Original Article

Diversity in the Pattern of the Subvalvular Apparatus of the Mitral Valve: A Study of 29 Normal Human Hearts

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The subvalvular apparatus of the mitral valve was studied in 29 normal Pakistani subjects who died in road traffic accidents or from fire arm injuries. A great diversity in the pattern of the subvalvular apparatus was noted. We believe that the papillary muscles are not discrete structures, that these are modified trabeculae carneae and they should better be designated as an anterolateral and posteromedial set of papillary muscles. Terms like stem and head of papillary muscles and bifid or trifid muscles were defined. In an anterolateral set of papillary muscles, 23 were single and six were bifid. In the posteromedial set, 19 were single, four were bifid, and six were trifid. Heads of papillary muscles are from three to six in our study. These heads arrange in three distinct groups (i.e. commissural, aortic and mural). The commissural head is always single, whereas mural and aortic heads were up to three each in number. In our study the posteromedial set of papillary muscles had a greater tendency towards multiplicity of heads, and this was more so at the mural position. (*Annals of Thoracic and Cardiovascular Surgery 1996; 2–6: 399–403*)

Key words: Subvalvular apparatus, Papillary muscles, Stems heads

Introduction

The subvalvular apparatus of the mitral valve plays a very important role in normal function of the valve. A small change in the shape or size of this apparatus may result in gross incompetence and may need surgical intervention. However at the same time there exists a wide variation in the normal pattern of the subvalvular apparatus, and it will not be an oversimplification to declare that each mitral valve is unique in its subvalvular pattern. This fact emphasizes that although a surgeon can not claim to have complete knowledge of all these patterns, it is necessary to have a sound concept about limits of normalacy. In this article we have highlighted a few patterns of papillary muscles and chordae tendineae which we noticed in our study of 29 normal human hearts from the Pakistani population.

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Methods

a. Heart Specimens

Twenty nine hearts were studied for the structural evaluation of the mitral valve. These hearts were obtained from the Forensic Medicine Department of King Edward Medical College, Lahore. The cause of death in these cases was head injury resulting either from a roadside automobile accident of fire arm injury. None of these subjects had any disease which could deform the anatomy of the mitral valve. The average age of these subjects was 30.2 (± 10.51) years. They included 23 male and six female subjects.

b. Exposure of the Subvalvular Apparatus

The mitral valve was studied systematically after removing the left atrium. The annulus was out at the middle of the posterior cusp with the help of a pair of scissors. The anterolateral and the posteromedial papillary muscles were saved and were meticulously studied. The pattern of origin and division of papillary muscles and chordae

Fig. 1. Separate origin of the commissural head of the papillary muscle
PM = Posteromedial papillary muscle: AM = Anterolateral papillary muscle: a = Aortic head: c = Commissural head: m = Mural head.

tendineae was noted down.

c. Definitions

Various terms like stem and head of papillary muscles are found in the literature. Similarly, papillary muscles are sometimes called bifid or trifid. However the exact definitions of these terms are not found in the literature. In this paper we have attempted to lay down a system for the description of subvalvular apparatus so that a uniformity of various terms may be achieved.

The term 'Stem' is defined as the part of the papillary muscle which is attached to the ventricular wall. The 'Head' relates to the distal free end of the muscle where the chordae tendineae are attached. The stem of the papillary muscle can be single, bifid or trifid. A bifid stem is that which divides into two muscles immediately after its origin or if the stems take entirely separate origins. When such a division is into three it is called trifid.

d. Notation for Description of the Subvalvular Apparatus

For simplicity and quick reference, a notation has been developed for the description of the papillary muscles. It is written as following:

a. For anterolateral papillary muscle:
$A/S_n/C_n$, A_n, M_n.

b. For posteromedial papillary muscle:
$P/S_n/C_n$, A_n, H_n.

In this notation 'A' and 'P' denotes the position of the muscle. The letter 'S' stands for the stem whereas 'n' is a number which tells whether the stem is single, bifid or trifid. Similarly the letters 'C', 'A'm 'M', followed by a number tell about the number of heads at the commissural, aortic and mural positions.

