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B-MODE ECHOCARDIOGRAPHIC IDENTIFICATION OF LEFT VENTRICULAR PAPILLARY MUSCLES IN THE ISOLATED CANINE HEARTS

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ABSTRACT

In order to identify which papillary muscle recorded in a B-mode echocardiogram was the posterior or anterior one, 22 isolated canine hearts were cut through a cross-section identical with the B-mode echocardiogram. Hearts were carefully suspended horizontally in physiologic saline solution to prevent any change in their position. The papillary muscles were presumed to be echoes emerging from the left ventricular wall or protruding into the left ventricular cavity. In the experiment of cutting the posterior papillary muscle, eight papillary muscles of nine hearts were easily identified and cut almost in half longitudinally. In contrast, it was difficult to identify the anterior papillary muscle and in only four cases of 13 hearts was the papillary muscle cut almost in half longitudinally. However, nine anterior papillary muscles were cut somewhere in total. The papillary muscle was not detected in one case and the cutting plane deviated from the papillary muscle in three hearts, medially in one and laterally in two cases. The B-mode echocardiogram of the identified posterior papillary muscle showed that it emerged from the left ventricular posterior wall and there was a wide space in front of it. In contrast, the anterior papillary muscle cut almost in half longitudinally protruded into the left ventricular cavity and showed a finger-like shape. There was a narrow space in front and behind.

Since the introduction of B-mode echocardiography, it has revealed conditions of the mitral valve[1~3] and in practice it has provided an increased chance of detecting subvalvular structures including chordae tendineae and papillary muscles.[1,4] It will also make it possible to diagnose the ruptured papillary muscle itself and other diseases of papillary muslces.[5] However, the identification of a papillary muscle recorded in a B-mode scan or a B-mode echocardiogram as an anterior or posterior one is still uncertain, although it has been considered to be the posterior papillary muscle[6] since the echo source of the presumed papillary muscle has not been confirmed.

In mitral stenosis, the identification of papillary muscle is important to evaluate mitral commissures non-invasively since each commissure may show differences in the severity of the affection.[7] The anterior papillary muscle connects with the anterior commissure and the posterior with the posterior commissure via the chordae tendineae respectively. Thus, commissures may be identified on the basis of the identified papillary muscles. In this paper a method of identifying anterior and posterior papillary muscles and their B-mode echocardiographic characteristics in extacted canine hearts will be described.

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METHODS AND MATERIAL

A mechanical sector scanner,[1] Toshiba SSL-51H Sonolayergraph was utilized at the rate of 30 frames per second to record B-mode echocardiogram. Photographic recording of an image on an oscilloscope was done with an 8 mm cinecamera at the rate of 15 frames and with an ordinary 35 mm camera at the shutter speed of 1/15 second.

B-mode echocardiography was performed in the 22 extracted hearts of mongrel dogs weighing 5 to 17 kg (hearts 65 to 100 g), which were divided into two groups; one with nine dogs utilized to identify the posterior papillary muscle and the other with 13 to identify the anterior papillary muscle (Table 1). The dogs were all anesthetized with Nembutal (10 ml) in the abdominal cavity and positioned on their backs. The thorax on both sides and the sternum was opened transversely at the fourth or fifth intercostal space as widely as possible. Respiration was maintained with air-mixed oxygen administered through an endotracheal tube. The pericardium was opened partially at six points, that is, two in the neighborhood of the apex, one at the lateral wall of the left ventricle, one at the transitional portion between the pulmonary trunk and the outflow tract of the right ven-

