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Original Research Article

A Study of Morphology and Histomorphometry of Adult Human Papillary Muscles- A Prospective Study

Preetam Pratyush Dash[1], Jami Sagar Prusti[2], Manoj Kumar Naik[3], Sulata Choudhury[4]

[1]Postgraduate, Department of Anatomy, M.K.C.G. Medical College, Berhampur, Ganjam, Odisha, India.
[2] Professor and Head, Department of Anatomy, M.K.C.G. Medical College, Berhampur, Ganjam, Odisha, India.
[3]Associate Professor, Department of Anatomy, M.K.C.G. Medical College, Berhampur, Ganjam, Odisha, India.
[4]Associate Professor, Department of Pathology, M.K.C.G. Medical College, Berhampur, Ganjam, Odisha, India.

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Corresponding author: Dr. Sulata Choudhury
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Abstract

Background: Historical documentation of the existence of papillary muscles as a component of cardiac anatomy exists at least as early as 16th century. They are pillar-like muscles seen within the ventricles attached to their walls. They have an integral role in proper cardiac valvular function. They are attached to mitral and tricuspid valve via chordae tendineae. The present study was done to analyse the papillary muscles of heart with respect to the variations in their number, length, shape, position and pattern in both ventricles.

Aims and Objectives:

1. The objective of this study is to analyse morphological and histomorphometric features of papillary muscles in both ventricles of human heart.
2. Number of chordal attachments in each Papillary muscle and also the attachments of chordae to mitral and tricuspid annulus.

Materials & Methods: The study was carried out on 60 human cadaveric hearts from Anatomy and Forensic Medicine Department of M.K.C.G. Medical College, Berhampur, after obtaining necessary clearance from institutional ethical committee. The morphometric and histomorphometric variations of the papillary muscles of both right and left ventricles were categorized and documented.

Results: In the present study, the variations in number of papillary muscles were up to five(5) bellies. Increased number of bellies were found more in anterior papillary muscles of left ventricle. The shape of anterior papillary muscles in both ventricles was predominantly conical and posterior papillary muscles was predominantly cylindrical. The mean length of posterior papillary muscle of left ventricle was 18.73±3.8 mm, which was longer than that of papillary muscle of right ventricle. The breadth of anterior papillary muscle of left ventricle was 4.32±1.35 mm, which was more than all papillary muscles. In the present study, number of chordae tendineae attached to anterior papillary muscles were more than posterior papillary muscles in both ventricles. Histomorphometric findings of left posterior papillary myocyte mean length marginally higher than that of the remaining papillary myocyte

Conclusion: These results may be of great value in endoscopic and conventional mitral valve replacement or reconstruction of the chordae tendineae and the valvular homograft

implantation. Thus, different architectural patterns of papillary muscles will be helpful for cardiac surgeons, which is necessary for successful cadaveric heart valve replacement surgeries.

Keywords: Papillary muscle bellies, ventricles, chordae tendineae, morphometric, reconstruction.

Introduction

The History of existence of papillary muscles as an integral part of cardiac anatomy is evident from 16th century[1]. The cavity of the ventricles contain the papillary muscles which are pillar like muscular structures attached to the walls of the ventricles, mitral and tricuspid valve leaflets via chordae tendineaelike the shrouds of a parachute. In right and left ventricles, the number of papillary muscles is three and two respectively. The two major papillary muscles in the right ventricle are situated in anterior and posterior aspect. A third smaller septal muscle present in medial position[2]. The apical areas and the papillary muscles are the first regions of each ventricle to undergo contraction. The atrioventricular valve leaflets are therefore initially drawn into the ventricle by the chordae tendineae due to the shortening of papillary muscles. The function of the atrioventricular valve is dependent on the precise interaction of cusps, chordae, ventricular base, and ventricular wall[3]. This arrangement prevents prolapse as well as the inversion of the cusps of the mitral and tricuspid valves[4]. Morphological alterations in these muscles and loss of contractility as in myocardial infarction with muscle fibrosis or ischemia can result in malformation of these valves leading to regurgitation[5,6].