Results

The mean weight of hearts was 317.6 (± 44.02) grams in males and 267.5 (± 26.22) grams in females. In a majority of cases there were three heads in each set of muscles (i.e. one each for aortic, mural and commissural position). But their number varied from three to six. Most of the time the extra heads were found at the mural position. The commissural head was always single. Moreover, the commissural head was found to have a tendency of arising as a separate muscle (Fig. 1). Other details of the individual sets are given below.

The Anterolateral Set of Papillary Muscles

The anterolateral set of papillary muscles was found to arise from the anterior wall of the ventricle from the junction of its middle and lower third. This finding was similar to that of Brock et al[1].

The stems and heads of the muscles were labelled according to the guiding principles laid down in the previous section. A single stem was found in 23 cases (i.e. 79.3%). It was bifid in six (20.68%) cases. Trifid antero-

Table 1. Patterns of anterolateral set of papillary muscles

No. of cases	Type of stem	No. of Heads			Anjum jalal & cheema's notation
		commissural	aortic	mural	
19	Single	1	1	1	$A/S_1/C_1, A_1, M_1$.
02	Single	1	1	2	$A/S_1/C_1, A_1, M_2$.
02	Single	1	2	2	$A/S_1/C_1, A_2, M_2$.
05	Bifid	1	1	1	$A/S_2/C_1, A_1, M_1$.
01	Bifid	1	1	2	$A/S_2/C_1, A_1, M_2$.

Table 2. Patterns of posteromedial set of papillary muscles

No. of cases	Type of stem	No. of Heads			Anjum jalal & cheema's notation
		commissural	aortic	mural	
12	Single	1	1	1	$P/S_1/C_1, A_1, M_1$.
02	Single	1	1	2	$P/S_1/C_1, A_1, M_2$.
04	Single	1	2	2	$P/S_1/C_1, A_2, M_2$.
01	Single	1	2	3	$P/S_1/C_1, A_2, M_3$.
03	Bifid	1	1	1	$P/S_2/C_1, A_1, M_1$.
01	Bifid	1	2	2	$P/B_2/C_1, A_2, M_2$.
02	Trifid	1	1	1	$P/S_3/C_1, A_1, M_1$.
01	Trifid	1	2	1	$P/S_3/C_1, A_2, M_1$.
03	Trifid	1	2	2	$P/S_3/C_1, A_2, M_2$.

lateral muscle could not be found in any cases. The number of heads varied from three to five. The detailed arrangement of this set of muscles has been described in Table 1.

The Posteromedial Set of Papillary Muscles

This set had its origin from the left ventricular wall between the junction of interventricular septum and the posterior wall as described by Davila Palmer[2].

The muscle has a single stem in 19 (65.55%) cases. It was bifid in 4 (13.70%) and trifid in six (20.69%) cases.

The detailed arrangement of these papillary muscles have been given in Table 2.

Chordae Tendineae

Each set of papillary muscles gave rise to three groups of chordae tendineae (i.e. aortic, commissural, mural). Almost all were fan shaped. In one specimen the chordae retained their muscular tissue and the rest of them were fibrous. We noticed all the three orders of true chordae as were classified by Davila Palmer[2].

Discussion

In standard texts of anatomy, the structure of the mitral valve appears to be very simple. It is described as having a fibrous annulus and two cusps attached to it. The free edges of these cusps are attached to the papillary muscles via "fine glistening cord like structures" known as chordae tendineae. The papillary muscles are stated to be two in number, "varying considerably in their formation from long and finger like to short and stubby, occassionally with bifid tips"[3]. Although such a naive structured mitral valve is good for a description by a student of anatomy, it is almost rare for a cardiac surgeon to find so beautifully arranged "fine glistening chordae" or such discrete papillary muscles only two in number. This highlights that the austerity in the concept of this subvalvular apparatus needs thorough revision.

It is interesting to note that in most of the articles on surgical anatomy, more emphasis has been laid on the mitral valve annulus and cusps. A majority of the authors have made very brief remarks on the subvalvular apparatus. Indeed for an anatomist, the study of the subvalvular apparatus may not be as important as for a cardiac surgeon because a successful mitral valve repair depends on understanding the variations in the arrangement of the subvalvular apparatus. Those articles published previously, according to a surgeon's point of view, have given more importance to this aspect.