Table 1. Results of cutting papillary muscles

	Case (No.)	Body Weight (kg)	Heart Weight (g)	Angle (degree)	Position of a section
PPM	1	8	58	–	between both muscles
	2	7.5	48	+ 8	cut in half longitudinally
	3	7.5	75	+12	cut in half longitudinally
	4	9	70	+18	cut in half longitudinally
	5	17	90	+ 9	cut in half longitudinally
	6	10	70	+ 8	cut in half longitudinally
	7	10	70	+ 9	cut in half longitudinally
	17	10	70	+12	cut in half longitudinally
	19	9.5	60	+12	cut in half longitudinally
APM	8	10	60	–	not detectable
	9	9	65	– 9	through the base
	10	12	85	–26	outside the APM
	11	13.5	90	– 7	cut in half longitudinally
	12	9	70	– 7	outside the APM
	13	5	60	– 7	through the base
	14	9	60	– 9	between both muscles
	15	8	60	– 9	cut in half longitudinally
	16	10	86	– 7	through the base
	18	10	100	– 4	cut in half longitudinally
	20	12	90	+ 2	through the base
	21	12	80	– 6	cut in half longitudinally
	22	10	75	– 1	through the base

APM = anterior papillary muscle, PPM = posterior papillary muscle.

Angle: Angle between a plane through the anterior or posterior papillary muscle and that along a long axis of the left ventricle. +sign indicates that the plane was rotated clockwise from that along a long axis of the left ventricle. –sign indicates a counterclockwise rotation.

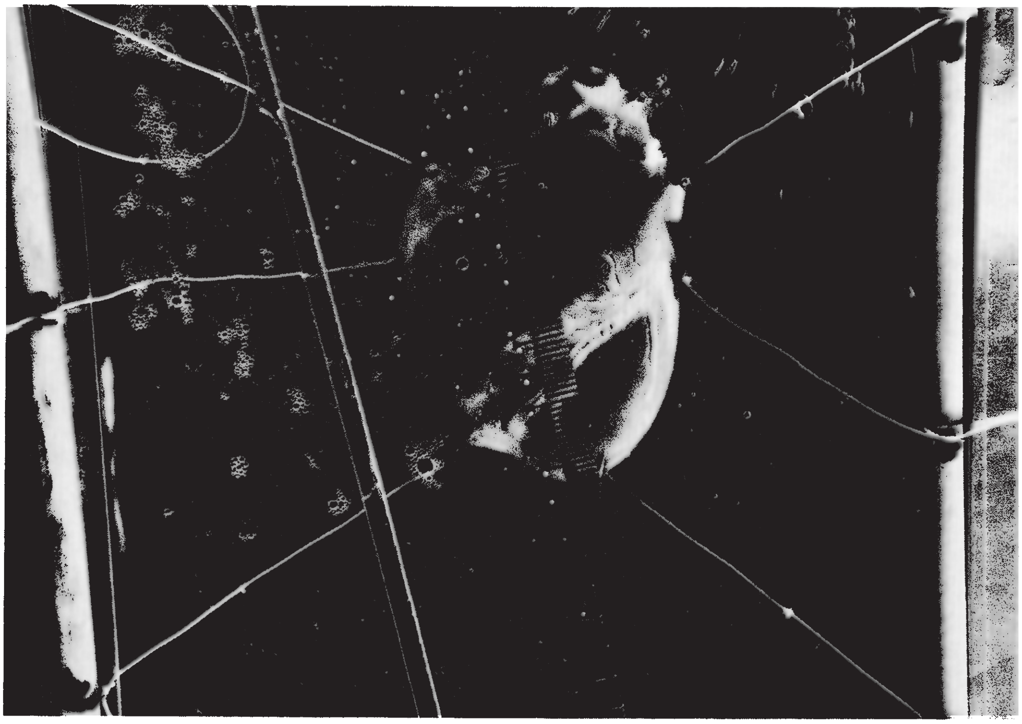

Fig. 1. A view of No. 19 dog heart from above, suspended in physiologic saline solution with six threads attached to the wooden frame placed on a vessel. The heart was positioned as closely as possible to that one in the opened chest of a dog placed in the supine position. The left edge of the ruler indicates a cross-section in which the posterior papillary muscle was recorded.

tricle, one at the right ventricle, and the last at the area between the right atrial appendage and the right ventricle. Through these pericardial windows, six silk threads were attached to the corresponding parts of the heart and the other ends were fixed to a rectangular wooden frame on the chest, pulling carefully so that the position of the heart might not be changed. After marking the threads and the frame, the threads were released and the pericardium was peeled off, and then the heart was separated from the supporting tissue. The heart was immediately immersed in physiologic saline solution and fixed again with the threads to the frame on a vessel at the previously marked points (Figure 1). For the acoustic coupling between the heart and scanner (or transducer), caster oil was utilized. A vinyl bath with the oil was placed on the heart and the scanner was immersed in No. 1 tc 14 hearts, but in No. 15 to 22, a vinyl bath with the oil directly attached to the scanner was placed on the heart.

