 %), three bellies (19 %) and complex form (8 %).

The length of attachment of papillary muscle to ventricular wall varied. In ALPM 69 % of muscles were partly attached to the ventricular wall and partly protruded into ventricular cavity (mixed type) and 26 % were freely protruding finger like papillary muscle and 5 % were completely tethered. In the PMPM group, 60 % of muscles had a mixed type, 32 % were finger like and 8 % were completely tethered muscles.

Measurement of papillary muscle

The mean distance separating the mitral annulus from the apex of the ALPM was 19.38 mm ± 3 SD (range 5 – 26) and from the apex of the PMPM was 20.36 mm ± 3.7 SD (range 10 – 32). The average length of ALPM was 32.24 mm ± 4.8 SD (range 20 - 45) and that of the PMPM was 29.92 mm ± 4.9 SD (range 16 - 44). The thickness and the number of bellies varied, the cumulative girth had a wide variability and the measurements were not included in the study.

Discussion

Morphology papillary muscle

Lam et al devised a simplified description of the papillary muscles and chordae tendinae and introduced a basic nomenclature which has been used since. [2] This classical picture of papillary muscles, ie the presence of two papillary muscles in the ventricle, sometimes bifid PMPM as described in standard textbooks was noted only in few specimens. [1] Study of 116 hearts by Gunnal et al. [8] found this simplest form of papillary muscles in only 4 specimens. Instead groups of papillary muscles were found. This is in accord with the literature. [3 – 10] Ozog et al reported a case of single group papillary muscle. [9] The observation of bases of muscles within a group bridged by muscular and fibrous tissue was already reported. [3, 5] In addition, the present study reports intergroup muscular bridge in 2 hearts. In any form of papillary muscle, the chordae distribute from a papillary muscle group to the corresponding hemi

half of both mitral leaflets. [3 – 10] Therefore, rupture of a papillary muscle group, following infarction of the adjoining ventricular wall, will lead to heavy regurgitation as the half of the support of each leaflet is lost. [10]

There is considerable variation in the morphology of papillary muscle. Victor and Nayak presented a classification of 100 cases of papillary muscles in self-explanatory figurative language as conical, mammillated, flat topped, grooved, wavy, stepped etc. [3] They stated that such variation in morphology can be explained by embryological development; papillary muscles develop from trabecular myocardial ridges by a process of delamination. Aberrations in this process would lead to diversity in morphology. They also added that mitral valve apparatus is the unique to each individual as one's own fingerprint.

Ramsheyi et al, in their presentation of the left ventricular subvalvular apparatus, defined four groups of morphological variants and included the relationship between the apical portion of the papillary muscle and the chordal distribution to the mitral valve leaflets. [4] Berdajs et al adopted a modified form of the above classification, including the basal attachment of the papillary muscle and divided the papillary muscles into three groups. [6] Gunnal et al, in his study classified the papillary muscles as classical papillary muscle where the muscle has single base and apex; multiapical or multibellied where the papillary muscle had single base and divided apex; multi-segmental or groups of papillary muscle, where papillary muscle with separate bases. [8] Therefore classification of papillary muscles is highly variable and subjective.

Our findings show that ALPM group consists of a single muscle belly in the majority (73%). This finding accords with the recent reports; Ozog et al - 75.8 % & Vadlamani & Awari – single belly 22 % & single belly with 2 muscles heads – 24 %. Current study showed majority of the PMPM consists of two bellies (40 %). Study of Vadlamani & Awari showed similar result (38 %). But Ozog reported single (38.4 %) and two bellies (36.4 %) are common in PMPM. [9,10] Ozan et al analysed the morphology of papillary muscles in 120 cadaveric hearts and classified the muscles in to three groups with increasing complexity. [7]

Victor & Nayak pointed out; the variations in papillary muscle morphology would influence the pathophysiological effects of various cardiac disorders. [3] Shape of the muscle influence the passage of blood flow. [8, 10] Conical shape of muscles facilitate smooth cardiovascular physiology. [10] Chances of left ventricular outflow tract obstruction is higher in muscles with broad apex, increase in number and size. [8, 10] On the other hand, if there are only two papillary muscle in the ventricle, an ischemic event affecting one papillary muscle will lead to severe valve impairment than heart with multiple bellies. [8]

Morphological variation of papillary muscles has a tremendous effect on selection of homograft on replacement of valve with homograft. [4, 13] In homograft replacement, single headed muscles are easy to handle & Implanting a total homograft in multiheaded ones the respective position of different portions of the papillary muscle must be maintained in order to obtain an even distribution of traction on the leaflet tissue. [3, 4, 13] Therefore in tissue bank ID card, homograft can be labeled according to its morphology. The ones which are difficult to handle could be discarded.

Victor & Nayak pointed out in the mitral valve replacement with artificial valve, retention of chordopapillary support is being favoured to preserve the optimum function of the left ventricle. [3] If the native valve has too many papillary muscle

bellies, these may interfere with the function of prosthetic disc or ball, especially if they are of the intraluminal type.

