



ELSEVIER

REVIEW

Management of incidentally detected heart murmurs in dogs and cats^{☆,☆☆}



Etienne Côté, DVM^{a,*}, N. Joel Edwards, DVM^b,
Stephen J. Ettinger, DVM^c, Virginia Luis Fuentes,
VETMB, PhD^d, Kristin A. MacDonald, DVM, PhD^e,
Brian A. Scansen, DVM, MS^f, D. David Sisson, DVM^g,
Jonathan A. Abbott, DVM^h

^a *Department of Companion Animals, Atlantic Veterinary College, University of Prince Edward Island, 550 University Ave., Charlottetown, PE C1A 4P3, Canada*

^b *Upstate Veterinary Specialties, 222 Troy Schenectady Rd, Latham, NY 12110, USA*

^c *VetCorp Inc, 1736 S. Sepulveda Blvd., Los Angeles, CA 90025, USA*

^d *Department of Clinical Sciences and Services, The Royal Veterinary College, University of London, Hawkshead Lane, Hatfield, Herts AL9 7TA, UK*

^e *VCA Animal Care Center of Sonoma County, 6470 Redwood Dr, Rohnert Park, CA 94928, USA*

^f *Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, 601 Vernon L Tharp St, Columbus, OH 43210, USA*

^g *Department of Small Animal Services, College of Veterinary Medicine, Oregon State University, 700 SW 30th Street, Corvallis, OR 97331, USA*

^h *Department of Small Animal Clinical Sciences, Virginia-Maryland Regional College of Veterinary Medicine, 215 Duck Pond Drive, Blacksburg, VA 24061, USA*

Received 31 March 2015; received in revised form 6 May 2015; accepted 11 May 2015

Prepared by the Working Group of the American College of Veterinary Internal Medicine Specialty of Cardiology on Incidentally Detected Heart Murmurs.

* A unique aspect of the Journal of Veterinary Cardiology is the emphasis of additional web-based materials permitting the detailing of procedures and diagnostics. These materials can be viewed (by those readers with subscription access) by going to <http://www.sciencedirect.com/science/journal/17602734>. The issue to be viewed is clicked and the available PDF and image downloading is available via the Summary Plus link. The supplementary material for a given article appears at the end of the page. To view the material is to go to <http://www.doi.org> and enter the doi number unique to this paper which is indicated at the end of the manuscript.

** This article was first published in the Journal of the American Veterinary Medical Association, 2015 May 15;246(10):1076–1088. <http://dx.doi.org/10.2460/javma.246.10.1076>.

* Corresponding author.

E-mail address: ecote@upe.ca (E. Côté).

<http://dx.doi.org/10.1016/j.jvc.2015.05.001>

1760-2734/ © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

KEYWORDS

Cardiac;
Canine;
Feline;
Physiologic;
Innocent

Abstract A dog or a cat has an incidentally detected heart murmur if the murmur is an unexpected discovery during a veterinary consultation that was not initially focused on the cardiovascular system. This document presents approaches for managing dogs and cats that have incidentally-detected heart murmurs, with an emphasis on murmur characteristics, signalment profiling, and multifactorial decision-making to choose an optimal course for a given patient.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Abbreviations

CHF	congestive heart failure
CKCS	Cavalier King Charles spaniel
DCM	dilated cardiomyopathy
DMVD	degenerative or myxomatous atrioventricular valve disease
NT-proBNP	amino-terminal pro-B-type natriuretic peptide
VHS	vertebral heart score
VSD	ventricular septal defect
2-D	two-dimensional

Introduction

A dog or cat has an incidentally detected heart murmur if the murmur is an unexpected discovery during a veterinary consultation that was not initially focused on the cardiovascular system. Common examples include auscultation of a murmur during an annual wellness examination, prior to general anesthesia, or during evaluation of a patient for a noncardiac medical condition.

Successful management of an animal with an incidentally detected heart murmur requires a correct diagnosis to accomplish the goals of accurate prognostication, appropriate initiation of treatment, if needed, and having a satisfied client who fully understands the implications of the murmur, including the impact of the underlying disorder on the animal's health. This document presents current information by species and age group to help veterinarians make appropriate decisions and initial diagnostic plans after incidental detection of a murmur in a dog or cat. This article was first published in the *Journal of the American Veterinary Medical Association*.¹

An incidentally detected heart murmur might or might not require further diagnostic investigation. Definitive diagnosis of the cause of a murmur benefits the patient because it serves as the basis for providing an appropriate level of treatment and

monitoring. It also provides value for the client (by allowing an accurate assessment of presence and severity of disease in the pet and its prognosis) and for the veterinarian (by corroborating or expanding on auscultatory findings and on the understanding of the impact that a given condition can have on the patient). In general, the veterinarian who has detected a murmur is in the best position to develop the initial diagnostic and case management plans in conjunction with the client, given the veterinarian's familiarity with the patient, the client, and the characteristics of the murmur, as determined by careful auscultation.

The first and often most challenging step is to determine the clinical importance of a murmur. Its characteristics may suggest that it most likely results from a cardiovascular lesion (termed pathological murmur) or that it is most likely associated with a structurally normal heart (termed nonpathological murmur). The terms nonpathological murmur, functional murmur, innocent murmur, and flow murmur are similar inasmuch as they all signify that a murmur is not caused by a structural cardiovascular lesion; however, each has a specific meaning (Fig. 1).² In this document, nonpathological murmur will be used as the principal term to describe murmurs that are not associated with structural cardiovascular lesions.

Veterinarians investigating the clinical significance of a heart murmur should optimally include the following steps in the patient's evaluation:

- Determine, by careful auscultation, whether the murmur is most likely to be pathological or nonpathological (Tables 1 and 2).^{2–4} A veterinarian's ability to make this determination increases with experience in auscultating dogs;⁵ in cats, often it is not possible to classify systolic murmurs of intensity grades 1/6 through 3/6 as clearly pathological or nonpathological.
- When auscultation reveals that the murmur is convincingly nonpathological, identify and

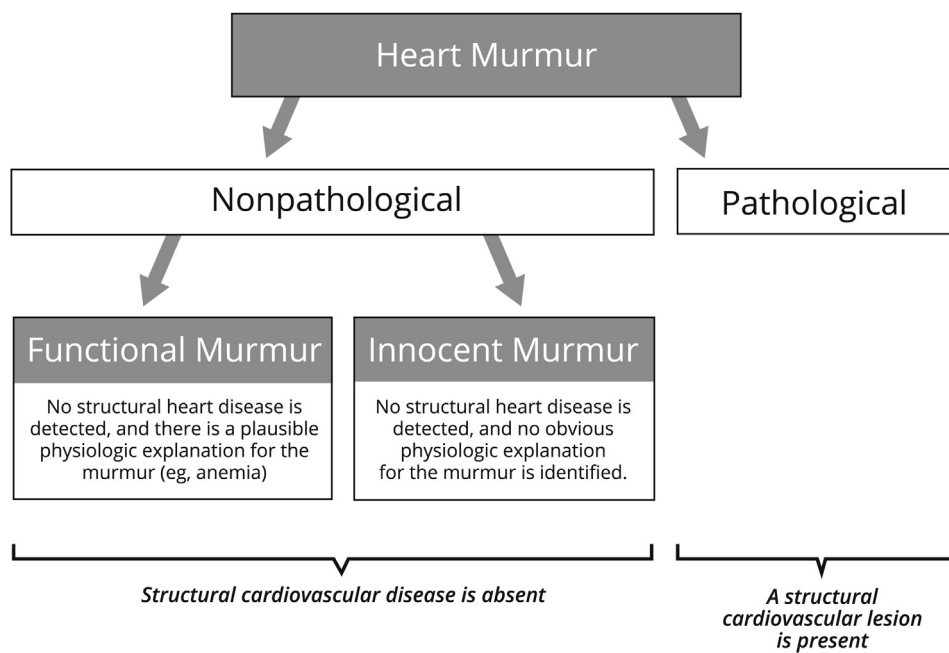


Figure 1 Nomenclature of pathologic and nonpathologic heart murmurs.¹

address the systemic disorder likely causing the murmur (e.g. anemia), if any. In the absence of a systemic cause, the purpose of further cardiovascular diagnostic tests is confirmation that the heart is structurally normal.

- When auscultation reveals that the murmur is pathological, or could be pathological or nonpathological, use additional information to prioritize differential diagnoses according to likelihood, and refine the initial case management plan. This should include assessment of all of the murmur's auscultatory features (e.g. where it is heard the loudest [point of maximal intensity: right or left side of the thorax, over the base or apex of the heart], whether it radiates and, if so, to which regions of the thorax [or beyond), the frequency characteristics and sound quality of the murmur, and whether it is limited to systole]. Concurrently, findings from the remainder of the physical examination, particularly mucous membrane color, femoral pulse quality, heart rate and rhythm, and respiratory rate should be considered carefully. Finally, the patient's age, breed, sex, and body size can help the veterinarian consider certain disorders to be more plausible, or less so, in a specific patient (signalment profiling). Together, these elements should be used for creating a differential diagnosis list, ranging from most likely to least likely conditions.