The detection and identification of papillary muscles

At first, a plane along a long axis of the left ventricle was examined, which showed mitral leaflets and aortic root but did not show the chordae tendineae. When the scannig plane was moved gradually rightwards, an echo probably indicating the posterior papillary muscle appeared as an echo prominent from that of the left ventricle. Then the plane was rotated clockwise to detect the muscle echo as clearly as possible. After the directions of the plane along a left ventricular long axis (A) and of the plane detecting the papillary muscle (B) were marked on the frame, the scanner was taken out of the oil bath (No. 1 to 14 hearts) or from the saline solution with the attached oil bath (No. 15 to 22). The angle between both planes was measured. For the identification of the echo source of the presumed papillary muscle, the heart was penetrated perpendicularly from above along the plane B with three to five needles and sectioned along these needles. In the detection of the anterior papillary muscle, the initial plane was moved leftwards and rotated counterclockwise. When a protruding echo into the left ventricular cavity from the ventricular wall was detected, it was taken to be that of the anterior papillary muscle. Thereafter, the above-mentioned method was performed to identify echo source.

RESULTS

The posterior papillary muscle in all hearts except the first case was sectioned almost in half longitudinally. The angle between the long axis plane of the left ventricle and that along the posterior papillary muscle ranged from eight to 18 degrees (Table 1).

In contrast to the detection of the posterior papillary muscle, it was difficult to cut the anterior papillary muscle in half longitudinally. The procedure was successful in only four cases, but five were sectioned obliquely through the base of the papillary muscle.

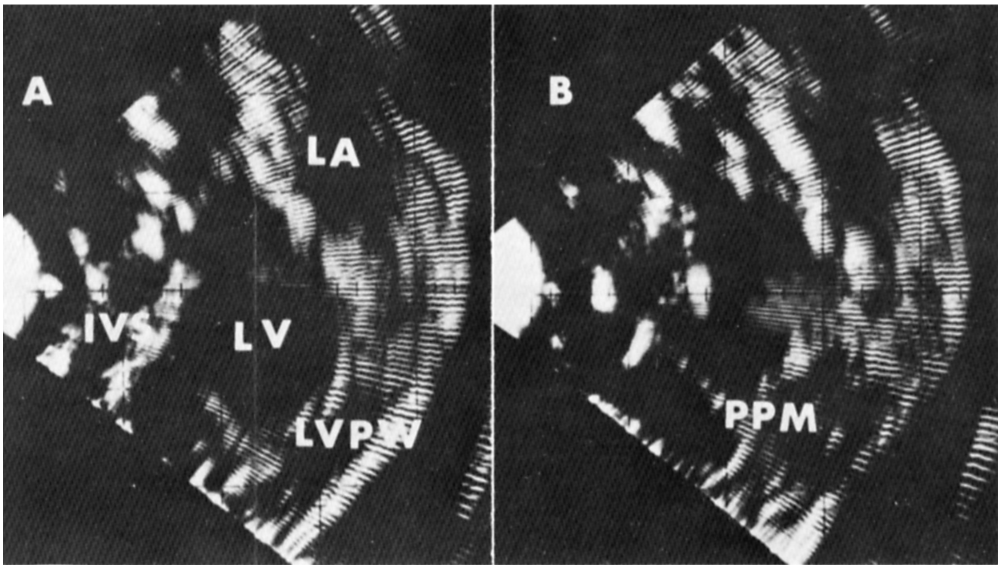

Fig. 2. B-mode echocardiograms obtained from No. 19 dog heart. Panel A shows a long axis of the left ventricle and panel B shows the posterior papillary muscle. The posterior papillary muscle emerges from the left ventricular posterior wall and the wall of the left ventricle in panel B appears thicker than that in panel A. There is a broad space in front of the posterior papillary muscle, but a shallow cleft behind it.
IVS = interventricular septum; LA = left atrium; LV = left ventricle; LVPW = left ventricular posterior wall; PPM posterior papillary muscle.