Muscularization of chordae were observed in 3 % of the hearts, similar to the finding reported in the literature. [2, 3, 8, 9,11] Anomalous insertion of papillary muscle directly into anterior mitral leaflet may lead to midventricular obstruction. [8]

Our findings show mixed type (partly tethered and partly protruding) is the common form of papillary muscle attachment to the ventricular wall in both ALPM and PMPM groups. Ranganathan & Burch pointed out, arterial supply to the muscle depend on the nature of muscle attachment to the ventricular wall. [12] They explained that freely protruding finger like papillary muscle have very few or no anastomotic connections with the extra papillary subendocardial plexus. On the other hand, the tethered variety of papillary muscles has a segmental distribution of the long penetrating intramyocardial vessels.These branches make connections with one another and with the extra papillary subendocardial plexus. This helps to perfuse the papillary muscles even in the presence of occlusion or narrowing of the larger epicardial feeder vessel.

Measurements of papillary muscle

In our study, we report the shortest distance between the papillary muscle and mitral valve annulus; 19.38 ± 3 mm (range 5-26) for the ALPM group and 20.36 ± 3.7 mm (range 10-32) for PMPM group. The respective values reported by Ramsheyi et al. [4] are 20 ± 3 mm (range 15 – 27 mm) and 25 ± 3 mm (range 20 – 31 mm) and by Acar et al. [13] are 21 ± 3 mm & 26 ± 4 mm. The results show the distance is shorter between ALPM and annulus than that between PMPM and mitral annulus. Sri Lankan values are comparatively lower than the values of Caucasians. These measurements are useful in homograft replacement. In this procedure, the placement of the donor papillary muscle in the recipient heart needs to be tailored, ensuring even distribution of traction on the leaflet tissue and optimum fanning out of chordae, to ensure its systolic and diastolic function. [3. 4, 13]

The average length of ALPM in the present study is 32.24 mm ± 4.8 SD (range 20 - 45) and that of the PMPM is 29.92 mm ± 4.9 SD (range 16 - 44). It shows ALPM are langer than the PMPM. The average length of ALPM & PMPM reported by Vadlamani & Awari [10] is 22.85 mm & 22.43 mm respectively

In conclusion, the present study has found considerable variations in the number, shape, attachment to ventricular wall and dimensions and position of the papillary muscles. The findings would be of great value during endoscopic and conventional mitral valve replacement and in mitral valve homograft implantation

Acknowledgement

We thank the staff of department of Anatomy, University of Colombo for their valuable technical assistance

References

1. Sinnatamby. “Last’s anatomy: regional and applied, 12th edition, 2013.
2. Lam JHC, Ranganathan N, Wigle ED, Silver MD. Morphology of the human mitral valve I – Chordae tendineae: A new classification. Circulation 1970; XLI : 449-58
3. Victor S Nayak VM. Variations of the papillary muscles of the normal mitral valve and their surgical relevance, J card surg, 1995; 10 (5) : 597-607.
4. Ramsheyi SA, Pargaonkar S, Lassau JP, Acar C. Morphologic classification of the mitral papillary muscles. J Heart Valve Dis, 1996; 5: 472-76.

5. Ho SY. Anatomy of the mitral valve. Heart 2002; 88 : 5 - 10

6. Berdajs D, Lajos P, Turina MI. A new classification of the mitral papillary muscle. Med Sci Monit, 2005; 11 (1): 18-21.

7. Ozan H, Kocabiyik N, Demirel B, Yalcin B, Comert A. Pattern of connection between papillary muscle and chordae of left ventricle. Gulhane Med J 2012 doi: 10.5455.

8. Gunnal SA, Wabale RN, Farooqui MS. Morphological variations of papillary muscles in the mitral valve complex in human cadaveric hearts. Singapore Med J 2013; 54(1): 44-48

9. Ozog AK, Holda MK et al. Anatomy of the mitral subvalvular apparatus. The Journal of thoracic and cardiovascular surgery 2018; 155 (5) : 2002 - 10

10. Vadlamani PC, Awari PS. Disparity in morphology of papillary muscles of the mitral value complex with surgical significance. Int J Anat Res 2020; 8 (1.2) : 7294-99

11. Khanna SK, Talwar JK, Gobinath N and Chandra J. Morphology of mitral valve. Indian Heart Journal 1976; 28 (1) : 46 – 51.

12. Ranganathan N and Burch GE. Gross morphology and arterial supply of the papillary muscles of the left ventricle of man. American Heart Journal 1969; 77 (4) : 506 – 16.

13. Acar C, Tolan M, Berrebi A at al. Surgery for acquired heart disease. Homograft replacement of the mitral valve. Graft selection, technique of implantation and results in forty-three patients. The Journal of Thoracic and Cardiovascular Surgery 1996; 3 (2) : 367 -80