

Morphological Investigations of the Anterior Leaflet and its Chordae Tendineae in Canine Mitral Valves

Takuma Aoki

Yoko Fujii

Hiroshi Sunahara

Keisuke Sugimoto

Yoshito Wakao

Laboratory of Veterinary Surgery I, Azabu University, 1-17-71 Fuchinobe, Chuo-ku, Sagamihara-shi, Kanagawa, Japan, zip 252-5201

Correspondence: Takuma Aoki, DVM, Ph.D., Laboratory of Veterinary Surgery I, Azabu University, 1-17-71 Fuchinobe, Chuo-ku, Sagamihara-shi, Kanagawa, Japan, Zip 252-5201; Tel +81-42-754-7111; Fax +81-42-850-2456

This study was performed at the Laboratory of Veterinary Surgery I, Azabu University and Azabu University Veterinary Teaching Hospital.

We have no conflicts of interest.

KEY WORDS: morphology, mitral valve, anterior leaflet, myxomatous mitral valve disease, dogs

ABSTRACT

Although mitral valve repair (MVR)—for mitral regurgitation (MR) secondary to chronic valvular heart disease (CVHD)—is becoming more common in veterinary medicine, there is little information about the morphology of the mitral valve apparatus that is used to guide veterinary surgeons. Therefore, we investigated the locations of MR using echocardiography in 12 client-owned dogs with MR. Nine (75%) of these dogs had MR arising from the tip of the anterior leaflet (AL). In addition, we investigated the morphology of the AL and its chordae tendineae by examining the heart specimens of 10 healthy beagles. The tip of the AL—determined by echocardiography as the cause of MR—was secured by the

chordae tendineae (CT), which were thinner than those attached to the base of the AL on each papillary muscle (anterior and posterior papillary muscle; $p = 0.0186$ and $p = 0.0198$, respectively). In the normal AL, the free edge of the posterior half was broader than that of the anterior half ($p = 0.0001$). In conclusion, the CT attached to the tip of the AL might be a contributor of MR in dogs because of its thin nature. It should be reconstructed during MVR, since the tip of the valve cusp in the left ventricle is secured for mitral valve coaptation. The posterior half of the anterior leaflet might require the use of more artificial chords because of its wide free edge.

INTRODUCTION

Mitral regurgitation (MR) caused by chronic valvular heart disease (CVHD) is the most common acquired heart disease among old dogs.¹⁻² In this condition, the valve cusps are

thickened and the chordae tendineae (CT) are extended and/or ruptured.² Left-sided heart failure caused by MR is commonly managed by medical treatments. However, surgical management is becoming more common, particularly in dogs with refractory MR.³⁻⁶ Although surgical management includes mitral valve repair (MVR) and mitral valve replacement, MVR is currently the most appropriate surgical treatment for dogs with MR, since mitral valve replacement requires a costly artificial valve and lifelong anticoagulant administration.

The anterior leaflet (AL, known as the septal leaflet) is usually affected in dogs with MR,^{2,7} whereas the posterior leaflet (known as the mural leaflet) is more commonly affected in humans with MR.^{8,9} However, although anatomical and physical appreciation of target organs is required for performing accurate surgery, there is little available information regarding the detailed morphology of the mitral valve leaflet and its CT for veterinary surgeons during MVR.

Therefore, the objective of the present study was to describe in detail the morphological and physical properties of the canine AL in order to guide veterinary surgeons in clinical practice.

MATERIALS AND METHODS

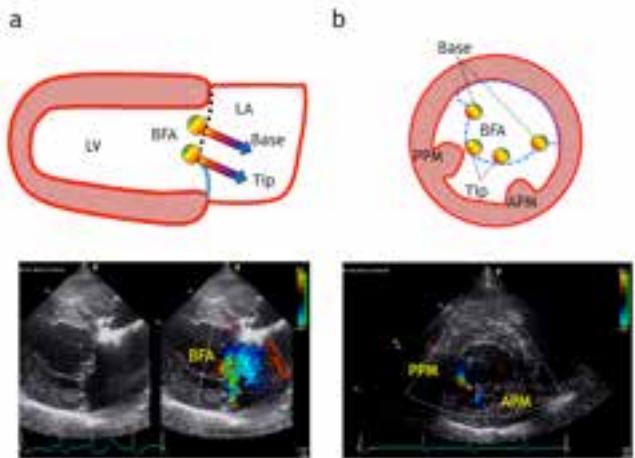
Animals

This study was approved by the ethical committee of Azabu University and was conducted in accordance with the guidelines established by the Animal Welfare Act and the National Institutes of Health Guide for Care and Use of Laboratory Animals.