Thus, in total, the anterior papillary muscle was sectioned somewhere in nine of 13 hearts. In two cases, the sectioned plane deviated laterally outside the papillary muscle and in one case it deviated medially. Moreover, in the experiment in which the posterior papillary muscle was cut, the anterior papillary muscle could not be sectioned anywhere and vice versa.

Figure 2B shows an echocardiogram of the posterior papillary muscle in case No. 19 dog. The posterior papillary muscle is recognized as a prominence on the left ventricular posterior wall. There is a wide echo-free left ventricular cavity in front of it but only a shallow cleft behind it. Actually the sectioned heart (Figure 3) shows the same relationship to the left ventricular cavity, the posterior papillary muscle and the left ventricular posterior wall. The posterior papillary muscle was cut longitudinally and the cutting plane was almost perpendicular to the left ventricular posterior wall.

Figure 4A shows a two-dimensional echocardiogram of the anterior papillary muscle in No. 21 dog. The papillary muscle protrudes into the left ventricular cavity from the transitional wall between the left ventricular posterior wall and the left ventricle which is probably the anterior wall leading to the interventricular septum. There is a narrow space

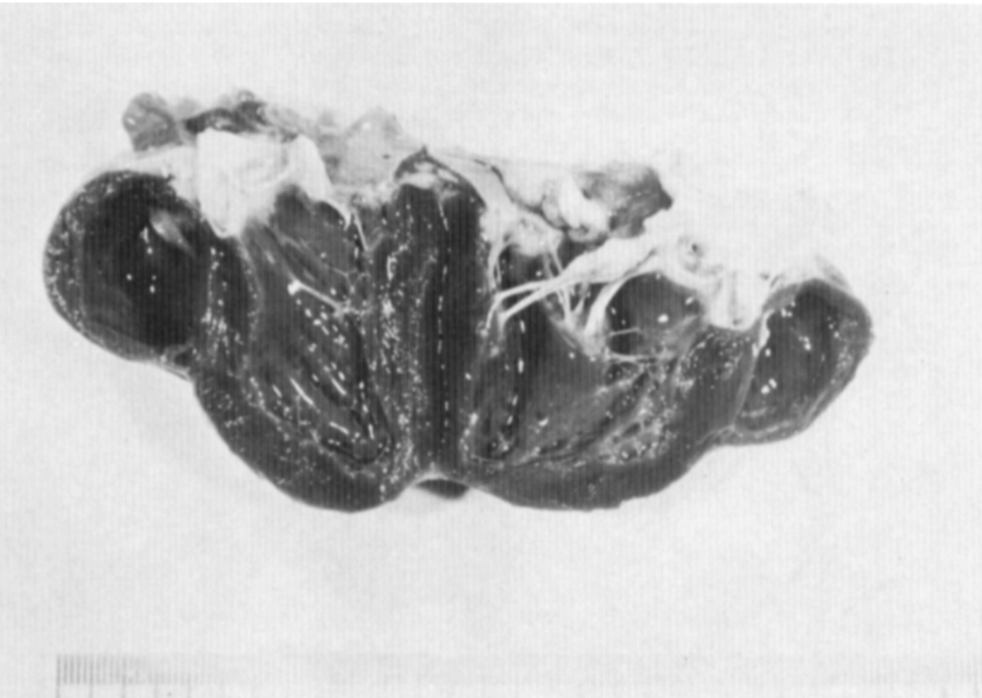

Fig. 3. The identified posterior papillary muscle of No. 19 dog heart. The posterior papillary muscle was sectioned longitudinally. The same relationship between the left ventricular cavity and the posterior papillary muscle as in Fig. 2 is recognized. There is a broad space in front of the posterior papillary muscle, but a shallow cleft behind it. On the left side is the anterior papillary muscle having a narrow, deep cleft in front and behind.