Several important factors then help the veterinarian and client determine whether cardiovascular

diagnostic testing should be pursued. Indications for further testing include: suspicion of a pathological murmur on the basis of auscultatory features or difficulty in interpreting the murmur; presence of additional abnormal heart sounds; detection of overt clinical signs that could be referable to cardiac disease; need to investigate whether a new murmur is associated with other, seemingly unrelated, findings (e.g. shifting leg lameness that could be associated with infective endocarditis); client concern, anxiety, or desire to be fully aware of the cause of the murmur, and associated prognosis and treatment options; the animal's intended use; whether an event or intervention that could increase the risk of arrhythmia, congestive heart failure, or thromboembolism (e.g. general anesthesia or plane travel) is imminent; and the availability, cost, and perceived value of diagnostic tests (Fig. 2). Two patients could have identical heart murmurs, but be differently evaluated on the basis of differences in these factors. Ultimately, the murmur must be evaluated to a degree that is appropriate for the patient, and acceptable to the veterinarian and client (Fig. 3).

Heart murmurs in puppies

Dogs can be considered pediatric patients when they are between 6 weeks of age and the age of full adult height and normal organ physiology (6 months in toy breeds; ≥ 1 year in giant breeds).⁶ Nonpathological murmurs are commonly recognized in puppies, although objective information

Table 1 Criteria for helping differentiate nonpathological from pathological heart murmurs in dogs and cats.

Descriptor	A nonpathological murmur is more likely	A pathological murmur is more likely
Sensitive	The murmur is absent or much softer at rest than with excitement or exercise; it changes with position or phase of respiration	The murmur is present at rest or with activity; it can be heard at all times
Short	The murmur is of short duration, predominantly heard in early or mid systole	The murmur remains loud through most of systole
Single	There are no other associated abnormal heart sounds or physical examination abnormalities; no clicks, gallops, or arrhythmias are heard	Additional auscultatory abnormalities are present, there are other abnormalities on physical examination, or both
Small	The murmur is localized to the left heart base or to one location; it does not radiate	The murmur radiates from the point of maximal intensity
Soft	The murmur is soft or quiet; generally grade 1/6 or 2/6	The murmur is loud, i.e. grade 3/6 or louder
Systolic	The murmur duration is limited to mid systole	The murmur is continuous or a diastolic component is also audible

Evaluation of murmurs with the 6-S rubric can be a useful means to help determine the need for additional diagnostic testing. It is important to note that pathological murmurs may, if caused by lesions that generate minimal turbulence, be mistaken for nonpathological murmurs.

(Modified from Bronzetti G, Corzani A. The seven "S" murmurs: an alliteration about innocent murmurs in cardiac auscultation. *Clin Pediatr (Phila)* 2010;49:713,³ © 2010 by Sage publications. Reprinted by permission of Sage publications.)

Table 2 Heart murmur grading scale.

Grade	Features of cardiac auscultation and palpation
1/6	Nearly imperceptible, may be heard with very careful auscultation in a quiet environment; always focal
2/6	Heard readily but very soft; always focal
3/6	Heard readily, moderate intensity; usually regional (can be heard in several auscultatory regions of the heart)
4/6	Heard readily, loud, and usually radiates widely (can be heard in most or all auscultatory regions of the heart), but without a palpable thrill
5/6	Heard readily, loud, and associated with a precordial thrill, but the murmur is not heard with the stethoscope lifted off the surface of the thorax
6/6	Heard readily, loud, associated with a precordial thrill, and the murmur remains audible with the stethoscope lifted 1 cm off the surface of the thorax

(Modified from *Canine Cardiology*, Ettinger SJ, Suter PF. Heart sounds and phonocardiography, pp 12–39.⁴ Copyright Elsevier [1970]. Reprinted with permission.)

on prevalence and temporal evolution is scarce.⁷ The characteristics of nonpathological murmurs are described (Table 1); anecdotally, the often-noted musical qualities of nonpathological murmurs detected in human patients are less commonly identified in dogs. Nonpathological murmurs also can be caused by such systemic disturbances as anemia, and evaluation for noncardiac disorders is warranted in puppies with incidentally detected murmurs and a history or physical examination findings consistent with noncardiac disease.

Pathological murmurs in puppies typically result from congenital heart malformations. The overall prevalence of congenital heart disease has been estimated to be 4.6–8.5 per 1000 in clinical populations.⁸ The most common congenital heart defects reported in dogs in the United States include pulmonic stenosis, subvalvular aortic stenosis, patent ductus arteriosus, and ventricular septal defect (VSD).⁸ Similar findings have been reported for dogs in Europe, with variations including a high prevalence of atrial septal defects in France, and mitral valve dysplasia in the United Kingdom and France. Although particular breeds as a group can be predisposed to certain congenital malformations, the examiner must guard against applying such generalizations too rigorously to individual animals.

As mentioned for veterinary patients in general, the examination is intended to differentiate pathological from nonpathological murmurs, and in the case of pathological murmurs, to narrow down the differential diagnosis. Two common

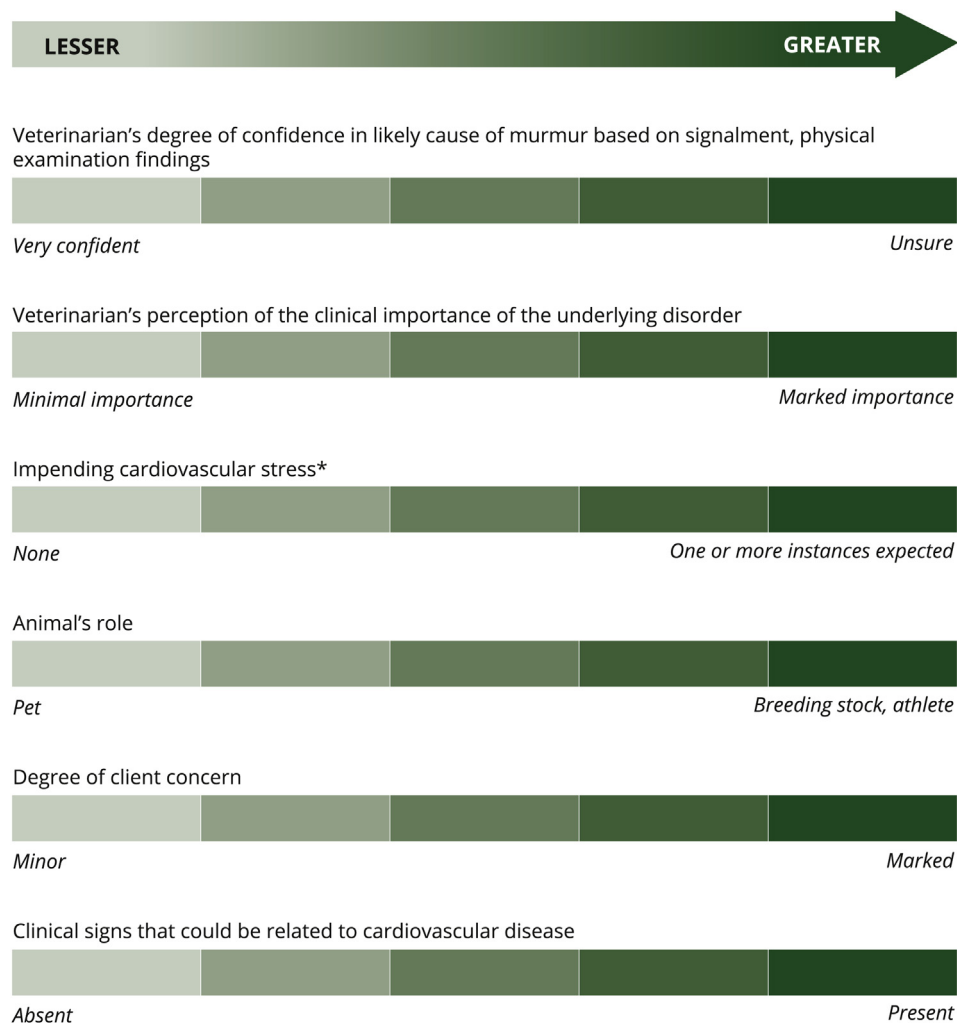


Figure 2 Illustration depicting degree of importance and likely benefit of cardiovascular diagnostic testing in dogs and cats with incidentally detected heart murmurs. As the features of a given case move from left to right in the six categories, the expected importance and yield of diagnostic tests increase. *Examples of activities that could lead to cardiovascular stress include airplane travel and general anesthesia.

scenarios are described in the following sections as practical examples.

