Inter-Basal and Septal Connections of Papillary Muscles - An Anatomical Rationale for Rhythmic Opening of AV Valves - A Multicentric Medical College Based Cross Sectional Study

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ABSTRACT

BACKGROUND

The papillary muscle basal connections have significant clinical implications. Variety of studies done on its morphology and function by various specialists in different departments. A close look on these revealed the interconnections of papillary muscles to one another and to the interventricular septum of both ventricles is related to uncoordinated contractions of papillary muscles, leading to hyper or hypokinesia or prolapse or even its rupture.

METHODS

Our study done in 25 formalin soaked hearts revealed after the deep and meticulous dissection, reflecting the walls of ventricles laterally the numerous interconnections of papillary muscles at its bases and IVS. Ventricles are opened by inverted 'L' shaped incision and its reflected more laterally till all the papillary muscles is visible in one frame after incising the moderator band. The connections were noted, measured, photographed, tabulated, compared with similar studies and analysed with experts with respective fields.

RESULTS

Almost all the specimens did have the interconnections. Further the post mortem findings of the cardiac related deaths with involvement of papillary muscles suggest damage to such 'bridges'. The moderator band extensions to the base of right APM, and its extension to the posterior groups is noted in all the specimens. The bridge from the IVS to bases of both the groups of papillary muscles is noted in left ventricle. In90% of specimens the one PPM is found to be loosely connected, more so in left ventricle.

CONCLUSIONS

We are of a conclusion that such basal interconnections and to the interventricular septum are responsible for rhythmic contractions of papillary muscles of both ventricles. Since the AV valves have to open simultaneously, interconnections becomes mandatory as the impulse has to reach it before it reaches the trabeculae carniae. One of the Posterior papillary muscles is loosely connected to other papillary muscles, may be the reason for its rupture, more so in left ventricle.

KEYWORDS

Papillary Muscle, Interbasal Connection, Moderator Band, Valvular Prolapse, AV Valves

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BACKGROUND

Papillary muscles morphologies were studied worldwide by anatomists. Its length, breadth, numbers and all morphological variations were studied in detail. The inter-papillary basal connections were noted in anterior and posterior groups of papillary muscles. The papillary muscles contracts fractions of seconds earlier than the atrial systole or the ventricular diastole begins.[1]

The initial contraction occurs in papillary muscles as shown in animal studies.[2] The conduction impulse pass via sino atrial node to atrioventricular node then via bundle of His branch into right and left branches, further disposed into Purkinje fibres. Its proved that the Purkinje network runs subendocardinally, in trabecular carniae.[3] The moderator band connecting interventricular septum to base of the anterior papillary muscles in right ventricle contains the right bundle branch.[4] The depolarization wave reaches the base of the papillary muscles from the inter ventricular septum via the septomarginal ridges to both ventricles and myocardium, more precisely via moderator band in right ventricle. It is proved that the moderator band contains Purkinje cells and associated with normal rhythm and has a role in arrthmias.[5] The disturbance in blood supply due to ischemia or any other pathological reasons affecting the basal connection can affect the rhythmicity of the heart. The individual papillary muscles can cause specific arrhythmias.[6] Papillary muscle dysfunction or rupture is a rare but catastrophic consequence of acute myocardial infarction; the posterior papillary muscle is involved in about 75 % of cases and the anterior in about 25 %. However, despite extensive anatomic and clinical studies on papillary muscle vasculature since 1885, the reason for this difference has still not been determined.[7]

The impulse propagation is through interventricular septum reaching onto trabecular crania is well demonstrated in developmental studies.[8] In left ventricle the groups of papillary muscles are closely arranged. Papillary muscles are narrowly interconnected at its base in left ventricle.[9] A non-functioning papillary muscle can cause improper closing of valves, hypo kinesis or regurgitation of valves into atria. Abnormal papillary muscle can cause valve prolapse and can be picked up my MRI.[10] The left bundle branch divides into two and heads towards the base of both anterior and posterior papillary muscles in left ventricle.[11] The attachment 'bridge' to SPM, APM and PPM is found to be absent in most of the death due to cardiac cause as found in autopsies.[12]

Objectives

We wanted to find out the inter-basal connections of all the groups of papillary muscles in both ventricles. We intend to note the number of connections and the pattern of 'bridge connections'. We intend to note and analyze the trabecular link from the interventricular septum leading to one or groups of papillary muscles of both ventricles. We intend to note the moderator band morphology of right ventricle and its connections.