Due to affluent lifestyle, heart disease has become an important cause of death and valvular diseases contribute significantly to increasing morbidity and mortality. Artificial and Cadaveric valves are used in replacement surgeries of cardiac valves. For fixation of cadaveric heart valve, the operating surgeon should be well versed in both the dimension and architecture of both valves of heart[7,8]. With this view, the present work will be undertaken to observe the dimensions of both valves, papillary muscles, and number of chordal attachments in papillary muscles of both ventricles.

Objectives

The human heart specimens were analyzed for morphology and morphometric variations of papillary muscles in both ventricles regarding location, number, length, breadth and bellies. Also, these specimens were observed for number of chordal attachments in each Papillary muscle with attachments of chordae to mitral and tricuspid annulus and to measure the Circumference Mitral Annulus Diameter (CMAD). Histomorphometric features of papillary muscles in both ventricles were analyzed.

Materials and Methods

The present study was carried out on sixty adult human heart specimens irrespective of age and sex after obtaining necessary clearances from the Institutional Review Board and Institutional Ethical Committee of M.K.C.G Medical College, Berhampur, Odisha in the department of Anatomy, F.M.T and Pathology during the period from November 2020 - May 2022. The collected heart specimens were immersed in the preservative 10% formalin solution containing (10 litres of normal saline with 1 litre of formaldehyde and 50 ml of glycerine and 5 gms. of powdered thymol were added). The parameters of the study

were to count the number of papillary muscles in both ventricles, variations of number of each papillary muscle bellies, shape of papillary muscles, tip of papillary muscles, length and breadth of papillary muscles and chordae tendineae, circumference of mitral valve annulus. The dissection procedure was followed by Cunningham manual[9] with the help of digital vernier calliper, dissecting instruments, and hand lens. The tissue to be evaluated for histological study will be processed in automatic tissue processor. Paraffin blocks will be cut into 3-4 micrometers section and stained with Haematoxylin & Eosin[10]. Histomorphometric study of cardiac myocyte will be measured under microscope using Motic Images Plus 2.0 software.

The hearts were opened with 1st incision made on the right ventricle 2 cms from anterior interventricular sulcus approximately to its right. Then incision was made parallel to the interventricular septum. The 2nd incision was made from the coronary sulcus parallel to the atrioventricular groove. Dissection of left ventricles were carried by incision on diaphragmatic surface along the posterior interventricular sulcus. Subsequently the incision was given parallel to the left atrioventricular groove. The flaps were reflected laterally to observe the internal anatomy. The blood clots were removed, and the chambers washed clearly with water in order to accurately visualise the papillary muscles. The variation in number, position, length, pattern and shape of the papillary muscles were noted. The digital Vernier calliper (Mitutoyo) with 0.02 mm precision was used to measure the length of the papillary muscle (from tip to the basal attachment). With careful observation, the number of bellies in papillary muscle were documented. The shape of papillary muscles was classified as conical, broad-based and cylindrical. Similarly, the tip of the muscles was classified as undivided, bifid and trifid. In both left and right ventricles, the variation of the papillary muscles was observed and divided into separate base & fused apex, single base and divided apex, small projections of papillary muscles, long papillary muscles, perforated papillary muscles and base attached to a large bridge (Figures 1, 2, 3). The values of the length of papillary muscles of both ventricles of cadaveric heart specimens were presented as Mean± S.D and p value were calculated by comparing the length between two ventricles using paired t-test. P-value < 0.05 were considered as statistically significant. Graph-Pad Prism 7.0 was used for statistical analysis.

Results

The number of the papillary muscles found in the present study were highly variable. The classical picture of the papillary muscles in both left and right ventricle were found in 43 cases(71.6%) of this specimen. In right ventricle, majority of papillary muscles with 3 bellies seen in 43 cases (71.6%) followed by 4 bellies in 11 cases (18.4%), 2 bellies in 4 cases (6.6%) and 5 bellies in 2 cases (3.5%) [Fig. 1]. Similarly, in left ventricle, maximum papillary muscles showed 2 bellies in 43 cases (71.6%) [fig. 2] and minimum with 5 bellies in 2 cases (3.5%). [Table 1]

In the present study, varied shapes of papillary muscles were noticed. In right ventricle, anterolateral papillary muscles were conical in 80% and cylindrical in 20%, posteromedial papillary muscles were conical in 10% and cylindrical in 90% and septal papillary muscles were conical in all the specimens. In left ventricle, anterolateral papillary muscles were conical in all specimens and posteromedial papillary muscles were conical in 10%, cylindrical in 60%, pyramidal in 15% and broad apex in 15%.