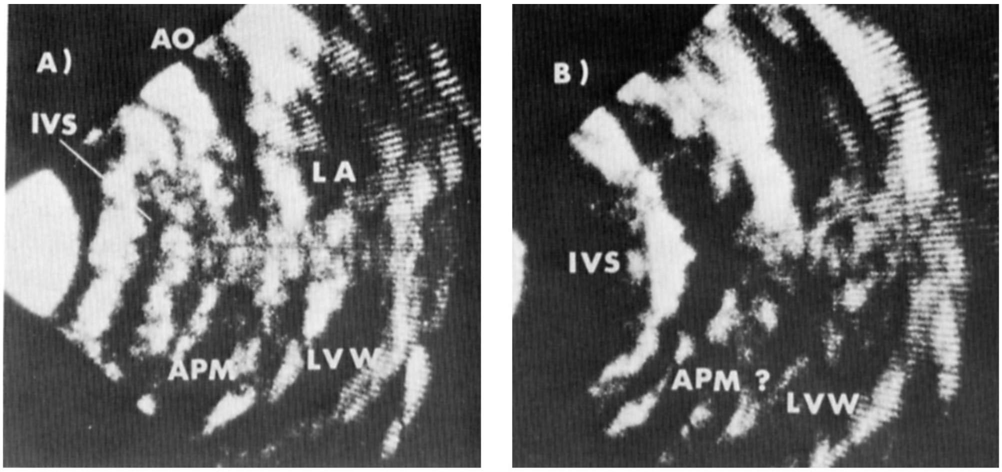

Fig. 4. Panel A: B-mode echocardiogram showing the identified anterior papillary muscle, obtained from No. 21 dog heart. The anterior papillary muscle is recognized as an echo protruding into the left ventricular cavity. There is a narrow ventricular cavity in front and behind it. Panel B: B-mode echocardiogram showing the non-identified anterior papillary muscle, obtained from No. 10 dog heart.
AO = aortic root; APM = anterior papillary muscle; IVS = interventricular septum; LA = left atrium; LVW = left ventricular wall.

Fig. 5. The sectioned anterior papillary muscle of No. 21 dog heart. The anterior papillary muscle was sectioned longitudinally and the same relationship between the left ventricular cavity and the anterior papillary muscle is recognized. The aortic root and the mitral leaflets were sectioned simultaneously.

between the anterior wall and the anterior papillary muscle. Further, a narrow space is recognized behind the anterior papillary muscle, which is thus unlike the posterior papillary muscle. The opened heart (Figure 5) revealed the same space-relationship between the anterior papillary muscle and the left ventricular cavity. The anterior papillary muscle was sectioned through the plane which ran almost parallel to the lateral wall of the left ventricle.

DISCUSSION

In the identification of human papillary muscle, the authors[4)] consider that if a papillary muscle is detected when the B-mode echocardiographic cross-sectional plane is moved rightwards from the position at which the mitral leaflets and aortic root are detected, then somewhat clockwise rotated, it may indeed be a posterior papillary muscle. Moreover, when the scanning plane is moved leftwards and rotated somewhat counterclockwise, an anterior papillary muscle may be detected in some, but not all cases.

In the present experiment the posterior papillary muscle was easily detected and identified. However, in the first case the authors failed to cut the papillary muscle, which was attributed to their inexperience in the experimental procedure. The posterior papillary muscle showed a characteristic echo building up from the left ventricular posterior wall, having only a shallow cleft between the muscle and the ventricular wall but a wide cavity in front of the papillary muscle. This finding reflects the anatomical relationship between the posterior papillary muscle and the left ventricle. The posterior papillary muscle of the left ventricle in dog is located near the dorsal interventricular groove[8)] and protrudes into the ventricular cavity. But it does not correspond to a free finger-like structure in the cavity. It transposes at the back to the left ventricular wall without making a deep cleft. Thus, it is possible for scanning beams passing through the transitional area of the posterior papillary muscle to yield the B-mode echocardiographic characteristic.