Though the papillary muscles are studied extensively, its basal connections with each other and with both ventricular surface is not well documented. Our hypothesis is all these connections when taken together and analyzed will form the basis of anatomical rationale for early rhythmic contractions of papillary muscles. We intend to find these through the cadaveric dissection of 25 formalin soaked hearts. We also intend to compare and contrast the autopsy findings in cardiac related deaths such as myocardial ischemia, valvular hyper or hypokinesia, conduction delays.

METHODS

It's a cross sectional observational dissection study, done over the period of one year from March 2020 to March 2021, involving three medical colleges. 25 formalin-soaked hearts were chosen from three neighbouring medical colleges. The morphological variations of papillary muscles were noted both in right and left ventricles. The moderator band morphology in right ventricle and similar band connection to papillary muscles in left ventricle were noted. The measurements were taken by simple vernier calipers. The basal attachments of papillary muscles were noted, recorded and photographed analysed, tabulated, compared and interpreted with pathology, autopsy and craniological findings. Connections between the APM and PPM 'S was noted .SPM measurements were not noted and omitted from the study, unless the same is part of basal connections with other papillary muscles.

The right ventricle is opened inverted 'L' Incision. After noting the initial attachment of moderator band the incision is extended laterally, taking care of papillary muscle. The moderator band is incised, which will enable the sternocostal surface to turn more laterally. All the chordae tendinae were cut from its attachment to cusps, after noting its morphology. This enables entire wall to turn laterally and all papillary muscles can be viewed in one plane. Deep and meticulous dissection is made to visualize the basal connections of all papillary muscles. Similar procedure is done on left ventricle. The blood clots were cleaned up, morphology is noted and recorded. The APMS present in right or basal surface is taken with the count of APM. PPMS if marginally fused taken as separate count. Findings of 5 post-mortem reports of heart related to cardiac events and 5 non cardiac related deaths were noted. The necrosis of basal attachments of papillary muscles, fibrosis or any related papillary muscles pathology is noted. The results were tabulated and compared with the previous studies done with similar interest. The findings were discussed with respective experts in field and analysed.

Statistical Analysis

Data collected was entered in MS excel and analysed using the same. Descriptive statistical measures like percentages were applied and the data was tabulated.

RESULTS

	No. of APM	No. of PPM	MB to APM (S)	MB to APM (M)	MB to Both	Septum to APM	Septum to PPM	Septum to Both	Variation Percentage	Buried MB	Absent Bridge
Rt v	37	52	25	8	6	-	-	-	30%	1	nil
Lt v	43	65	-	-	-	To all in mesh network	To all in mesh network	18	20%	-	Nil

Table 1. Gross Morphology, Showing the Connections of Both Right and Left Ventricular Papillary Muscles Single or Paired from Interventricular Septum, Either Directly or Via the Moderator Band

Right ventricle	Only to APM	Both APM/PPM	Additional MB to APM	Connecting APM / PPM / SPM	Bifurcating / trifurcating	SPM from origin	False cordae origin	Connected to apex	Branching on to trabaecula	More than two / sub branch
MB	17	8	5	3	8	1	2	1	100%	5/23
Bridge connecting APM to PPM	-	23	-	6	12	-	2	2	18	5/18
Bridge connecting to PPM TO SPM	-	-	-	-	5	2	4	1	0	2/5
Bridge connecting IVS to ppm	-	4	-	12	10	1	3	3	4	3/10
Bridges extending from trabeculae carniae	25	25	-	nil	All	nil	5	5	All	numerous
Interconnection of APMs	4	-	2 (only to add APM)	4	4	-	0	1	4	2/4
Connections when APM is conical	-	Multiple (3 or >)	1	3	-	-	-	-	Always	-
Connections when APM is biped or triped	-	Single but highly branched	4	3	-	-	-	-	Always	-
Other features	+	+	+	+	+	_	_	_	_	+