Scenario 1: a diagnostic evaluation beyond the physical examination is indicated

Young dogs with incidentally detected heart murmurs that warrant further investigation include those with: a continuous murmur; a diastolic murmur; a murmur that obscures the second (or both) heart sounds; a murmur accompanied by transient abnormal heart sounds (e.g. a split second heart sound); a murmur that radiates to the carotid region; a systolic murmur best heard at the left apex over the mitral valve area; or a murmur that is best heard on the right hemithorax, regardless of the intensity grade of the murmur. In addition, further investigation is warranted for

young dogs with systolic murmurs of grade 3/6 or louder with a point of maximal intensity over the left heart base. Any murmur in a dog that is directly related (e.g. parent, offspring, or sibling) to a dog with known congenital heart disease warrants further investigation, even if the characteristics of the murmur suggest that it is a non-pathological murmur, as is common in several breeds.^{9,10,i} Additional indications for further evaluation include: the finding of a soft murmur in association with abnormal pulsations or distension of jugular veins; abnormalities of the femoral arterial pulse (e.g. bounding, or hypokinetic and delayed [parvus et tardus] pulse); evidence of poor

ⁱ Stepien RL, Kellihan H, Luis Fuentes V. Accuracy of auscultation alone to identify mitral insufficiency in adult whippets (abstr). *J Vet Intern Med* 2011;25:1480.

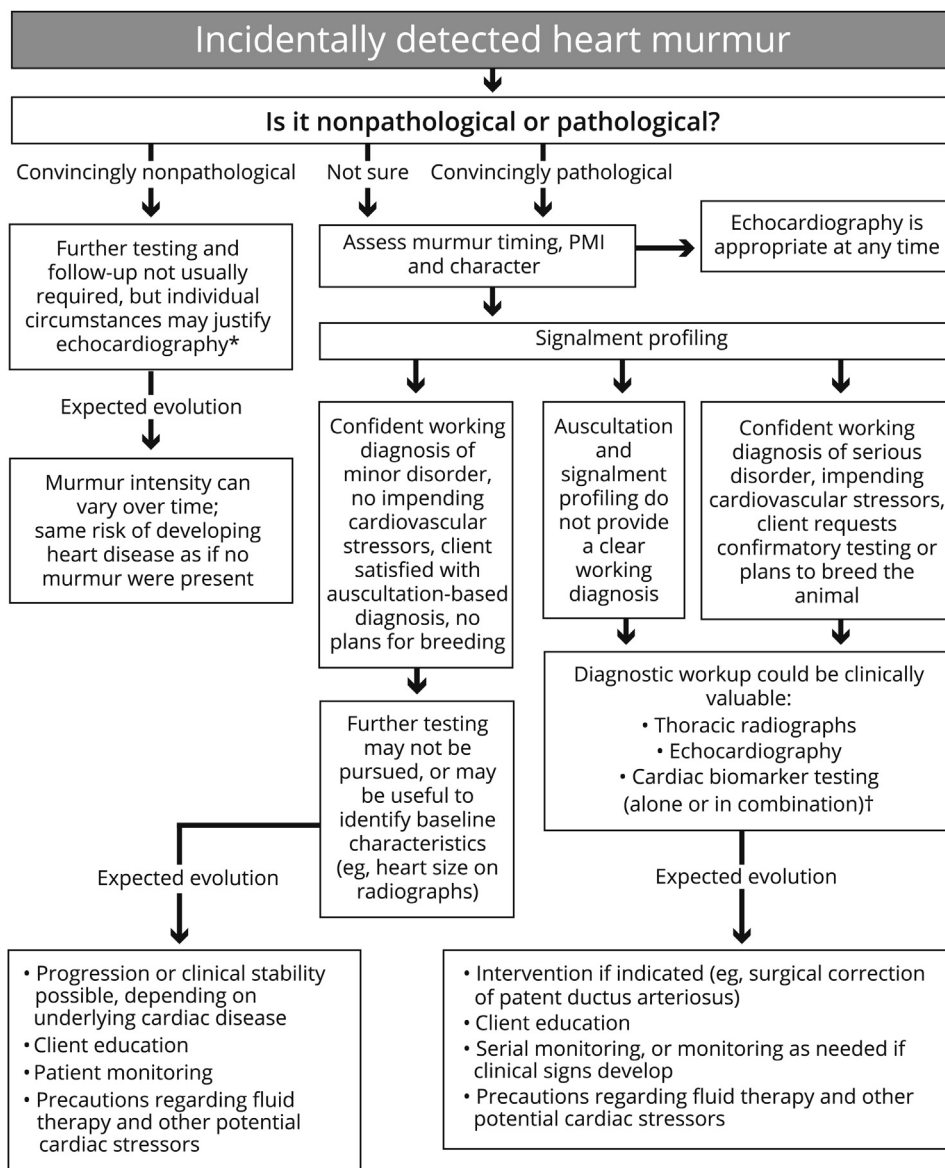


Figure 3 Flow diagram of the general approach to evaluating incidentally detected heart murmurs in dogs and cats. *Circumstances in which echocardiography of a patient with a convincingly nonpathological murmur could be warranted include plans to breed the animal or a client's desire to confirm or refute structural cardiac disease. †Tests should be selected on the basis of logistical limitations and expected diagnostic yield. PMI = point of maximal intensity.

peripheral perfusion; abnormalities of mucous membrane color; or a cardiac arrhythmia other than respiratory sinus arrhythmia.

Many young dogs with serious congenital heart defects that have no obvious clinical signs will have easily recognizable abnormalities on an electrocardiogram (ECG) or thoracic radiographs. Although these methods may offer useful ancillary information, they cannot provide a definitive etiologic diagnosis of the murmur. For example, in a study¹¹ to assess the use of survey radiography for diagnosis of congenital cardiac anomalies in dogs, the

differential diagnoses included the correct diagnosis for 21–23 of 57 (37–40%) dogs with congenital heart disease. For evaluation of young dogs, the diagnostic yield of echocardiography is superior to that of radiographic examination, in that it is more likely to provide the information needed to identify a congenital heart defect and enables the clinician to better assess disease severity, the occurrence of multiple defects, and the suitability of surgical or medical treatment, and to establish a more accurate prognosis. For greatest accuracy, a cardiologist should perform echocardiography.¹² The accuracy

of high-resolution Doppler echocardiography for the identification of congenital heart defects is well established.¹³

Scenario 2: a diagnostic evaluation beyond the physical examination may or may not be indicated or can be deferred

In a young dog, a grade 1/6–2/6, short-duration, systolic heart murmur (e.g. a midsystolic murmur with clearly audible first and second heart sounds) that is localized to the region of the left heart base is typically nonpathological. Such a finding would not necessarily indicate the need for diagnostic tests, but would warrant a discussion with the client regarding the advisability of further evaluation. Considerations would include complete identification and description of the murmur's characteristics – the breed of dog, its athleticism or intended purpose (breeding, field trial, or other) – and the concerns and desires of the client (Fig. 2).

With auscultation alone, it is difficult or impossible to distinguish a nonpathological murmur from a murmur with similar characteristics that is caused by a trivial congenital lesion. This issue has little practical importance for the management of most dogs; for example, a very mild subaortic stenosis lesion would not be expected to substantially impact the health of a given patient. In a situation such as this, watchful waiting can be a reasonable approach if additional features of the case suggest that the importance of further diagnostic testing will be low (Fig. 2). However, such dogs should not be bred until a definitive diagnosis is established, which usually requires a complete echocardiographic examination.

Heart murmurs in adult dogs

Systolic murmurs are more common than diastolic or continuous murmurs in adult dogs. Diastolic or continuous murmurs are invariably pathological, and in all cases should be investigated with echocardiography, considering that these dogs can benefit from definitive clinical diagnosis and treatment (e.g. confirmation and treatment of infective endocarditis, or surgical/catheter-based closure of patent ductus arteriosus).

When a veterinarian detects a systolic murmur, it is appropriate to seek a second opinion from a cardiologist who may make an assessment on the basis of auscultation or, if deemed necessary, echocardiography. This approach may not be feasible for every pet owner, however. A skilled veterinarian often can make a provisional diagnosis on the basis of history,

and a physical examination that includes careful cardiac auscultation. For some clients and their pets this approach can be sufficient, whereas for others it might not be (Fig. 2). Nonpathological systolic ejection murmurs (Table 1) may be due to identifiable extracardiac disorders, for which an in-depth cardiac evaluation is not needed. When such a murmur is detected incidentally in adult dogs and a plausible systemic cause is identified, the evaluative approach can proceed, as described in Scenario 2 for pediatric dogs with murmurs that may or may not require further cardiovascular system testing. It is expected that the murmur will resolve with normalization of the systemic disturbance, and if not, cardiovascular diagnostic testing should be performed.

Acoustic features of a murmur may further narrow down the differential diagnosis at the time of auscultation. Ventricular septal defect and degenerative or myxomatous atrioventricular valve disease (DMVD) are examples of disorders that cause so-called plateau-shaped systolic murmurs, which are named this way because of their phonocardiographic appearance. Plateau-shaped murmurs are recognized on auscultation by a similar sounding intensity throughout systole, and, typically, their obliteration of the second heart sound. Conversely, subaortic stenosis and pulmonic stenosis are examples of disorders that cause systolic ejection murmurs. Ejection murmurs have a crescendo (i.e. increase in loudness during systole) or crescendo-decrescendo (i.e. loudest during midsystole) character and do not typically interfere with audibility of the second heart sound. In some adult dogs, the sound intensity profile of a murmur – corresponding to its phonocardiographic shape – can be difficult to discern on auscultation, making the auditory distinction between plateau murmurs and ejection murmurs difficult. If auscultation results are ambiguous in this respect, further diagnostic testing is justified.