It was difficult to detect and identify the anterior papillary muscle for two reasons: (a) the location of the anterior papillary muscle in the left ventricle and (b) the procedure which was employed to detect and identify the papillary muscle. The anterior papillary muscle rises from the anterolateral wall of the left ventricle and transposes to the wall with a shallow cleft. To detect the anterior papillary muscle, the scanning plane must pass through the left ventricle in the neighborhood of the lateral wall. Moreover, the space in front of and behind the anterior papillary muscle is narrow. These factors may make it difficult to clearly distinguish the anterior papillary muscle from the left ventricular wall, because of the breadth of ultrasonic beams. The difficulty in the detection probably resulted in the failure to section the anterior papillary muscle. Conversely, although the anterior papillary muscle could be detected in case No. 10 (Figure 4B), it failed to cut the anterior papillary muscle. In this case the failure must be attributed to the procedure after the detection. When the scanner, which slightly pressured a heart to avoid a multiple layer echo from a bottom of the oil bath, was taken out from the oil bath, the heart was able to move rightwards or leftwards in consequence of unloading. Moreover, when needles penetrated the heart, it might have deviated slightly because the penetrating points were not at the center of gravity and the heart was contracted by stimuli of the penetration.

B-mode echocardiographic characteristics of the anterior papillary muscle sectioned almost in half longitudinally were a narrow space in front of the anterior papillary muscle and a comparatively large space behind it, which was in contrast to the posterior papillary muscle. It is for this reason that the scanning plane passes through the papillary muscle out of the transitional portion to the left ventricular wall (Figure 6).

In the present experiment, it was possible to differentiate the anterior papillary muscle from the posterior papillary muscle on the basis of the described detection method and the space relationship between the papillary muscles and the left ventricular cavity. Moreover, we think the present method of detecting papillary muscles may be applicable to differentiate the human left ventricular papillary muscles. However, a heart in vivo acts more violently and beats at a higher rhythm than in the isolated condition. The position and conformation of the heart changes with beats and respiration. Thus the papillary muscle is not always recorded as a constant echocardiographic figure. A certain scanning plane may not show a papillary muscle at all times, but show the other muscle in some or another