In the present study, the tip of right anterior papillary muscle was undivided in 72%, bifid in 23% and trifid in 5% of the cases [Fig. 3]. In the tips of right posterior papillary muscle, it was undivided in 5%,

bifid in 42% and trifid in 53% of the heart specimens. In the septal papillary muscle, the tips were undivided in 83% and bifid in 17%.

Similarly, the tip of left anterior papillary muscle was undivided in 5%, bifid in 77% and trifid in 18% of the cases. In the tips of left posterior papillary muscle, it was bifid in 72% and trifid in 28% of the heart specimens.

In the present study, most of the right anterior papillary muscles originated below anteroposterior commissure in 43 cases (71.6%), right posterior papillary muscles mostly originated below posteroseptal commissure in 37 cases (61.6%), & septal papillary muscles mostly below anteroseptal commissure in 43 cases (71.6%). Similarly, most of the left posterior papillary muscles took origin from diaphragmatic wall (76.7%) &left anterior papillary muscles from sternocostal wall (78.3%)

In the present study, the length of right anterolateral papillary muscle ranged from 9.42mm to 24.48 mm with a mean of 15.55 ± 3.15mm [Fig. 4] and breadth ranged from 1.48 mm to 8.42 mm with a mean of 4.99 ± 1.31 mm. In right posteromedial papillary muscle, length ranged from 7.15mm to 23.92 mm with a mean of 15.45± 2.94mm and breadth ranged from 2.12 mm to 9.48 mm with a mean of 5.04 ± 1.57 mm. The length of septal papillary muscle ranged from 4.18mm to 14.32 mm with a mean of 9.97± 1.96mm and breadth ranged from 1.12mm to 3.12mm with a mean of 2.46 mm ± 0.42mm. Length of the left anterolateral papillary muscle ranged from 8.32mm to 25.84 mm with a mean of 17.14 ± 3.25 mm and breadth ranged from 2.32mm to 10.12mm with a mean of 6.03 ± 1.79mm.The left posteromedial papillary muscle length ranged from 9.15mm to 26.32 mm with a mean of 18.9 ± 3.91 mm and breadth ranged from 2.22 mm to 9.88mm with a mean of 5.63 ± 1.41mm. (Table 2)

In the present study, the length of chordae tendineae attached to right anterolateral papillary muscle ranged from 4.32 to 11.32 mm with a mean of 8.12 ± 1.54 mm and breadth of chordae tendineae ranged from 0.12mm to 0.66mm with a mean of 0.44 ± 0.13mm , those attached to right posteromedial papillary muscle length ranged from 9.72mm to 17.39 mm with a mean of 12.6± 1.42 mm and breadth of chordae tendineae ranged from 0.14mm to 0.67mm with a mean of 0.45 ± 0.09 mm, those attached to septal papillary muscle length ranged from 7.42mm to 16.81mm with a mean of 11.60 ± 1.61mmand breadth of chordae tendineae ranged from 0.04 mm to 0.58 mm with a mean of 0.43 ± 0.11mm. Length of chordae tendineae attached to left anterolateral papillary muscle ranged from 8.22mm to 22.15mm with a mean of 13.42 ± 3.18 mm and breadth of chordae tendineae ranged from 0.12mm to 0.61mm with a mean of 0.42±0.08mm,those attached to left posteromedial papillary muscle length ranged from 8.58mm to 21.08mm with a mean of 15.82 ± 2.92 mm and breadth of chordae tendineae ranged from 0.16 mm to 0.64 mm with a mean of 0.41 ± 0.07 mm. (Table 3)

In the present study, left ventricle mitral annulus transverse diameter ranged from 13.21mm to 24.22 mm with a mean of 20.76 ± 2.28 mm. Similarly, vertical diameter ranged from 10.42mm to 17.83mm with a mean of 14.94 ± 1.25mm and circumference mitral annulus diameter was 17.85 ± 1.77 mm.