The location of a murmur's point of maximal intensity is also helpful for identifying the likely cause of the murmur. For example, an investigationⁱ of the diagnostic accuracy of auscultation for identification of mitral regurgitation in Whippets revealed that auscultation of any murmur was associated with very low specificity: false-positive diagnoses of mitral regurgitation were made for 166 of the 186 (89%) dogs with murmurs. Partly, this likely reflected the high prevalence of functional left basilar murmurs in Whippets; indeed, when only those murmurs heard over the left cardiac apex were considered, indices of diagnostic accuracy substantially improved and the frequency of false-positive diagnoses decreased to 15 of the 186 (8%) dogs.ⁱ

Finally, murmur intensity or loudness is of some limited benefit in determining severity of mitral valvular regurgitation in adult small-breed dogs with DMVD. Overall, adult small-breed dogs typically have a larger amount of mitral regurgitation if the murmur is louder (corresponding to a higher grade).¹⁴ This generalization, however, cannot be used for providing a precise prognosis for individual patients because body condition, orientation of the regurgitant jet, and sympathetic activation may alter a murmur's grade irrespective of the severity of DMVD.

Some veterinary cardiologists deliberately auscult adult dogs at rest and again immediately after exercise as a means of identifying flow-dependent or heart rate-associated murmurs. For example, in one study, 68 out of 100 (68%) auscultations in 19 Boxers revealed a murmur at rest, and 95 (95%) auscultations of the same dogs revealed a murmur after the dogs had 3 min of exercise.¹⁵ Furthermore, murmur intensity increased after exercise: 2 out of 100 (2%) murmurs were grade 3/6 with exercise compared with 0 (0%) at rest; 74 (74%) were grade 2/6 after exercise compared with 24 (24%) at rest; and 19 (19%) were grade 1/6 after exercise compared with 44 (44%) at rest.¹⁵ The practice of auscultation after physical exercise increases the detection rate of pathological murmurs and nonpathological murmurs.¹⁵ Therefore, it may be considered when the veterinarian and the client understand that the emergence of a new murmur at a higher heart rate is not a conclusive finding, but justification for additional diagnostic testing.

In an adult dog, systolic murmurs heard loudest over the left cardiac apex are most commonly caused by mitral regurgitation; in turn, DMVD is the most frequent cause of mitral regurgitation, but dilated cardiomyopathy (DCM), infective endocarditis, and congenital mitral valve dysplasia are also recognized causes of mitral regurgitation. Systolic murmurs heard best over the left heart base are managed in adult dogs as described for young dogs. Systolic murmurs that are loudest over the right hemithorax are most commonly caused by tricuspid valve regurgitation (with or without pulmonary hypertension), subaortic stenosis, or VSD, and further evaluation should be considered on the basis of concomitant factors (Fig. 2).

In conjunction with the features of the murmur, signalment profiling can be helpful. The simple process of evaluating the murmur's characteristics together with the patient's signalment narrows the differential diagnosis, and helps the practitioner

to select appropriate diagnostic tests (Fig. 4 and 5). This process is illustrated with the following two examples.

Example 1: evaluation of a small-breed (< 20 kg) adult dog with a systolic murmur loudest over the left apex

This type of murmur may be pathological (e.g. DMVD, mitral valve dysplasia, or infective endocarditis of the mitral valve) or nonpathological (e.g. anemia, breed-associated or individual variation). Auscultatory features of the murmur help to make this distinction (Table 1), as do extracardiac observations (e.g. pallor, suggesting anemia) and the prevalence of specific disorders in the patient's breed. If uncertainty persists despite these observations, or if the murmur is convincingly pathological, additional investigation is justified (Fig. 3).

Echocardiography provides a more precise and more accurate diagnosis of the cause of a murmur than radiographic examination, and is advised; however, thoracic radiographs often are performed first because of lower cost, greater availability than echocardiography, and ability to identify pulmonary and vascular abnormalities. Absence of radiographic evidence of cardiomegaly in an adult dog with a systolic left apical murmur suggests a nonpathological murmur, mild heart disease (e.g. early stage of DMVD), or heart disease that may be clinically important but not yet associated with cardiomegaly (e.g. infective endocarditis). In adult small-breed dogs with incidentally detected murmurs, clinically important heart disease is uncommon if thoracic radiographic findings are normal. The decision to pursue further diagnostic testing should be based on assessment of all factors that pertain to the case (Fig. 2). Echocardiography performed by a cardiologist is the gold standard for identifying the cause of such murmurs.¹² Assessment of circulating amino-terminal pro-B-type natriuretic peptide (NT-proBNP) concentrations provides additional information of limited value in this situation; for example, in a study¹⁶ of dogs with preclinical DMVD, the median NT-proBNP concentration was significantly ($p < 0.001$) higher in dogs with cardiomegaly than in those with a cardiac silhouette of normal size. However, the range of results was broad, and many clinical results can be expected to fall in a range of overlap between radiographically normal heart size and cardiomegaly, conferring limited use for clinical decision making for individual patients.

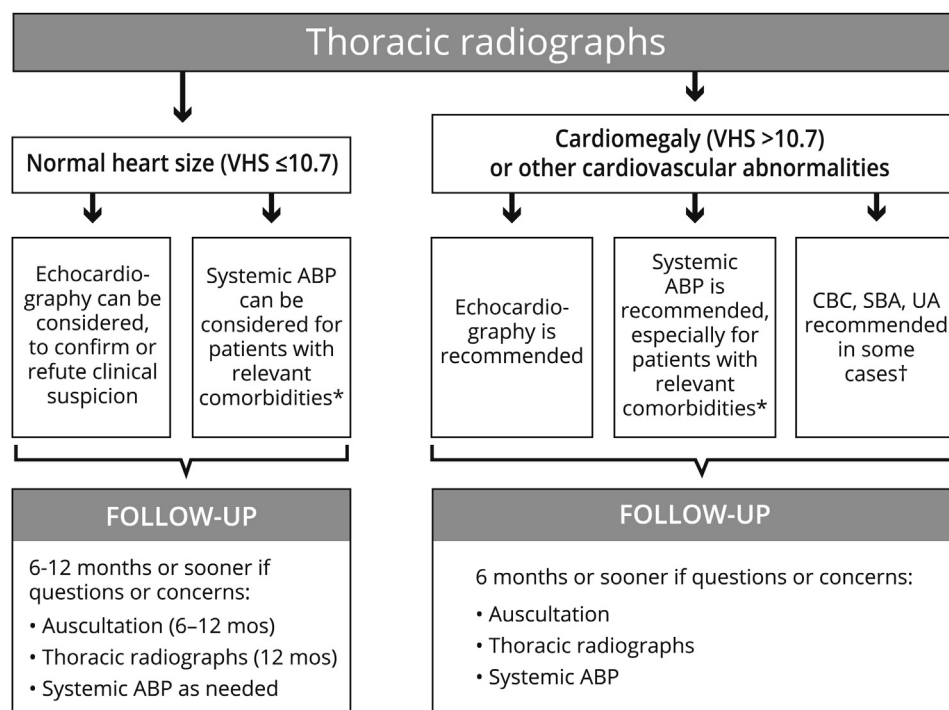


Figure 4 Flow diagram of a diagnostic testing approach for assessing an adult small-breed dog with an incidentally detected left apical systolic heart murmur and no overt signs of CHF. *Relevant conditions include chronic kidney disease, adrenal gland disease, or diabetes mellitus. †Recommended for patients that have comorbidities or that are receiving treatment for congestive heart failure, cardiac arrhythmias, myocardial systolic dysfunction, or any combination of these disorders. ABP = arterial blood pressure measurement; SBA = serum biochemical analysis; UA = urinalysis.

In adult small-breed dogs with incidentally detected left apical systolic murmurs, serial follow-up of cardiac size on thoracic radiographs can be a useful monitoring tool (Fig. 4). For example, Cavalier King Charles spaniels (CKCS) with DMVD may have a vertebral heart score (VHS) that is stable and may not have clinical signs for years, followed by a rapid increase in VHS and, eventually, the development of congestive heart failure (CHF). In a longitudinal study of 94 CKCS with DMVD, the median VHS was 11 at 3.5–4 years, 11 at 2.5–3 years, 11.25 at 1.5–2 years, and 11.7 at 0.5–1 year before diagnosis of CHF; at the onset of CHF, the median VHS had increased to 13.25.¹⁷ Thus, in a typical case, an unchanging VHS of 10.6–11.3 in an adult CKCS with an incidentally identified left apical systolic murmur is unlikely to reflect extensive cardiac changes or imminent CHF.