We included 12 consecutive client-owned dogs with MR secondary to CVHD

Figure 1. Echocardiography for the estimation of the location of the MR. CT elongation at the tip, base, or both were surmised according to the site where blood flow acceleration was observed during MR based on (a) the right parasternal 4-chamber view and (b) the right parasternal short axis view at the level of the mitral valve.

LA, left atrium; LV, left ventricle; BFA, blood flow acceleration; CT, chordae tendineae; AL, anterior leaflet; APM, anterior papillary muscle; PPM, posterior papillary muscle.



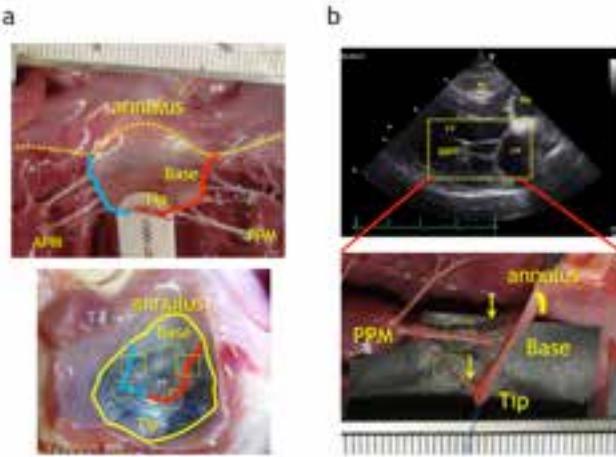
(5 males, 2 neutered males, 3 females, and 2 spayed females) that were admitted to the Cardiology Service, Veterinary Teaching Hospital, Azabu University, in 2010. Of these 12 dogs, 5 were Cavalier King Charles spaniels, 2 were Shih Tzu, and 1 each was Maltese, miniature schnauzer, papillon, Shetland sheepdog, and mixed breeds. The mean (SD) age and body weight were 10.1 (3.5) years and 7.2 (2.2) kg, respectively. The American College of Veterinary Internal Medicine (ACVIM) stages B1, B2, and C were 5, 4, and 3, respectively.¹

MR was diagnosed after a thorough physical examination, thoracic radiography, and two-dimensional, M-mode, Doppler echocardiography.

After obtaining the approval of our university's animal research committee, cardiac morphology was investigated using whole heart specimens obtained from 10 clinically healthy beagles that were euthanized for purposes other than the present study. The mean (SD) body weight and the

Figure 2. Morphological investigations conducted with healthy beagles. The lengths of the anterior (blue line) and posterior halves (red line) were measured from the annulus (yellow dotted line) to the CT attached to the tip of the AL (a, top). The sites in which the CT attached to the tip of the AL (yellow circle) and the base of the AL (yellow box) were indicated (a, bottom). The widths of the CT were measured at the thinnest site (b, bottom; yellow dotted outlines) on each papillary muscle. The anatomical image (b, bottom) is equivalent to a right parasternal 4-chamber echocardiographic view (b, top). The CT attached to the tip of the AL secured the mitral valve in the left ventricle for coaptation of the mitral valve. The thin CT branched from the wider CT (b, bottom; arrows).

RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle; APM, anterior papillary muscle; PPM, posterior papillary muscle; CT, chordae tendineae; AL, anterior leaflet.



mean (SD) age of the 10 beagles (3 males and 7 females) were 10.3 (1.3) kg and 1.7 (0.2) years, respectively. They all underwent complete physical and echocardiographic examinations before being euthanized. None of these dogs had MR based on the examinations mentioned above.

Echocardiographic methods to detect extended (or ruptured) CT

All the dogs were examined with the Vivid 7 Dimension cardiovascular ultrasound system (GE Healthcare Japan Corporation, Tokyo, Japan), with mechanical phased array transducer frequencies ranging from 2 to 5, 3.1 to 8, and 4 to 11.5 MHz. The echocar-

diographic view was obtained according to the guidelines of the American Society of Echocardiography.¹⁰ Right parasternal long and short axis views were obtained and color Doppler echocardiography was used to visualize the mitral valve region. Elongation of the CT was surmised from the prolapse of valve cusps⁷ and the locations of blood flow acceleration in systole (Figure 1).

Morphological investigation of the heart specimens

The left ventricular free wall of each heart specimen was dissected longitudinally between the anterior papillary muscle (APM) and the posterior papillary muscle (PPM, A). The valve cusp was classified into two parts: tip and base. Figure 2B shows the AL, CT, and papillary muscle in a right parasternal 4-chamber echocardiographic view.