In the present study the length of left anterior papillary myocyte ranged from 22.41 to 41.87µm with a mean of 32.14±3.12 µm and length of left posterior papillary myocyte ranged from 20.14 to 57.28 µm with a mean of 38.71±4.31µm. It has been found that the mean length of left posterior papillary myocyte was higher than all other papillary myocytes (Table 4). In cardiac muscle fibers, the nucleus was characteristically oval and centrally placed.

Other features like branching, striations and intercalated discs were also seen [Fig. 5].

Table 1: Number of Bellies of the Papillary Muscle of Both Ventricles

N= 60 hearts	Papillary muscle of right ventricle (%)	Papillary muscle of left ventricle (%)
2 bellies	(N=4) 6.6%	(N=43) 71.6%
3 bellies	(N=43) 71.6%	(N=8) 13.3%
4 bellies	(N=11) 18.4%	(N=7) 11.6%
5 bellies	(N=2) 3.4%	(N=2) 3.5%

Table 2: (Length and Breadth of Papillary Muscles of Both Ventricles)

	RAPM		RPPM		SPM		LAPM		LPPM	
	Length in mm	Breadth in mm	Length in mm	Breadth in mm	Length in mm	Breadth in mm	Length in mm	Breadth in mm	Length in mm	Breadth in mm
Mean ± S.D	15.55± 3.15	4.99± 1.31	15.45± 2.94	5.04± 1.57	9.97± 1.95	2.46± 0.42	17.14± 3.25	6.03± 1.79	18.9± 3.91	5.63± 1.41
Range	9.42-24.48	1.48-8.42	7.15-23.92	2.12-9.48	4.18-14.32	1.12-3.12	8.32-25.84	2.32-10.12	9.15-26.32	2.22-9.88

Table 3: (Length and Breadth of Chordae Tendineae of Both Ventricles)

	Chordae attached to RAPM		Chordae attached to RPPM		Chordae attached to SPM		Chordae attached to LAPM		Chordae attached to LPPM	
	Length in mm	Breadth in mm	Length in mm	Breadth in mm	Length in mm	Breadth in mm	Length in mm	Breadth in mm	Length in mm	Breadth in mm
Mean ± S.D	8.12± 1.54	0.44± 0.13	12.6± 1.42	0.45± 0.09	11.60± 1.61	0.43± 0.11	13.42± 3.18	0.42± 0.08	15.82± 2.92	0.41± 0.07
Range	4.32-11.32	0.12-0.66	9.72-17.39	0.14-0.67	7.42-16.81	0.04-0.58	8.22-22.15	0.12-0.61	8.58-21.08	0.16-0.64

Table 4: Histomorphometric Study: Length of Papillary Myocyte of Both Ventricles

N=60	RIGHT VENTRICLE PAPILLARY MYOCYTE (µm)			LEFT VENTRICLE PAPILLARY MYOCYTE (µm)	
	Anterior	Posterior	Septal	Anterior	Posterior
Mean ± S.D	28.32±3.91	22.61 ± 3.23	31.12 ± 3.51	32.14±3.12	38.71±4.31
Range	13.04-43.6	12.18-33.04	18.8-43.44	22.41-41.87	20.14-57.28

Table 5: Comparison of the Lengths of Papillary Muscles Cited from Previous Studies

Sl. No	Author/ Year / Race	Country	No. of heart studied	Right ventricle papillary muscle length (mm)			Left ventricle papillary muscle (mm)	
				RAPM	RPPM	SEPTAL	LAPM	LPPM
1.	Gerola / 2001/ Hispanic	Brazil	50	9±2	-	-	-	-

2.	Nigri / 2001/ Hispanic	Boston (USA)	79	19.16	11.53	5.59	-	-
3.	Harsha / 2014 / Asian	South India	96	14.9±4.0	-	-	-	-
4.	Hosapatna / 2014 / Asian	South India	15	13±4.0	9.8±4.0	5.5±2.0	16.3±0.5	21.4±0.6
5.	S.Kavitha / 2015 / Asian	South India	125	14.89±4.19	14.86±4.05	10.27±3.28	18.80±3.97	18.89±4.28
6.	Present study/ 2022/ Asian	South India	60	15.55±3.15	15.45±2.94	9.97±1.95	17.14±3.25	18.90±3.91