Example 2: assessment of a large-breed (≥20 kg) adult dog with a systolic murmur loudest over the left apex

The causes of left apical systolic murmurs in large-breed dogs are similar to those for small-breed

dogs. However, the prevalence of individual diseases in the two populations are generally very different, and fewer conclusions may be confidently reached on the basis of physical examination results alone for large-breed dogs. Indeed, differentiation between the principal causes of left apical systolic murmurs in large-breed dogs via auscultation alone is unreliable, and thoracic radiographs may reveal few or no abnormalities in the early stages of disease. Therefore, echocardiography is the single best diagnostic test for evaluating an adult large-breed dog with an incidentally detected murmur (Fig. 5).

Nonpathological murmurs must be considered first, and the cardiac apex is rarely their point of maximal intensity. If nonpathological murmurs are considered less likely on the basis of auscultatory features (Table 1) and the rest of the physical examination does not reveal a likely basis for a nonpathological murmur, a pathological murmur is more likely and further diagnostic testing is recommended. In adult large-breed dogs, disorders that produce systolic murmurs that are loudest over the left apex include DCM,¹⁸ mitral valve dysplasia, DMVD of large-breed dogs,¹⁹ and infective endocarditis. In large-breed dogs, DCM and

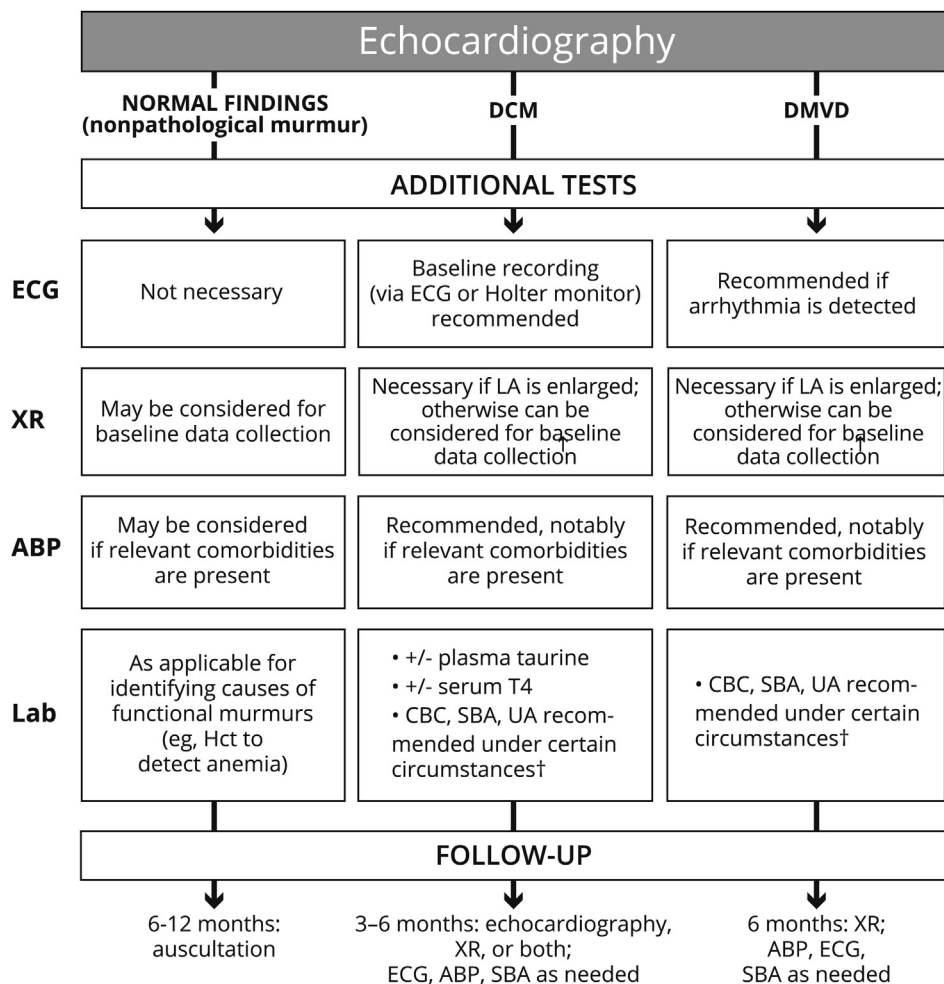


Figure 5 Flow diagram of a diagnostic testing approach for assessment of an adult large-breed dog with an incidentally detected left apical systolic heart murmur and no overt signs of CHF. It should be noted that, in the absence of echocardiography, the cause of most systolic murmurs in large-breed dogs couldn't be definitively determined; thoracic radiography then becomes the most important test to evaluate for cardiomegaly or evidence of CHF. Recommendations are provided for the most common causes of murmurs in adult dogs; others are possible but less prevalent. †In specific cases, measurement of analyte concentrations can be beneficial. ABP = arterial blood pressure measurement; Lab = laboratory tests; SBA = serum biochemical analysis; T4 = thyroxine concentration; UA = urinalysis; XR = radiography.

DMVD often produce soft, systolic, plateau-type murmurs, despite a potentially aggressive disease course over time. If the dog's breed or other features suggest a particular disorder, a differential diagnosis may be narrowed or better prioritized, but in adult large-breed dogs, not to the point of eliminating the need for echocardiography.

Inevitably, the distinction between large- and small-breed dogs involves overlap with dogs of an intermediate body size. It is also possible for small-breed dogs to develop heart diseases that occur more commonly in large-breed dogs, and vice versa. Therefore, the examples presented here should be considered to offer general diagnostic

approaches that need to be modified when individual variations are encountered.

Heart murmurs in geriatric dogs

A geriatric animal is one that has entered the last 25% of the average expected lifespan for the species and breed.²⁰ In this age group, murmurs due to congenital heart disease are identified occasionally,²¹ but those caused by adult-onset heart disease are much more prevalent. Features of the cardiac auscultation and the rest of the physical examination are at the core of an accurate

differential diagnosis. Characterization of the murmur's sound quality, point of maximal intensity, and timing allow a skilled veterinarian to differentiate initially between findings suggestive of common disorders versus those that suggest unusual disorders. For example, a 10-year-old Dachshund with an incidentally detected grade 4/6 systolic left apical murmur most likely has DMVD, but an otherwise similar dog with a grade 4/6 left basilar systolic murmur that radiates to the carotid region almost certainly has a disorder other than DMVD. In each case, the veterinarian's confidence in the presumptive diagnosis helps guide the client's decision on whether to pursue diagnostic testing (Fig. 2).

Geriatric small-breed dogs with murmurs commonly have DMVD, particularly if the murmur is systolic and loudest over the left apex.^{14,22} The demarcation between adult and geriatric age groups must be considered indistinct, and different breeds have characteristic prevalence of murmurs that span the adult and geriatric age categories. Results of one retrospective study²³ indicated that a left apical systolic murmur develops in approximately 20% of each of the following dog breeds at these median ages: CKCS by 4 years of age, Shih Tzus by 8.6 years of age, Dachshunds by 9.5 years of age, Bichon Frisés by 10.4 years of age, Miniature Poodles by 11.1 years of age, Yorkshire Terriers by 12.7 years of age, and Lhasa Apsos by 13.2 years of age, with DMVD as the most likely cause. Thus, in geriatric dogs or any adult dogs of unknown age, signalment profiling is a useful tool in developing and prioritizing differential diagnoses. This process helps the veterinarian offer general guidance to a client, but does not replace the information provided by thoracic radiography, echocardiography, or both.

In the absence of any other clinical signs possibly related to heart disease, geriatric small-breed dogs with systolic murmurs that have a point of maximal intensity over the left apex can be evaluated by thoracic radiography. As mentioned for adult small-breed dogs (Example 1), thoracic radiographs can provide important prognostic and therapeutic information for patients with presumed or confirmed DMVD: a cardiac silhouette of normal size and shape in a dog that has no overt signs of decompensated heart disease is consistent with mild DMVD, and no currently available treatment appears to alter the progression of DMVD at this stage. Additionally, such radiographs may then provide baseline information for comparison as the disease progresses.¹⁷

Echocardiography can provide clinically important information about any geriatric dog with an incidentally detected murmur. It is especially warranted if the murmur has a point of maximal intensity over the right hemithorax or is equally loud on the right and left sides of the thorax; is loudest over the heart base; radiates to the thoracic inlet, carotid arteries, or both; or is diastolic or continuous. An echocardiogram is indicated in a geriatric dog with a murmur that is accompanied by a cardiac arrhythmia other than respiratory sinus arrhythmia, distension or abnormal pulsations of the jugular veins, or abnormalities of the femoral arterial pulse. A murmur that is recent in onset and coexists with vague systemic signs justifies diagnostic testing to address the possibility of infective endocarditis.

