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# Echocardiographic Assessment of Papillary Muscle Size and Function in Normal Beagle Dogs

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**Abstract :** Morphologic changes or functional impairments of the papillary muscle (PM) can influence mitral valve competence. The purpose of this study was to investigate PM size and contractile function using two-dimensional and color tissue Doppler echocardiography in normal dogs. 35 unsedated Beagle dogs without cardiovascular disease were examined. The vertical (VD) and horizontal diameter (HD) of the posterior and anterior PM was measured at end-diastole, and compared with the thickness of the left ventricular posterior wall (LVPWd). Longitudinal systolic movement of the PM was quantified as myocardial velocity and strain using tissue Doppler. The VD, HD, and ratios (VD/LVPWd, HD/LVPWd, VD/HD) were significantly greater in the posterior than anterior PM ($P < 0.001$). The VD and HD of posterior PM and the HD of anterior PM were significantly correlated with LVPWd (r = 0.47, 0.44, and 0.42, respectively). Body weight was significantly correlated with VD of posterior PM (r = 0.37). The peak systolic tissue velocity of the PM was $4.93 \pm 1.25$ cm/sec and peak strain was $-30.83 \pm 11.92\%$. PM size and systolic function can be quantitatively assessed using two-dimensional and tissue Doppler. The establishment of these objective PM measurements may be useful to evaluate morphological and functional abnormalities of the canine PM.

*Key words* **:** canine, diameter, papillary muscle, strain, tissue Doppler.

## Introduction

Morphological abnormalities of the papillary muscle (PM) are found in conditions of hypertrophic or dilated cardiomyopathy, congenital dysplasia, or ischemic heart disease. Hypertrophy of the PM can lead to left ventricular (LV) outflow obstruction independent of septal thickness (16,17). An enlarged and thickened PM is also associated with LV wall hypertrophy, and can be the only indication of early hypertrophic cardiomyopathy in cats and humans (14,15,25). In dilated cardiomyopathy or ischemic heart disease, the PM is thinner and longer than its normal shape (19,27). Rarely, PM rupture occurs as a result of acute myocardial infarction or as a consequence of trauma (9,10). Atrophy of the PM, usually observed with other mitral apparatus abnormalities, contributes to mitral or tricuspid regurgitation (7,13). In veterinary medicine, there has been only one previous study measuring PM size using two-dimensional echocardiography (1). That study reported that the mean size of the PM in cats with LV wall hypertrophy was significantly greater than in normal cats. There has been no study measuring PM size in dogs.

Contraction of the PM prevents leaflet prolapse from the high ventricular pressure by tightening chordae tendineae shortly before the ventricular systole and maintains the tension during systole. Dysfunction of the PM and underlying myocardium has been attributed to ischemic mitral regurgitation (8,11,18). PM function has been assessed for fractional shortening, which was calculated as the percentage change in PM length at end-diastole and end-systole (12,20). One previous study reported that mean fractional shortening of the PM was $30 \pm 8\%$ in clinically healthy humans, and patients with diminished PM shortening exhibited the most severe mitral regurgitation (12). In recent studies, PM systolic function was quantitatively assessed as longitudinal contraction using tissue and strain Doppler echocardiography (6,22,27). A dysfunctional, elongated PM has, paradoxically, been found to attenuate mitral regurgitation in patients with ischemic heart disease, compared with a similar degree of LV remodeling (22,27).

It is important to evaluate the size and function of the PM accurately because any morphological changes or functional impairments of the PM can influence mitral valve competence and cause various hemodynamic alterations. However, the size and function of the PM has not been studied using echocardiography in dogs, although the PM has been evaluated using subjective impressions of the sonographer. The purpose of the present study was to provide objective measurements of PM size using two-dimensional echocardiography, and quantitation of PM function using tissue and strain Doppler in normal dogs.

## Materials and Methods

**Animals**
This study was performed under the guidance of the Kyung-

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pook National University Animal Care and Use Committee. 35 Beagle dogs (32 intact males, 2 intact females, and 1 castrated male) weighing between 7.7 and 13.9 kg, and ranging in age from 2 to 10 years were examined. Dogs on medication or that had a history of cardiovascular disease were excluded. All dogs underwent general physical examination, auscultation, laboratory examination, and thoracic radiography.