Table 6: Comparison of the Circumference Mitral Annulus Diameter with Previous Studies

Sl. no	Author/Year	Race	Country	CMAD (mm)
1.	Rusted / 1952	North American	Canada	25.01±2.1
2.	Sakai / 1999	Japanese	Japan	29.7±3.5
3.	Gunnal / 2011	South Asian	India	22.2±5.01
4.	S.Kavitha / 2015	South Asian	India	17.3±3.11
5.	Present study/ 2022	South Asian	India	17.85±1.77

Figure 1: Photograph of Interior of Right ventricle showing 5 bellies out of which one anterior papillary muscle which is Cylindrical in shape having tip undivided, two posterior papillary muscles which is cylindrical in shape having tip undivided and two septal papillary muscles which is conical in shape having tip undivided.

Figure 2: Photograph of interior of left ventricle showing two bellies of papillary muscles having Bifid tips.

Figure 3: Photograph of interior of right ventricle showing Anterior papillary muscle which is cylindrical in shape and having Trifid tips.

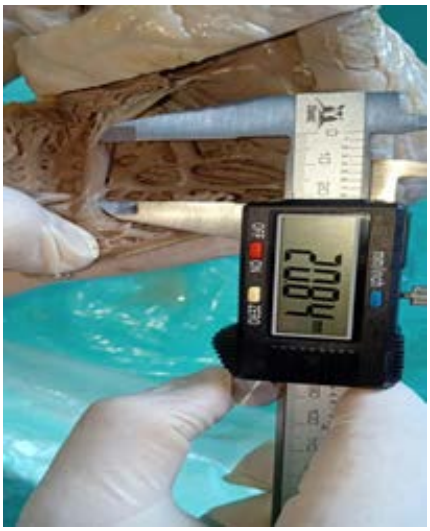

Figure 4: Measurement of length of ventricular papillary muscles by digital vernier callipers.

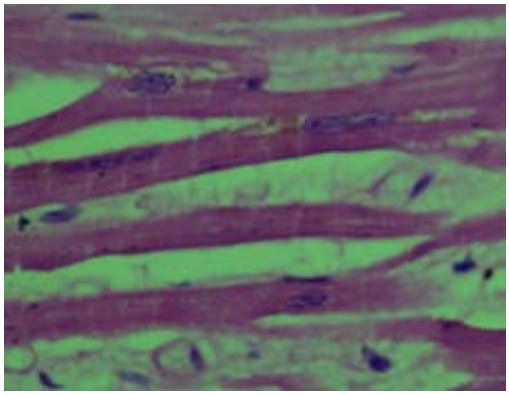

Figure 5: Histology of papillary myocyte with H&E stain (40 X) showing nucleus, muscle fibre and intercalated disc.

Discussion

Aktas et al., (2004) stated that the number of bellies of papillary muscles in the right ventricle may vary from a minimum of two bellies to a maximum of nine bellies. They found that in some of the cases the frequent cause of cardiac death was found to be one

headed anterior papillary muscle. Due to the morphological variations and rupture of papillary muscle are caused by atrioventricular deformity like tricuspid and mitral regurgitation due to defective or improper valve closure. One of the papillary muscles may rupture and, in such circumstances, surgical procedure for papillary muscle repositioning would be necessary, when the data on the morphology of the papillary muscle will be of use[11]. In our study, five bellies of papillary muscles were observed in both ventricles.

According Joudinaud et al., (2006) have proposed the functional terminology for the tricuspid valve: the papillary muscles can be grouped according to the distribution of their cords to a definite commissure and its contiguous main leaflets. Therefore, the anterior papillary muscle becomes the anteroposterior, the posterior papillary muscle the posteroseptal and the septal papillary muscle the anteroseptal papillary muscle respectively[12].

In present study right anterior, Septal &left anterior papillary muscles were mostly conical, followed by cylindrical in right posterior papillary muscle & left anterior papillary muscles. Hosapatna et al; (2014) has reported majority shape of papillary muscles in the right ventricle were found to be cone shaped followed by flat topped papillary muscles. In the left ventricle all the anterior, posterior papillary muscles were cone shaped which is similar to our present study[13]. Similar findings were also observed by Gunnal et al., (2013)[14].