The images of the mitral valve apparatus were obtained using a digital camera, and were uploaded to a computer. The following parameters were measured using a computer software (Excel

measurement of lengths and areas, Free Ver. 2.00, Copyright 2003, 2004, Furu, Japan): the length of each free edge of the AL for the anterior and posterior halves (Figure 2A; lengths from the annulus to the CT attached to the tip of the AL) and the width of the CT at the thinnest site (Figure 2B bottom; dotted outlines).

Statistical analysis

To compare the 2 groups, the Student t test was used for cases in which normality was observed in the result of the chi-squared (χ^2) goodness-of-fit test in both groups, and when the two groups had equal popula-

tion variance values obtained by the F test. The Welch t test was used for cases in which the population variance values were not equal, and the Mann-Whitney U test was used for cases in which normality was not observed in either groups.

The results are expressed as median (range) or mean (SD). A p value of < 0.05 was considered statistically significant. All the statistical procedures were performed using the Ekuseru-Toukei 2010 (Social Survey Research Information Co., Ltd., Tokyo, Japan) statistical software.

RESULTS

Estimation of Extended CT Using Color Doppler Echocardiography

Based on the echocardiography, nine dogs (75%) had AL prolapse while the remaining three dogs (25%) had bileaflet prolapse. We determined that the CT attached to the tip of the AL was elongated in the nine dogs (75%), since the blood flow acceleration was observed in the tip of the AL. Similarly, we determined that the CT attached to the base of the AL was elongated in one dog (8.3%), and those attached to the tip and base of the AL was elongated in 2 dogs (16.7%).

Morphological Investigation of Heart Specimens

The CT attached to the tip of the AL secured the tip of the AL in the left ventricle in all heart specimens. The median (range) length of the anterior half of the AL was 1.18 cm (0.92–1.64 cm) and that of the posterior half was 1.64 cm (1.38–1.80 cm). The posterior half of the AL was significantly longer than the anterior half ($p = 0.0001$).

In the APM, the median (range) widths of the CT attached to the base and tip were 0.65 mm (0.50–1.00 mm) and 0.45 mm (0.30–0.70 mm), respectively. The former was significantly wider than the latter ($p = 0.0186$). In the PPM, the median (range) widths of the CT attached to the base and tip were 0.70 mm (0.60–1.00 mm) and 0.55 mm (0.40–1.00 mm), respectively. The former was significantly wider than the latter ($p = 0.0198$).

DISCUSSION

Although medical treatment is the most common option in dogs with MR, it has limitations since MR is a progressive disease.² Therefore, MVR is the radical surgery of choice for MR since it does not require a costly artificial valve and lifelong anticoagulant administration. It is becoming more common, particularly in dogs with refractory MR.^{3, 5, 6} However, the procedure of MVR is complex because the severely affected mitral valve apparatus should be reconstructed using only artificial sutures and sheets. In addition, to the authors' knowledge, there is little information about the detailed morphology of the mitral valve apparatus used by veterinary surgeons, although that knowledge is essential to performing an accurate MVR procedure.

In the present study, we suggested that prolapse of the tip of the AL was the main cause of MR in dogs and that the CT attached to the tip of the AL should be reconstructed during MVR. Indeed, previous study has shown that the CT attached to the tip of the AL was ruptured in dogs with MR.¹¹ The CT attached to the tip and base of the AL seemed equivalent to the human marginal and strut chordae, respectively. As observed in humans, the strut chordae was wider than the marginal chordae in the present study.¹²⁻¹⁴ The strength of a material is proportional to its cross-sectional area.¹⁷ Therefore, although the marginal chordae has smaller loads than the strut chordate,^{15, 16} they might be prone to elongation because of their thin nature. The thinner CT might be more sensitive to breaking caused by fatigue. Conversely, because of their large cross-sectional area, the strut chordae might be strong enough to bear the heavy repeated load. Indeed, strut chordae bear the heaviest blood pressure load of all the CT.^{15, 16} However, mitral valve coaptation improved in ischemic MR when the strut chordae were severed.¹⁸

Furthermore, the marginal chordae—and not the strut chordae—are reportedly vital for mitral valve coaptation.¹² These

studies suggest that although the CT that are attached to the base of the AL might be slightly elongated, they were not the main cause of MR.