A left apical systolic murmur might be incidentally detected in a geriatric small-breed dog with signs that the client attributes to aging — including exercise intolerance and decreased interaction with people — but such signs can be caused by heart disease. In this instance, thoracic radiographs and clinicopathologic tests (e.g. complete blood count, serum biochemical analysis, and urinalysis, as appropriate) are warranted; a radiographically normal cardiac size lessens the likelihood of a cardiogenic basis for the signs, whereas cardiomegaly should prompt a recommendation for echocardiography to differentiate structural heart disease from a large cardiac silhouette caused by innocuous technical or individual animal factors.

In medium-breed, large-breed, and giant-breed geriatric dogs with incidentally detected left apical systolic murmurs, it is important to consider that the murmur may be caused by such disorders as DMVD, which can progress more rapidly in large-breed than small-breed dogs; DCM; or infective endocarditis. Therefore, in dogs that weigh approximately 20 kg or more, a left apical systolic murmur should prompt a recommendation for echocardiography as the initial diagnostic test of choice.

Heart murmurs that are convincingly non-pathological on the basis of a thorough auscultation are by definition not caused by structural heart disease, and therefore do not require radiographic or echocardiographic evaluation. As previously noted, it may be difficult to differentiate nonpathological murmurs from soft pathological murmurs, and any uncertainty warrants additional evaluation as appropriate for the signalment of the patient: auscultation by a cardiologist or echocardiography would be logical choices in this context.

Heart murmurs in kittens

The pediatric age group for cats can be considered to include patients ≤ 6 months of age,⁶ which is roughly analogous to the pediatric population in human medicine. In these young cats, the prevalence of congenital heart disease has been estimated at 1.6% and 5% in adoption centers and the referral setting, respectively.^{24,j} It is important to consider that young cats may have heart diseases commonly recognized in adult cats (notably hypertrophic cardiomyopathy), and that non-pathological murmurs can occur in cats of any age.^{24,j}

In young cats, a nonpathological murmur may be caused by systemic disturbances (e.g. anemia), iatrogenic factors (e.g. excitement), or can be detected in patients with no identifiable systemic or structural cardiovascular disorder.^j Murmurs attributable to anemia may be somewhat easier to recognize in young cats because they often have a hematocrit that is below laboratory reference intervals for adult cats and have a thin chest wall. These murmurs are high-frequency, midsystolic (whereby the first and second heart sounds are still heard clearly), and often soft and variable in their intensity, depending on the severity of the anemia, but seldom of grade $>2/6$. They often are best heard at the left heart base or apex. Concurrent findings of pallor or other physical abnormalities should be evaluated because the murmur, in such instances, might be only one indicator of a systemic disturbance.

The specific characteristics that separate pathological and nonpathological murmurs fail to reliably do so in most cats with grade 1/6–3/6 systolic murmurs. This uncertainty can be addressed with one of three approaches: further cardiovascular diagnostic testing (e.g. Doppler echocardiography), second-opinion auscultation by a cardiologist, or simple reexamination and reauscultation, typically after a period of 2–4 weeks. A pediatric stethoscope is often helpful for accurate auscultation of kittens and small cats. The course to be pursued should be decided on the basis of perceived advantages and liabilities of each approach, and is a matter for discussion between the veterinarian and the client according

to several important criteria (Fig. 2). A persistent, soft, left parasternal murmur may be either pathological or nonpathological, and this distinction is best made by Doppler echocardiography. As another example, there is a greater incentive to obtain an echocardiographic diagnosis when a murmur is incidentally detected in a young cat that is a member of a breeding colony or is scheduled to undergo general anesthesia, to assist with breeding decisions and anesthetic planning, respectively.

When young cats have incidentally detected murmurs with clearly pathological characteristics (Table 1), diagnostic testing is warranted. Except for most cases of patent ductus arteriosus in patients with normal pulmonary artery pressures, where a continuous murmur is evident,^k congenital cardiac malformations in cats generally produce a systolic murmur. Murmur intensity and location, while helpful for narrowing the differential diagnosis list, have limited value regarding specific diagnosis and prognosis in cats. Cats with clinically unimportant VSDs routinely have loud (e.g. grade 5/6) systolic murmurs, and murmur intensity cannot be used for judging lesion severity. In this age group, 2-D and Doppler echocardiography by a cardiologist are recommended for diagnosis and prognosis because they are the most effective means of identifying the lesion and its degree of severity, concurrent defects, risk of complications, need and options for corrective treatment, and broad prognosis. Thoracic radiographs are of value, and a cardiac silhouette of normal size, in the absence of evidence of pulmonary abnormalities, provides some reassurance that severe congenital heart disease is unlikely. However, assessment of cardiac size on thoracic radiographs in young cats can have limited accuracy; structural heart disease can be wrongly suspected if peritoneopericardial diaphragmatic hernia causes a large cardiac silhouette in a cat with a normal heart and, conversely, it may be missed if the murmur is caused by a congenital malformation that causes concentric ventricular hypertrophy. It is believed that, to date, no investigations have been published of the use of circulating biomarkers (e.g. NT-proBNP and cardiac troponins) for evaluating cardiac status in young cats.

^j Dirven MJM, Barendse MA, vanMook MC, Sterenberg JA, vanden Wildenberg A. Prevalence of heart murmurs and congenital heart disease in 2935 young cats (abstr). *J Vet Intern Med* 2012;26:1513.

^k Hitchcock LS, Lehmkuhl LB, Bonagura JD. Patent ductus arteriosus in cats: 21 cases (abstr). *J Vet Intern Med* 2000;14:338.

Heart murmurs in adult and geriatric cats

Systolic murmurs are common in overtly healthy adult cats, and have been reported to affect 16/103 (16%) to 44/100 (44%) cats ausculted by veterinarians in hospital and shelter settings.^{25–27,l} The frequency of murmur detection appears to increase with repeated examinations²⁷ and with stimulation of the cat.²⁶

Among adult cats with incidentally detected murmurs but no overt clinical signs, the prevalence of heart disease has been reported as 16/103 (16%) to 44/57 (77%), varying by geographic location, examiners, and study methods.^{25–30} The most common underlying heart disease in adult cats is hypertrophic cardiomyopathy (found in 15/103 (15%) to 38/61 (62%) of adult cats with incidentally detected murmurs), and the most common non-pathological murmur is caused by dynamic right ventricular outflow tract obstruction (8/103 [8%] to 9/57 [16%] of adult cats with incidentally detected murmurs).^{25–31,m} Subjectively, there is extensive overlap between the auscultatory characteristics of murmurs caused by cardiomyopathy and those resulting from nonpathological murmurs in cats, and generally, these cannot be differentiated from each other by auscultation alone. Auscultation of other cardiac abnormalities such as a gallop sound or arrhythmia might be even more valuable than the detection of a murmur for identifying cats at increased risk for CHF or arterial thromboembolism.³²

Clients might not initially recognize clinical signs, but a veterinarian can detect extracardiac physical findings that suggest a systemic disorder, and a client could then retrospectively realize that clinical signs were present after they have been resolved with treatment. This scenario is particularly relevant for geriatric cats, in which hyperthyroidism, other disorders causing systemic hypertension, and anemia are more prevalent than in younger cats and can cause a non-pathological murmur that resolves with identification and treatment of the underlying disorder (Fig. 6).

Before auscultation, important features of the physical examination include precordial palpation, because an increase in the force of the cardiac beat at the apex can occur with cardiomegaly or with diseases such as hyperthyroidism that are associated with high cardiac output, and a thrill indicates a murmur grade \geq of 5/6; mucous membrane color, because pallor could suggest anemia as the cause of a murmur; evaluation of the neck for jugular distension and the abdomen for ascites, both of which are very uncommon in overtly healthy cats; and pulse quality, which is highly variable in cats.

A systematic evaluation of the murmur's characteristics is indicated when a heart murmur is detected in a cat. The small size of cats' hearts can make specific distinctions between sounds with greatest intensity at the apex or base challenging in some; a common oversight is failure to auscult specifically over the sternum and parasternally. In cats, murmurs are often labile, changing in intensity with excitement or heart rate, or simply increasing or decreasing in intensity over time.^{26,27,l} This finding has little diagnostic significance, as it may occur with pathological or nonpathological murmurs.²⁶ Lateralization can narrow the differential diagnosis list in some patients: for example, right-sided systolic murmurs in adult cats are more commonly caused by dynamic right ventricular outflow tract obstruction, hypertrophic obstructive cardiomyopathy, or congenital malformations (notably tricuspid dysplasia and VSD).

Thoracic radiography can be helpful for detection of advanced cardiac disorders: a VHS >9.3 in cats is strongly associated with cardiac disease as a cause for dyspnea.³³ However, in cats with incidentally detected murmurs (where clinical signs are absent by definition), a higher rate of false-negative results could be expected than for cats with signs referable to the cardiovascular system. Measurement of circulating NT-proBNP concentration also has value for detection of occult cardiomyopathy; in one study,³⁴ a result of <50 pmol/L indicated that cardiomyopathy was very unlikely, whereas a result of >100 pmol/L suggested that cardiomyopathy was present. Thoracic radiography, NT-proBNP testing, or both may be useful when client limitations (financial, logistic, geographic, or other) prevent the cat from undergoing complete 2-D and Doppler echocardiography (Fig. 6). Echocardiography is considered the diagnostic test of choice for pinpointing the cause of a murmur. Furthermore, echocardiography was found to have superior results, compared with radiography (28–72%

^l Drourr LT, Gordon SG, Roland RM, Boggess M. Prevalence of heart murmurs and occult heart disease in apparently healthy adult cats, in *Proceedings. 28th Annu Ame Coll Vet Intern Med Forum 2010*. Available at www.vin.com/doc/?id=4504365 (last accessed 20 April 2014).