In right ventricle, tip of right anterior papillary muscle (72%) & Septal (83%) were mostly undivided, whereas, in left ventricular papillary muscles were found to be bifid. Begum et al; (2006) have observed that the tip of anterior papillary muscle of the right ventricle was undivided in 92% of the cases[15]. The septal papillary muscle tips were undivided in 46% cases. But Loukas et al., (2001) observed that in the septal papillary muscle, the tip was undivided in 51.8%[16].

Harsha et al., (2014) observed that the right anterior papillary muscle, which was largest, found attached to the anterior aspect of the right ventricle wall with chordae tendineae inserted to the posterior and anterior cusps of the tricuspid valve. Two or more parts of the right posterior papillary muscle was attached to the inferior wall of the right ventricle with chordae inserted to the posterior and septal cusps, and a variable group of small septal papillary muscles which was attached to the interventricular septum with chordae inserted to the anterior and septal cusps[17]. Similar observations were also seen in our study.

Kavitha S. et al (2018) also observed that the left anterior papillary muscle took origin from sternocostal mural in 82% and from the diaphragmatic wall in 18% cases. In 90% cases of left posterior papillary muscles took origin from diaphragmatic wall and in 10% cases from sternocostal wall[18]. Similar findings were also seen in the present study.

Comparison of the papillary muscle length of the present study with the previous studies is given in the (Table 5). While comparing the length of left and right papillary muscles the left posteromedial papillary muscle was found to be longer than all the other papillary muscles, which is similar to Hosapatna et al. (2014)[13] and Kavitha et al. (2015)[18]. So, the left papillary muscle length was statistically significantly longer in paired-t test.

In the present study, breadth of left anterolateral papillary muscle was higher than all other papillary muscles in both ventricles. Similar findings also observed in Kavitha et al. (2015) [18].

In the present study, the chordal length of left posterior papillary muscle was higher than the remaining papillary muscles of both ventricles, the chordal breadth of right posterior papillary muscles was marginally

higher than the remaining papillary muscles, which is similar to the study of Kavitha et al. (2015) [18].

In the present study, transverse diameter of mitral annulus ranged from 13.21mm to 24.22mm with a mean of 20.76 ± 2.28 mm and vertical diameter ranged from 10.42mm to 17.83mm with a mean of 14.94 ± 1.25mm. Hence, the circumference mitral annulus diameter (CMAD) was 17.85±1.77mm, which was compared with previous studies (Table 6). The mitral annulus diameter in our study was similar to S.Kavitha et al (2015) but was found to be less when compared with other studies, which were predominantly done on western and eastern population[19,20,21].

The normal human heart papillary myocyte size measured histologically is clinically very important because the myocyte structures differ in many disease conditions particularly hypertrophic cardiomyopathy[22,23].

Conclusion

Detailed knowledge of normal & variable anatomy of papillary muscles is not only necessary for better understanding of valvular pathologies, but also valuable for successful newer surgical approaches in cardiac treatment. These data will be helpful & relevant for cardiac surgeons performing valvular homograft implantation procedures. Papillary muscles serve an important landmark for the surgeons to reach the commissures. The shape of papillary muscle affects the passage of blood flow. The papillary muscles that best facilitates cardiovascular physiology by posing minimum obstruction to blood flow is conical shaped, broad based attached to the ventricular wall away from the center of cavity. So papillary muscles realignment& repositioning is the treatment of choice for symptomatic left ventricular tract obstruction. The variations in papillary muscles &chordae arising from these would influence the pathophysiological effects of various disorders. During surgery, the chordae can be studied by traction on the concerned papillary muscles. Finally, the appropriate diameter of mitral annulus was measured which is useful for determination of the size of the ring [Circumference= (transverse diameter + vertical diameter)/2] which serves as a guideline during annuloplasty procedure. The knowledge regarding microanatomical and morphological observations of papillary muscle with their variation presented here may help the cardiothoracic surgeons during surgical procedures carried out for correction of valvular defects. Current concepts of replacing the entire heart with cadaveric hearts instead of artificial heart valve replacement are more popular nowadays. So, normal anatomy and function of heart valves and papillary muscles have to be known meticulously before doing a heart replacement procedure

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