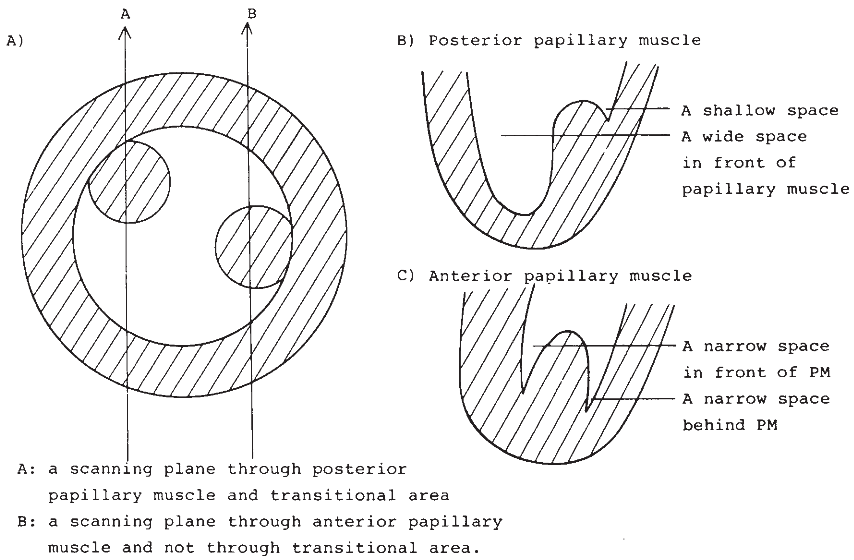

Fig. 6. Relation between the papillary muscles and scanning planes. Panel A shows scanning planes A and B, in which the posterior and the anterior papillary muscle are detected respectively. The scanning plane A passes through a transitional area between the posterior papillary muscle and the left ventricular posterior wall. Thus, as shown in panel B, a broad left ventricular cavity is recognized in front of the posterior papillary muscle. But there is only a shallow cleft behind it. The scanning plane B does not pass through a transitional area between the anterior papillary muscle and the anterolateral wall of the left ventricle. Since there is a narrow, deep cleft in front of and behind the anterior papillary muscle as shown in Fig. 3, a narrow space in front of and behind the papillary muscle is observed in a B-mode echocardiogram (panel C).

phase of a heart beat. However, in our experience, there is a cross-section between both papillary muscles at which the mitral leaflets and aortic root can be recorded without recording papillary muscles in the human heart. This means that both papillary muscles do not interlock even during a ventricular systole, contrary to the report of other authors.[9] The location of papillary muscles in the human is almost similar to that in a dog, but some difference[10,11] is recognized in their conformation. In particular, the human papillary muscle has a deep cleft between the anterior papillary muscle and the left ventricular wall, and the human posterior papillary muscle shows a deep cleft. The existence of a space behind a papillary muscle perhaps does not differentiate it from the other muscle in the human. But a comparatively wide space in front of the posterior papillary muscle recognized in canine hearts may possibly serve to identify the posterior papillary muscle in the human.

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REFERENCES

1) Nishimura, K., Hibi, N., Kato, T., Fukui, Y., Arakawa, T., Tatematsu, H., Miwa, A., Tada, H., Kambe, T., Nakagawa, K., Takemura, Y., Real-time observation of cardiac movement and structures in congenital and acquired heart diseases, *Am. Heart J.*, **92**, 340, 1976.
2) Henry, W. L., Griffith, J. M., Michaelis, L. L., McIntosh, C. L., Morrow, A. G., Epstein, S. E., Measurement of mitral orifice area in patients with mitral valve disease by real-time, two-dimensional echocardiography, *Circulation*, **55**, 827, 1975.
3) Nichol, P. M., Gilbert, B. W., Kisslo, J. A., Two-dimensional echocardiographic assessment of mitral stenosis, *Circulation*, **55**, 120, 1977.
4) Nishimura, K., Sakakibara, T., Hibi, N., Kato, T., Fukui, Y., Arakawa, T., Tatematsu, H., Miwa, A., Tada, H., Kambe, T., Hisanaga, M., High-speed ultrasono-cardiotomography; Echocardiographic manifestation of papillary muscles and their chordae tendineae, *J. Cardiography* (in press).
5) Robert, W. C., Cohen, L. S., Left ventricular papillary muscles, Description of the normal and a survey of conditions causing them to be abnormal, *Circulation*, **46**, 138, 1972.
6) Feigenbaum, H., Clinical applications of echocardiography, *Prog. Cardiovas. Dis.*, **14**, 531, 1972.
7) Rusted, I. E., Scheifly, C. H., Edwards, J. E., Studies of the mitral valve, II, Certain anatomic features of the mitral valve and associated structures in mitral stenosis, *Circulation*, **14**, 398, 1956.
8) Miller, M. E., Christensen, G. C., Evans, H. E. *Anatomy of the dog*, W. B. Saunders Company, Philadelphia and London.
9) Chiechi M. A., Lees, W. M., Thompson, R., Functional anatomy of the normal mitral valve, *J. Thoracic Surg.*, **32**, 378, 1956.
10) Rusted, I. E., Scheifly, C. H., Edwards, J. E., Kirklin, J. W., Guides to the commissures in operations upon the mitral valve, *Proc. Staff Meet. Mayo Clin.*, **26**, 297, 1951.
11) Ranganathan, N., Burch, G. E., Gross morphology and arterial supply of the papillary muscles of the left ventricle of man, *Am. Heart J.*, **77**, 506, 1969.