^m Allen JW, Yee K, Buckner MH, Ettinger SJ. NT-proBNP levels in 30 cats with dynamic right ventricular outflow obstruction (abstr). *J Vet Intern Med* 2010;24:695.

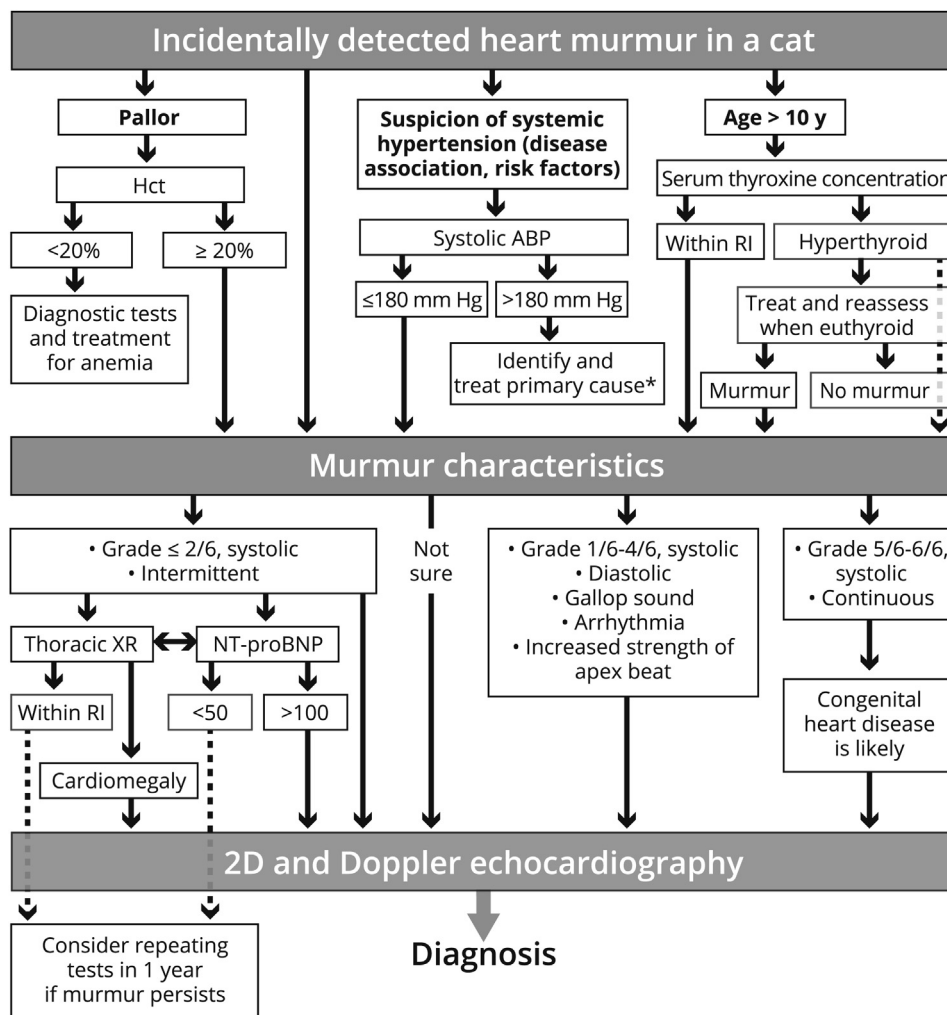


Figure 6 Flow diagram depicting a general diagnostic testing approach for assessment of an adult (>6 months of age) cat with an incidentally detected heart murmur. Dashed lines indicate areas of investigation or controversy where several approaches are possible. *Echocardiography may still be considered if other features support it. †Circulating concentration (pmol/L). ABP = arterial blood pressure measurement; Lab = laboratory tests; RI = reference interval; SBA = serum biochemical analysis; T4 = thyroxine concentration; UA = urinalysis; XR = radiography.

accuracy) or ECG (12–60% accuracy) for identifying left atrial enlargement in cats,³⁵ and left atrial enlargement is probably the most important risk factor for adverse cardiac events and shortened survival among many types of heart diseases of cats.^{32,36}

Areas of uncertainty

Many aspects of heart murmur assessment deserve greater attention. The following specific areas represent points that are especially relevant to a clinical setting.

Overlap between clinically normal animals with nonpathological murmurs and animals with mild forms of heart disease

It can be challenging, even for experienced cardiologists, to differentiate clinically normal animals with nonpathological heart murmurs from those with mild outflow tract obstruction or other subtle structural heart lesions. Breed-associated overlap between physiologic variants and pathological lesions has been investigated in Boxers, Whippets, and other dog breeds.^{9,10,1} It may not be important to differentiate functional murmurs from murmurs associated with mild forms of heart disease in pet

animals, as their management will be similar. It can be more important to make this distinction in breeding however, because an affected animal may have clinically unimportant heart disease but be capable of transmitting a predisposition to developing heart disease to its progeny.

Integration and value of newer diagnostic tests

Diagnostic tests of blood, serum or plasma (e.g. circulating concentrations of biomarkers for cardiac disease) offer the promise of information obtained without requiring referral for echocardiographic evaluation, although the cause of a heart murmur cannot be concluded from evaluation of blood-borne cardiac biomarkers alone. Investigations of such assays in large series of animals with similar murmurs would be useful; for example, differences may be detectable between dogs with pathological murmurs and dogs with nonpathological murmurs of similar intensity and character. Furthermore, it is believed that the role of circulating biomarker assays as one of multiple components of a diagnostic evaluation (e.g. assessment of thoracic radiographs and serum biomarker concentrations together, compared with echocardiographic examination) has not been explored in dogs or cats with incidentally detected murmurs, but could be of clinical benefit.

Outcome evaluation

The authors are aware of no specific studies that describe the long-term outcomes of dogs or cats that have undergone diagnostic evaluation of incidentally detected heart murmurs, compared with those in which murmurs were not evaluated further. Nevertheless, it is self-evident that failure to diagnose the cause of a murmur can sometimes lead to a worse outcome. In one retrospective study,³⁷ dogs with severe pulmonic stenosis that did not undergo balloon-valve dilation had a worse outcome than those that did; the same results have been found for dogs with corrected versus uncorrected patent ductus arteriosus in multiple studies.^{38,39} Failure to identify advanced cardiac disease prior to general anesthesia or IV fluid therapy can result in unexpected signs of CHF. Conversely, failure to identify a murmur as non-pathological (and therefore clinically benign) can lead to needless owner anxiety and an unjustifiably guarded prognosis.

Whether the benefit of diagnosing the cause of a murmur is distributed equally across different diseases, species and breeds, and murmur types is unknown. Similarly, many other important

questions remain, including which subgroups of patients receive the greatest long-term benefit from diagnostic testing, the recommended interval and methods for follow-up, and the costs and benefits of rechecking at various intervals.

Conclusions

It is easy to recommend that all patients with incidentally detected heart murmurs undergo echocardiography. A true understanding of the realities and imperatives of clinical practice says otherwise. This report is intended to provide a summary of the patient-based, client-based, and veterinarian-based factors that can help attending veterinarians recommend whether or not to pursue further diagnostic evaluation of patients with incidentally detected murmurs and the advantages and suitability of various diagnostic approaches.ⁿ

Supplementary data

Supplementary data, consisting of an executive summary for veterinarians and a client education sheet, can be found at <http://dx.doi.org/10.1016/j.jvc.2015.05.001>

References

1. Côté E, Edwards NJ, Ettinger SJ, Luis Fuentes V, MacDonald KA, Scansen BA, Sisson DD, Abbott JA. Management of incidentally detected heart murmurs. *J Am Vet Med Assoc* 2015;246:1076–1088.
2. Marriott HJL. Systolic murmurs. In: Marriott HJL, editor. *Bedside cardiac diagnosis*. Philadelphia: J.B. Lippincott; 1992. p. 83–87.
3. Bronzetti G, Corzani A. The seven “S” murmurs: an alliteration about innocent murmurs in cardiac auscultation. *Clin Pediatr (Phila)* 2010;49:713.
4. Ettinger SJ, Suter PF. Heart sounds and phonocardiography. In: Ettinger SJ, Suter PF, editors. *Canine cardiology*. Philadelphia: W.B. Saunders; 1970. p. 12–39.
5. Pedersen HD, Haggström J, Falk T, Mow T, Olsen LH, Iversen L, Jensen AL. Auscultation in mild mitral regurgitation in dogs: observer variation, effects of physical maneuvers, and agreement with color Doppler echocardiography and phonocardiography. *J Vet Intern Med* 1999;13:56–64.