As observed in humans,^{20, 21} the pathological investigation in dogs with MR revealed that the pathological change was more severe in the posterior half of the AL than in the anterior half.¹⁹ The posterior half of the AL might be more affected than the anterior half because of its broader area, which subjects it to larger blood pressure loads. In addition, the posterior half of the AL needs more artificial chords during MVR because of its large valve cusp and pressure load.

There are several limitations to the present study. First, the breed of dogs used for the morphological investigation only included beagles. Second, the cross-sectional areas of the CT should be investigated because the cross-sectional surface of canine CT might not be a true circle, like that in humans.²² In addition, the role of the posterior leaflet should be considered because the bileaflets were affected in approximately half of the dogs with MR.⁷

In conclusion, the CT attached to the tip of the AL might contribute to MR in dogs because they are thin. They should be reconstructed during MVR since they secure the tip of the valve cusp in the left ventricle for good coaptation of the mitral valve. The posterior half of the AL might require more artificial chords because it is broader than the anterior half of the AL.

REFERENCE

- Atkins C, et al. Guidelines for the diagnosis and treatment of canine chronic valvular heart disease. *J Vet Intern Med* 2009;23:1142-50.
- Haggstrom J, Duelund Pedersen H and Kvart C. New insights into degenerative mitral valve disease in dogs. *Vet Clin North Am Small Anim Pract* 2004;34:1209-26.
- Griffiths LG, Orton EC and Boon JA. Evaluation of techniques and outcomes of mitral valve repair in dogs. *J Am Vet Med Assoc* 2004;224:1941-5.
- Orton EC, et al. Technique and outcome of mitral valve replacement in dogs. *J Am Vet Med Assoc* 2005;226:1508-11.
- Kanemoto I, et al. Open heart surgery with deep hypothermia and cardiopulmonary bypass in small and toy dogs. *Vet Surg* 2010;39:674-9.
- Uechi M. Mitral valve repair in dogs. *J Vet Cardiol* 2012;14:185-92.
- Terzo E, et al. Echocardiographic assessment of 537 dogs with mitral valve prolapse and leaflet involvement. *Vet Radiol Ultrasound* 2009;50:416-22.
- Duran CM and Pekar F. Techniques for ensuring the correct length of new mitral chords. *J Heart Valve Dis* 2003;12:156-61.
- Lambert AS, et al. Improved evaluation of the location and mechanism of mitral valve regurgitation with a systematic transesophageal echocardiography examination. *Anesth Analg*;1999:1205-12.
- Gottdiener JS, et al. American Society of Echocardiography recommendations for use of echocardiography in clinical trials. *J Am Soc Echocardiogr* 2004;17:1086-119.
- Jacobs GJ, et al. Echocardiographic detection of flail left atrioventricular valve cusp from ruptured chordae tendineae in 4 dogs. *J Vet Intern Med* 1995;9:341-6.
- Espino DM, et al. The role of Chordae tendineae in mitral valve competence. *J Heart Valve Dis* 2005;14:603-9.
- He S, et al. Geometric distribution of chordae tendineae: an important anatomic feature in mitral valve function. *J Heart Valve Dis* 2000;9:495-503.
- Rodriguez F, et al. Cutting second-order chords does not prevent acute ischemic mitral regurgitation. *Circulation* 2004;110:II91-7.
- Salisbury PF, Cross CE and Rieben PA. Chorda Tendinea Tension. *Am J Physiol* 1963;205:385-92.
- Kunzelman KS, Einstein DR and Cochran RP. Fluid-structure interaction models of the mitral valve: function in normal and pathological states. *Philos Trans R Soc Lond B Biol Sci* 2007;362:1393-406.
- Morton MS and Joseph WK. 1998. Elastic Properties of Materials. pp.163-79. *In: General physics* (Ishii C trans.) Hirokawa Publishing Co, Tokyo (in Japanese).
- Messas E, et al. Chordal cutting: a new therapeutic approach for ischemic mitral regurgitation. *Circulation* 2001;104:1958-63.
- Kogure K. Pathology of chronic mitral valvular disease in the dog. *Nippon Juigaku Zasshi* 1980;42:323-35.
- Davies MJ, Moore BP and Braimbridge MV. The floppy mitral valve. Study of incidence, pathology, and complications in surgical, necropsy, and forensic material. *Br Heart J* 1978;40:468-81.
- Jeresaty RM. Mitral valve prolapse--Click syndrome. *Prog Cardiovasc Dis* 1973;15:623-52.
- Barber JE, et al. Mechanical properties of myxomatous mitral valves. *J Thorac Cardiovasc Surg* 2001;122:955-62.