### Echocardiographic examination

Echocardiographic examination was performed using a multi-frequency transducer (ProSound F75, Hitachi, Aloka, Tokyo, Japan) on non-anesthetized dogs with continuous ECG monitoring. The shape and motion of the mitral apparatus, including mitral annulus, mitral leaflets, and chordae tendineae, were assessed at the right parasternal long-axis view using two-dimensional echocardiography. Standard M-mode measurements were performed to obtain interventricular septal thickness, LV internal diameter, posterior LV wall thickness at end-diastole (LVPWd). The right parasternal short-axis view at the level of the maximal PM at end-diastole was used for measurements, and an LV eccentricity index of 1 was used to obtain the appropriate transverse plane (Fig 1A). The vertical diameter (VD) was defined as a subtraction between the shortest distance from the tip of the PM to the outer edge of the LV wall and LVPWd. For calculation of VD, LVPWd was measured on the same transverse image, because there was no significant difference with the M-mode measurement method. The horizontal diameter (HD) was defined as the length of the perpendicular line to the VD between the two bulging points of each anterior and posterior PM. For each anterior and posterior PM, VD to HD, VD to LVPWd, and HD to LVPWd ratios were calculated to consider body size. For assessment of PM function, color tissue Doppler imaging data were recorded on the left apical oblique view, which shows the PM entirely (Fig 1B). The Doppler gate was placed mid-portion of the PM and the ultrasonic beam was adjusted to achieve maximal alignment with the longitudinal axis of the PM. All measurements in the present study were performed off-line in triplicate and averaged by the same sonographer.

### Statistical analysis

Statistical analysis was performed using a statistical software program (Statistical Package for Social Sciences, SPSS Statistics version 22.0, SPSS Inc., Armonk, NY: IBM Corp) for data analysis. The PM parameters of size (VD, HD, VD/LVPWd, HD/LVPWd, VD/HD) and function (systolic velocity and strain) were tested for normality of distribution using the Shapiro-Wilk test. A paired t-test was used to compare VD, HD, VD/LVPWd, HD/LVPWd, and VD/HD of posterior and anterior PM. Pearson's correlation was used to examine the relationship between the following: VD and HD, VD and LVPWd, HD and LVPWd, VD/HD and LVPWd, VD and body weight, HD and body weight, VD/LVPWd and body weight, and HD/LVPWd and body weight. The relationship between longitudinal systolic velocity, systolic strain, and VD, HD, VD/LVPWd, HD/LVPWd, VD/HD were also analysed using Pearson's correlation coefficient. The values of VD, HD, VD/LVPWd, HD/LVPWd, VD/HD, systolic velocity, and strain were presented as mean ± standard deviation. A $P$ value less than 0.05 was considered to be statistically significant; $P$ values of $< 0.01$ and $< 0.05$ were described as * and **, respectively.

## Results

All dogs were normal according to the general physical examination, auscultation, laboratory examination, and thoracic radiography. There were no significant findings in two-dimensional and M-mode echocardiographic examination of the LV, including the mitral apparatus.

Diameter and ratio of the posterior and anterior PM are summarized in Table 1. The mean values of VD, HD, VD/LVPWd, HD/LVPWd, and VD/HD were significantly larger in the posterior PM than the anterior ($P < 0.001$), and the difference was significantly greater in VD than HD ($P < 0.001$). The VD and HD of posterior PM and the HD of anterior PM were significantly correlated with LVPWd (r = 0.47*, 0.44*, and 0.42**, respectively). Body weight was only significantly correlated with VD of posterior PM (r = 0.37**). The peak systolic tissue velocity of the PM was 4.93 ± 1.25 cm/
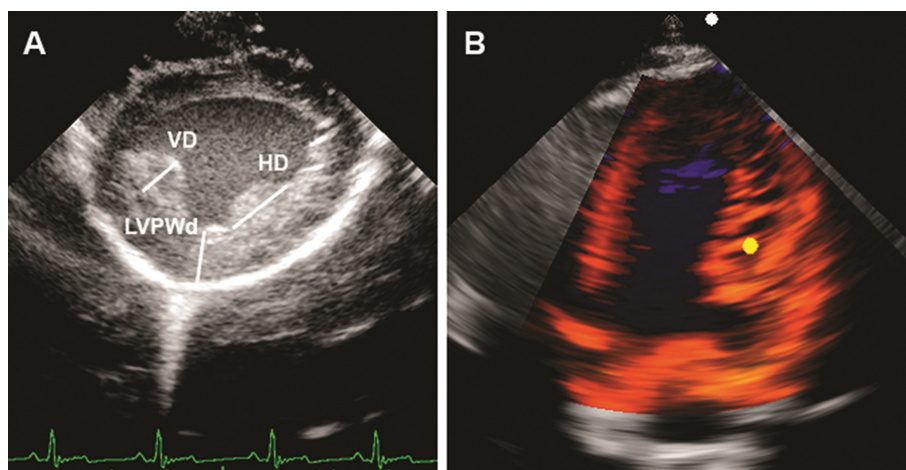


**Fig 1.** Right parasternal short-axis view at end-diastole for PM diameter measurement (A), left apical oblique view for color tissue Doppler imaging (B). HD - Horizontal diameter; LVPWd - Left ventricular posterior wall thickness at end-diastole; VD - Vertical diameter