Silverman and Hurst in 1968[4] described papillary muscles as two sets of muscles originating from the left

ventricular wall as a component of interlacing trabeculae carneae. This means that the concept of two discrete muscles is far from reality. In even older works by Rusted et al[5] and Cheichi et al[6], it has been mentioned that these muscles can be bifid or trifid or even a row of muscles. The division of the papillary muscles into various parts have been described in such articles and we may find terms like 'heads of papillary muscles'. Ranganathan et al[7] have described the division of papillary muscles in various heads and have stated that the commissural head lies below the respective commissures.

In our opinion the anatomy of the subvalvular apparatus cannot be described in categoric terms; it can only be conceptualized by giving due attention to its development. The embryologists believe that after the fusion of endocardial cushions each atrioventricular orifice is surrounded by a localized proliferation of mesenchymal tissue. As this proliferation continues, the veil of mesenchyme starts getting thinned and hollowed out from the ventricular side due to the impact of the blood stream. While maintaining contact at its base with the ventricular wall, it starts hanging like a free curtain. Yet its free margin holds in contact with trabeculac of the ventricle through muscular chords. Gradually these muscular chords are fibrosed to form chordae tendineae, and the papillary muscles take their final shape when these trabeculae get their distal ends freed from the ventricular wall[8].

Such an account of the development leads to a more enlightened view of the possible variations in the pattern of the subvalvular apparatus. There can be a number of variations in the size, number and shape of the papillary muscles. Similarly the chordae may remain thick and muscular or may become extremely fine and flimsy. Their size and origin may also vary considerably.

Victor and Nayak[9] have recently described varioùs configurations of the commissural choradae. Their description is very comprehensive and covers almost any possible pattern that may exist. In their study of 100 hearts, 47% of anterolateral and 53% of posteromedial commissural chordae were fan-shaped. This is at variance with the findings of previous workers where fan-shaped pattern was believed to be almost universal[10]. We also found that a fan-shaped arrangement was present in almost all of our specimens. This difference in findings is perhaps because of extremely detailed study of Victor and Nayak as about six out of 12 patterns described by them can be labelled as fan shaped by any observer who has not read their article. It will take some time to decide whether this understanding of 12 patterns will be of any significant help during mitral valve repair.

In addition to the stability of the mitral valve, the subvalvular apparatus is also thought to play a vital role in left ventricular function. There are studies providing evidence that disruption of the chordae causes reduction in the contraction of the left ventrical and the distortion of its normal geometry. One such experimental study[11] has demonstrated that anterior and posterior leaflet chordae make an almost similar and nearly additive contribution to maintaining the normal left ventricular mechanics and function. Such studies have initiated a trend of preserving the subvalvular apparatus while putting in a prosthetic valve. An interesting clinical study[12] has shown a decrease in end diastoliic volume, end systolic stress, end systolic volume and a better ejection fraction when valve replacement was done by preserving the chordae. These findings were significantly different and opposite to what they observed when the chordae were excised. Due to the small number of patients the authors could not conclude whether the preservation of one or both leaflet chordae had any significant difference. Technically the preservation of the posterior leaflet chordae is not difficult but the anterior leaflet chordae needs special maneuvers for preservation. In the light of our observations on the arrangements of papillary muscles we feel it is not necessary to preserve the anterior leaflet chordae in all cases for optimal results because in over two third of cases the papillary muscles arise as a single stem. Therefore, mere excision of the aortic heads of the papillary muscles with their chordae and anterior leaflet should not, theoretically, bring any change in the mechanics of the left ventricular function and geometry. Although at this stage it is premature to draw any conclusion in this regard, this insight in to the pattern of subvalvular apparatus is sufficient to initiate more clinical trials.

Conclusions

The concept of two discrete papillary muscles is oversimplified and far from reality. There are two sets of papillary muscles situated under the two commissures. These muscles are modified trabeculae carneae and may arise as a single stem or more than one stem. The distal ends of these stems which give origin to the chordae tendineae are the 'heads' of the papillary suscles. These heads point towards three directions (i.e. aortic cusp, commissural area and mural cusp). The number of heads

is also variable except at the commissural area which is almost always single. In our study the posteromedial set of the papillary muscles had a greater tendency to have more stems and heads than the anterolateral set. Chordae tendineae fan out from the heads and may take various patterns. More rarely, the chordae may be thick and muscular.

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