ⁿ An executive summary for veterinarians on incidentally detected heart murmurs in dogs and cats and a client information sheet are posted with the article at <http://www.sciencedirect.com/science/journal/17602734> <http://dx.doi.org/10.1016/j.jvc.2015.05.001>.

6. Root Kustritz M. History and physical examination of the weanling and adolescent. In: Peterson ME, Kutzler MA, editors. *Small animal pediatrics*. St Louis: Elsevier; 2011. p. 28–34.
7. Bélanger MC, Côté E. Innocent heart murmurs. In: Ettinger SJ, Feldman EC, editors. *Textbook of veterinary internal medicine*. 7th ed. St Louis: Elsevier; 2010. p. 255–258.
8. Buchanan JW. Prevalence of cardiovascular disorders. In: Fox PR, Sisson DD, Moïse NS, editors. *Textbook of canine and feline cardiology*. 2nd ed. Philadelphia: W.B. Saunders; 1998. p. 457–470.
9. Koplitz SL, Meurs KM, Bonagura JD. Echocardiographic assessment of the left ventricular outflow tract in the Boxer. *J Vet Intern Med* 2006;20:904–911.
10. Bavegems VC, Duchateau L, Polis IE, Van Ham LM, De Rick AF, Sys SU. Detection of innocent systolic murmurs by auscultation and their relation to hematologic and echocardiographic findings in clinically normal Whippets. *J Am Vet Med Assoc* 2011;238:468–471.
11. Lamb CR, Boswood A, Volkman A, Connolly DJ. Assessment of survey radiography as a method for diagnosis of congenital cardiac disease in dogs. *J Small Anim Pract* 2001;42:541–545.
12. Tse YC, Rush JE, Cunningham SM, Bulmer BJ, Freeman LM, Rozanski EA. Evaluation of a training course in focused echocardiography for noncardiology house officers. *J Vet Emerg Crit Care (San Antonio)* 2013;23:268–273.
13. Oyama MA, Sisson DD, Thomas WP, Bonagura JD. Congenital heart disease. In: Ettinger SJ, Feldman EC, editors. *Textbook of veterinary internal medicine*. 7th ed. St Louis: Elsevier; 2010. p. 1250–1298.
14. Ljungvall I, Ahlstrom C, Höglund K, Hult P, Kwart C, Borgarelli M, Ask P, Häggström J. Use of signal analysis of heart sounds and murmurs to assess severity of mitral valve regurgitation attributable to myxomatous mitral valve disease in dogs. *Am J Vet Res* 2009;70:604–613.
15. Höglund K, Häggström J, Bussadori C, Kwart C. A prospective study of systolic ejection murmurs and left ventricular outflow tract in Boxers. *J Small Anim Pract* 2011;52:11–17.
16. Chetboul V, Serres F, Tissier R, Lefebvre HP, Sampedrano CC, Gouni V, Poujol L, Hawa G, Pouchelon J-L. Association of plasma N-terminal pro-B-type natriuretic peptide concentration with mitral regurgitation severity and outcome in dogs with asymptomatic degenerative mitral valve disease. *J Vet Intern Med* 2009;23:984–994.
17. Lord PF, Hansson K, Carnabuci C, Kwart C, Häggström J. Radiographic heart size and its rate of increase as tests for onset of congestive heart failure in Cavalier King Charles Spaniels with mitral valve regurgitation. *J Vet Intern Med* 2011;25:1312–1319.
18. Wess G, Mäurer J, Simak J, Hartmann K. Use of Simpson's method of disc [sic] to detect early echocardiographic changes in Doberman Pinschers with dilated cardiomyopathy. *J Vet Intern Med* 2010;24:1069–1076.
19. Borgarelli M, Zini E, D'Agnolo G, Tarducci A, Santilli RA, Chiavegato D, Tursi M, Prunotto M, Häggström J. Comparison of primary mitral valve disease in German Shepherd dogs and in small breeds. *J Vet Cardiol* 2004;6:27–34.
20. Epstein M, Kuehn NF, Landsberg G, Lascelles BD, Marks SL, Schaedler JM, Tuzio H. AAHA senior care guidelines for dogs and cats. *J Am Anim Hosp Assoc* 2005;41:81–91.
21. Goodwin JK, Lombard CW. Patent ductus arteriosus in adult dogs: clinical features of 14 cases. *J Am Anim Hosp Assoc* 1992;28:349–354.
22. Detweiler DK, Patterson DF. The prevalence and types of cardiovascular diseases in dogs. *Ann N Y Acad Sci* 1965;127:481–516.
23. Serfass P, Chetboul V, Sampedrano CC, Nicolle A, Benalloul T, Laforge H, Gau C, Hébert C, Pouchelon JL, Tissier R. Retrospective study of 942 small-sized dogs: prevalence of left apical systolic heart murmur and left-sided heart failure, critical effects of breed and sex. *J Vet Cardiol* 2006;8:11–18.
24. Kittleson MD. The approach to the patient with cardiac disease. In: Kittleson MD, Kienle RD, editors. *Small animal cardiovascular medicine*. St. Louis: Mosby; 1998. p. 195–217.
25. Côté E, Manning AM, Emerson D, Laste NJ, Malakoff RL, Harpster NK. Assessment of the prevalence of heart murmurs in overtly healthy cats. *J Am Vet Med Assoc* 2004;225:384–388.
26. Paige CF, Abbott JA, Elvinger F, Pyle RL. Prevalence of cardiomyopathy in apparently healthy cats. *J Am Vet Med Assoc* 2009;234:1398–1403.
27. Wagner T, Fuentes VL, Payne JR, McDermott N, Brodbelt D. Comparison of auscultatory and echocardiographic findings in healthy adult cats. *J Vet Cardiol* 2010;12:171–182.
28. Bonagura JD. Feline echocardiography. *J Feline Med Surg* 2000;2:147–151.
29. Dirven MJ, Cornelissen JM, Barendse MA, van Mook MC, Sterenborg JA. Cause of heart murmurs in 57 apparently healthy cats. *Tijdschr Diergeneeskd* 2010;135:840–847.
30. Nakamura RK, Rishniw M, King MK, Sammarco CD. Prevalence of echocardiographic evidence of cardiac disease in apparently healthy cats with murmurs. *J Feline Med Surg* 2011;13:266–271.
31. Rishniw M, Thomas WP. Dynamic right ventricular outflow obstruction: a new cause of systolic murmurs in cats. *J Vet Intern Med* 2002;16:547–552.
32. Payne JR, Borgeat K, Connolly DJ, Boswood A, Dennis S, Wagner T, Menaut P, Maerz I, Evans D, Simons VE, Brodbelt DC, Luis Fuentes V. Prognostic indicators in cats with hypertrophic cardiomyopathy. *J Vet Intern Med* 2013;27:1427–1436.
33. Sleeper MM, Roland R, Drobatz KJ. Use of the vertebral heart scale for differentiation of cardiac and noncardiac causes of respiratory distress in cats: 67 cases (2002–2003). *J Am Vet Med Assoc* 2013;242:366–371.
34. Fox PR, Rush JE, Reynolds CA, DeFrancesco TC, Keene BW, Atkins CE, Gordon SG, Schober KE, Bonagura JD, Stepien RL, Kellihan HB, Macdonald KA, Lehmkuhl LB, Nguyenba TP, Sydney Moise N, Lefbom BK, Hogan DF, Oyama MA. Multi-center evaluation of plasma N-terminal probrain natriuretic peptide (NT-pro BNP) as a biochemical screening test for asymptomatic (occult) cardiomyopathy in cats. *J Vet Intern Med* 2011;25:1010–1016.
35. Schober KE, Maerz I, Ludewig E, Stern JA. Diagnostic accuracy of electrocardiography and thoracic radiography in the assessment of left atrial size in cats: comparison with transthoracic 2-dimensional echocardiography. *J Vet Intern Med* 2007;21:709–718.
36. Rush JE, Freeman LM, Fenollosa NK, Brown DJ. Population and survival characteristics of cats with hypertrophic cardiomyopathy: 260 cases (1990–1999). *J Am Vet Med Assoc* 2002;220:202–207.
37. Johnson MS, Martin M, Edwards D, French A, Henley W. Pulmonic stenosis in dogs: balloon dilation improves clinical outcome. *J Vet Intern Med* 2004;18:656–662.

38. Eyster GE, Eyster JT, Cords GB, Johnston J. Patent ductus arteriosus in the dog: characteristics of occurrence and results of surgery in one hundred consecutive cases. *J Am Vet Med Assoc* 1976;168:435–438.
39. Saunders AB, Gordon SG, Boggess MM, Miller MW. Long-term outcome in dogs with patent ductus arteriosus: 520 cases (1994–2009). *J Vet Intern Med* 2014;28:401–410.

Available online at www.sciencedirect.com

ScienceDirect