**Table 1.** Diameter and ratio of the posterior and anterior PM

|  | Posterior PM | Anterior PM |
|---|---|---|
| VD (mm) | 6.42 ± 1.19* | 3.69 ± 1.05 |
| HD (mm) | 12.8 ± 1.30* | 11.2 ± 1.00 |
| VD/LVPWd | 0.75 ± 0.12* | 0.44 ± 0.14 |
| HD/LVPWd | 1.50 ± 0.18* | 1.35 ± 0.16 |
| VD/HD | 0.50 ± 0.10* | 0.33 ± 0.08 |

*$P < 0.001$.
HD - Horizontal diameter; LVPWd - Left ventricular posterior wall thickness at end-diastole; VD - Vertical diameter.

sec and peak strain was −30.83 ± 11.92%. There were no significant correlations between peak systolic velocity and strain, peak systolic velocity and PM size (VD, HD, VD/LVPWd, HD/LVPWd, VD/HD), and peak strain and PM size (VD, HD, VD/LVPWd, HD/LVPWd, VD/HD).

## Discussion

The present study provided objective measurements of PM size in clinically normal dogs. Features of the canine PM on right parasternal short axis view of echocardiography has been described as a symmetric bulging structure at the 3-4 and 8-9 o'clock positions, resembling a mushroom-shape LV cavity (2). The results of this study demonstrated that the PM is asymmetric, and that posterior PM size was significantly greater than anterior size, with mean differences of 2.7 mm in VD and 1.6 mm in HD. In addition, in both the posterior and anterior PM, HD was greater than VD. These results suggest that the normal canine PM is elliptical in shape with a wide base, and the anterior PM is slightly more slender than the posterior. The results of this study are similar to those of previous studies involving humans considering that the PM is conical in shape with a broad base, and the antero-lateral PM is slightly longer and narrower than the postero-medial (19). However, there was a notable difference between normal PM shapes of dogs and cats considering that the PM is a slender elliptical shape with a narrow base in normal cats, but becomes wider at the base (triangular shape) in cats with hypertrophic cardiomyopathy (5).

This study was performed exclusively with the Beagle breed, a representative medium size dog. However, because adult dogs are extremely variable in body size, any measurements of the heart requires accounting for the variation caused by differences in body size. Therefore, we assumed that PM size was positively correlated with body weight, and used the PM diameter to LVPWd ratio as the parameters. In this study, the results of all measurements, including the diameters and ratios of the PM, showed a relatively narrow range; therefore, we suggest that values quietly above the upper or below the lower limit be interpreted as abnormal. However, because the diameters of the PM were significantly correlated with LVPWd, the dogs with hypertrophic myocardial disease may be expected to have a larger PM. Therefore, both diameters and ratios of the PM should be considered when evaluating PM size, based on relationship with body size and ventricular wall thickness. Further studies with larger numbers and various breeds, including small and large dogs, are needed.

Because the PM is perfused by the coronary arterial blood supply, it is vulnerable to myocardial ischemia (24). Although isolated PM dysfunction without affecting the underlying ventricular myocardium did not always cause mitral regurgitation in experimental animal models (11,21), dysfunction of the PM is usually accompanied by underlying myocardial ischemia (23). Thus, dysfunction of the PM may develop into ischemic mitral regurgitation (8,18,26) or, paradoxically, attenuate regurgitation by reducing the tethering distance of leaflets due to PM elongation (22,27). To our knowledge, this was the first study to examine normal systolic function of the PM in dogs using tissue and strain Doppler.

Tissue Doppler imaging has been recently introduced as an ultrasound technique to quantify regional myocardial function. Strain imaging is derived from tissue velocity data and represents deformation of the myocardial segment. The longitudinal systolic velocity and strain of the LV free wall were studied using tissue and strain Doppler in several previous studies involving normal dogs (3,4). In a previous study, the peak systolic velocity of the LV free wall was reported to be 7.6 ± 2.7 cm/sec at the base, 4.7 ± 2.48 cm/sec at the middle, and 1.8 ± 1.5 cm/sec at the apex in dogs (3). In another, the peak systolic strain of the LV free wall was reported to be −25.5 ± 3.6% at the base and −23.3 ± 4.0% at the apex in dogs (4). Comparing systolic function between the LV wall in the previous studies (3,4) and PM in the present study, peak systolic tissue velocity of the PM was similar with that at the middle of the LV wall; however, the absolute value of peak systolic strain was higher than that obtained at both the base and apex of the LV wall. These results suggest that the PM may be closely related with the myocardium of LV wall, and PM systolic function may be assessed using tissue and strain Doppler. However, Doppler has an angle dependency, which means that a difference in beam direction between the longitudinal axis of the LV wall and PM is believed to affect results, as well as actual velocity and deformation of the PM.

## Conclusion

The size and function of the PM can be quantitatively assessed using two-dimensional and tissue Doppler echocardiography. The establishment of these objective measurements may provide more information about PM shape and contraction. The combination of these parameters with conventional echocardiographic variables may be useful for evaluating myocardial disease in dogs.

## Conflict of Interest

No conflicts of interest have been declared.

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