Table 2. Morphological Pattern of Attachment Bridges in Right Ventricle

Figure 1. 1. Moderator Band, 2. 'Bridge' Connecting APM and PPM, 3, 4. APM and PPM, 5. SPM, 6. Bridge Connecting SPM to PPM, in Right Ventricle

Left Ventricle	No of Bridge > 2mm	No Bridge < 2mm	Mesh Network	To the apex	Sub Branching	Reflection onto trabeculae	Separate Connection from IVS	Connection with PPM
IVS to APM (s)	2 in all 25	3-4 in all 25	all	3	80%	extensive	-	-
IVS to APM (M)	Atleast 1 to 2nd or 3rd APM	3-4 to 2nd and 3rd	absent	nil	Never	do	Always to all	-
Bifid/ trifid APM	2in 20	>5in 10	dense	nil	80%	extensive	-	-
Multiple APM	DO	DO	absent in laterally placed	nil	-	do	Always to all	Connected to all PPM's by branching chain
PPM	2 to each in 20	1 or 2 to all	Very dense	2	50%	scanty	To all, always	Interconnected always
Inter APM/PPM	nil	>2 in 23	Absent in80%	3	Only to papillary muscles	nil	13	Do
Special features	+	+	+	+	+	_	+	-

Table 3. Morphological Pattern of Attachment Bridges in Left Ventricle

Figure 2. A, P, S, VS Represents APM, PPM, SPM and Ventricular Septum Respectively. 1. Connection from Moderator band to PPM, 2. Interconnecting Bridge between PPM. 3, 4 & 5. Direct Connections to Base of Papillary Muscles Directly from Septum or by Moderator Band Via Muscular Bridge, in Right Ventricle

Figure 3. 1 & 2. A, P - Are Anterior and Posterior Papillary Muscles left Ventricle 1 Connection from IVS 2 Inter Papillary Bridge. 3, 4 & 5. Muscular Cords Connecting Bases from IVS

Figure 4. 1. Connections to Base of APM from IVS, 2. Inter Papillary Connections, 3. Connections to Base of PPM from IVS, in the Left Ventricle

Figure 5. A, P S are Anterior, Posterior and Septal Papillary Muscles, 1. Cut End of Moderator Band, 2. APM to PPM, Multiple Basal Connections, 3 & 4 Connections to PPM and SPM from IVS and Interconnections

The number of bellies present in papillary muscles varies considerably in right and left ventricles, 75 % in right ventricle and 90 % of papillary muscles of left ventricle showed more than one belly. Septal papillary muscle always present, many times in multiple number, usually buried in septal wall but chordae can be seen clearly emerging out of it. One of the SPM usually prominent.

The trabecular meshwork is more complex in left ventricle than right and it interconnected at the base of papillary muscles by 'muscular bridges'. Moderator band always present in right ventricle and 25 % of times two or more is seen. In 25 % same band connects both APM and PPM. When septal papillary muscle is prominent this connects all the sets at their bases. One of the PPM in right ventricle is connected to APM via moderator band, if not will get direct link from IVS. The left ventricle group of papillary muscles, each set gets more than two ridges from IVS which is more than 2mm thick, it's also connected to IVS by meshy network. The bases of anterior groups and posterior groups are interconnected, getting the connection extension from IVS directly or via papillary muscles. The morphological details are displayed in table 1, 2, 3. It's clear from table 1 that all papillary muscles does get the link from ventricular septum. Table 2, represents the connections and pattern in right ventricle. Table 3 represents connection and pattern in left ventricle. Fig 1 shows the moderator band extending from APM, PPM and to trabeculae carniae in right ventricle. Fig 2 shows deep, meticulous dissection after reflecting sternocostal surface clearly demonstrates interconnections of all the papillary muscles to moderator band and to IVS.in right ventricle. The prominent SPM can be noted .FIG 3 shows series of bridges descending from IVS to base of papillary muscles in left ventricle. Fig 4 shows one of the papillary muscles in posterior group is loosely connected.

DISCUSSION

Our observation about papillary muscles morphology is in agreement with Kavitha et al.[13] However we disagree with Kavitha et al[13] to the statement that septal papillary muscle is absent in 40 % in right ventricle. All papillary muscles interconnected at their basses, agree with Gheorghiţescu (Jancă) Ruxandra et al.[14]

Though the morphological anatomy of papillary muscles is studied worldwide, its basal connections and its importance, wasn't recorded as appeared through the literature survey. When the various studies done by specialists of different departments were put together and analysed with our findings in this study, it is clear that the basal connections have a role to play in rhythmic opening of AV valves. It is well documented that the trabecular carnie has ridges a, bridges and papillary muscles. The papillary muscles contracts earlier than the rest of the trabecular carniae[1].it's only possible if the impulse reach its base earlier which in- turn only possible if the interbasal connections are present. The impulse might reach directly via connections to its base from interventricular septum or interbasal connections. The moderator band connects IVS to base of APM, but deep dissection reveals there are more than one connection in 25 % the bridge originating from band will connect the posterior papillary muscles in about 30 %. PPM get direct link to IVS via a bridge in about 30 %.these in turn may get connected to APM. A prominent SPM muscle is present in 20 %, in which case it is invariably connected to APM, PPM or both. We found at least one each posterior papillary muscle in 90 % of specimens in both ventricles which is comparatively smaller than others papillary muscles in height and width and it is not densely connected to other papillary muscles or IVS. This fact may explain why posterior papillary muscle is frequently ruptured when compared to anterior groups.[7]

The impulse is transmitted through the bundle of His, via which the right and left bundle branch depolarizes the trabeculae.[8] The basses of papillary muscles will get initial connections via which it is reflected on to trabeculae the fact that the interconnecting bridges of papillary muscles, direct connections from IVS, Is an overwhelming fact to conclude that the impulse does reach papillary muscles fractions of seconds earlier than that of the carniae. Our study agrees with Anubha saha et al,[9] further illustrated the link to IVS. The post mortem findings in the three hearts, confirms the discoloration, fibrous tissue involvement in cardiac related

deaths where valvular hypo or hyper kinesis is reported. This is in agreement with Akin 0 Ektas et al.[12] These bridges are many times multiple. Further studies might reveal the possibility of different chordae tendinae is regulated by these, either in single or in multiple papillary muscles.

The arrangements of chordee tendinae from the papillary tip to the bases of bicuspid and tricuspid valves are extensive, diverse and wide variety. Different groups diverge in different directions. it will be interesting to note that the each papillary muscle receive different load of impulse and in every papillary muscles there may be segments which conduct the impulse differently, which might be revealed on future studies, the only way the rhythmic opening can be justified.

The post-mortem findings of five hearts related to cardiac deaths were noted. Out of which two had previous history of IHD and valvular hypokinesia. Three had a acute extensive myocardial infarction. The two who had previous history of IHD and hyperkinesia, the more discoloration, fibrosis or absent of the 'bridge 'was noted in right ventricle only. In acute myocardial infarction, however such a findings is not noted.

CONCLUSIONS

1. All the papillary muscle bases are interconnected by a ridge, a muscular bridge. At least one APM or PPM will get direct connection from IVS.
2. The most superficial 'bridge' connecting APM's and PPM's are responsible for initial contraction of papillary muscles before the depolarization waves spreads.
3. Such a 'bridge' is responsible for rhythmic opening of both AV valves, as all sets of papillary muscles on both sides has to be 'switched on' together, the connections coming from right and left bundle braches in the interventricular septum via septal papillary muscles.
4. The absence or subendocardial burial of this 'bridge' may indicate conduction problems, valvular hypo or hyperkinesia or prolapse. The 'bridge' may be lost due to ischemia, fibrosis o any other pathological condition affecting the region.
5. When multiple PPM s are present, at least one will be loosely connected to other papillary muscles, and smaller in height and breadth, this might explain why the posterior papillary muscle usually ruptures when compared to anterior groups
6. The inter- basal connections of papillary muscles to be studied most extensively as minimum data base is available. The postmortem findings concentrating on inter-basal connection of papillary muscles, its pathology to be studied in detail, as it will through more light on importance of such 'bridges'.
7. Interdisciplinary experts must come together to solve these type problems as shown in this study. The anatomists, physiologists, pathologists, cardiologist, cardiac surgeons, forensic experts and radiologists were directly or indirectly involved in this study.

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