PAPER

Radiographic appearance of cardiogenic pulmonary oedema in 23 cats

Objective: To describe the radiographic appearance of pulmonary oedema in cats with cardiac failure.

Methods: Thoracic radiographs of 23 cats presented to a first opinion practice with signs of cardiac failure were reviewed. All cats had tachypnoea and/or dyspnoea and enlarged left atrium on echocardiography.

Results: Pulmonary oedema was characterised radiographically by an increased opacity associated with a range of patterns and variable distribution. All cats had evidence of a reticular or granular interstitial pattern. This occurred in combination with alveolar pattern in 19 (83 per cent) cats, including six with air bronchograms, with increased diameter of pulmonary vessels in 16 (71 per cent) cats and with bronchial pattern in 14 (61 per cent) cats. The distribution of pulmonary oedema was considered to be diffuse/non-uniform in 14 (61 per cent) cats, diffuse/uniform in four (17 per cent) cats, multi-focal in four (17 per cent) cats and focal in the remaining one (4 per cent). Nine (39 per cent) cats were considered to have a regional distribution of oedema, including five (22 per cent) with a ventral distribution, three (13 per cent) with a caudal distribution and one (4 per cent) cat with a hilar distribution. The distribution of pulmonary opacities was bilaterally symmetrical in five (22 per cent) cats.

Clinical Significance: The variable appearance of feline pulmonary oedema is likely to complicate its radiographic diagnosis.

L. Benigni, N. Morgan* and C. R. Lamb

Journal of Small Animal Practice (2009)
50, 9–14
DOI: 10.1111/j.1748-5827.2008.00655.x

Department of Veterinary Clinical Sciences, The Royal Veterinary College, Hawkshead Lane, North Mymms, Hertfordshire AL9 7TA

*Goddard Veterinary Group, Wanstead Veterinary Hospital, 84 New Wanstead, Wanstead, London E11 5SY

Morgan's current address is North Shore Veterinary Hospital, 64 Aitchison Street, Crows Nest, New South Wales 2065, Australia

INTRODUCTION

Cardiac failure may be divided into forward and backward (congestive) failure (Katz 2001). Forward cardiac failure may be defined as insufficient cardiac output to maintain normal physiological functions including ambulation and perfusion of vital organs, such as the brain and kidneys. Backward (congestive) cardiac failure may be defined as increased end-diastolic filling pressure, which leads to increased atrial pressure and congestion of the pulmonary and systemic veins, and ultimately results in pulmonary oedema and ascites. Diagnosis of cardiac failure may be based on findings on physical examination, radiographic signs and increased plasma levels of atrial natriuretic peptide (Connolly and others 2008), but there is no single optimal diagnostic test for this condition.

Thoracic radiography is an important method for diagnosis of cardiac failure because it enables non-invasive assessment of the pulmonary veins, may be used to detect pulmonary oedema and helps distinguish pulmonary oedema from other conditions that can cause similar clinical signs, such as bronchopneumonia (Kittleson and Kienle 1998, Lord and Suter 1999). In radiographs of dogs with acute left-sided cardiac failure, pulmonary oedema typically appears as a symmetrical alveolar pattern that is most marked in the caudodorsal lung field, although it can become generalised (Kittleson and Kienle 1998, Lord and Suter 1999).

The radiographic appearance of pulmonary oedema in cats with cardiac failure is said to be more variable than in dogs. Various textbooks and review articles include examples of radiographs apparently showing pulmonary oedema appearing as a patchy or localised infiltrate with a variable distribution within the lung (Bonagura 1977, Lord and Zontine 1977, Farrow and others 1994, Kittleson and Kienle 1998, Fox 1999, Lamb 2002, French and Wotton 2004). Also, cats with cardiac failure are prone to developing pleural effusion, which is superimposed on the lung and complicates its radiographic assessment. In some series of cats with cardiac failure, pleural effusion occurred more frequently than pulmonary oedema (Fox and others 1997, Ferasin and others 2003).

There are few primary sources of case material upon which to base statements about cardiogenic pulmonary oedema in cats. In a series of 51 cats with necropsy-proven cardiomyopathy (Lord and others 1974), 18 (35 per cent) had radiographic signs of pulmonary congestion, 16 (31 per cent) had pulmonary oedema and 13 (26 per cent) had pleural effusion. In that article, pulmonary oedema was described radiographically as a generalised or patchy alveolar type opacity, but it was illustrated in only one figure. This reflects the emphasis of that article, which (before the advent of echocardiography) was on correlations between the survey radiographic and the angiographic appearance of the heart and the pathological findings (Lord and others 1974).

More recently, McKlveen and Moon (1999) described briefly the radiographic appearance of the lung in 19 cats with probable cardiogenic pulmonary oedema. Pulmonary patterns were described as interstitial/alveolar in eight (42 per cent), interstitial in seven (37 per cent) and alveolar in four (21 per cent) cats. The distribution of oedema was highly variable with examples of diffuse, multi-focal, focal, perihilar, caudal and ventral lesions. The pulmonary vessels were obscured by oedema in nine (47 per cent) cats. Of the remaining 10 cats, five (26 per cent) had enlargement of both the pulmonary arteries and veins, and one had enlargement of the veins only (McKlveen and Moon 1999). This report did not include illustrations of the radiographs.

Other articles have mentioned the occurrence of pulmonary oedema in cats with cardiac disease but provide no description of the radiographic findings. For example, pulmonary congestion or oedema was reported in 16 of 18 (89 per cent) (Bright and others 1992) and 33 of 79 (42 per cent) (Peterson and others 1993) cats with hypertrophic cardiomyopathy and in 28 of 106 (26 per cent) cats with various types of cardiomyopathy (Ferasin and others 2003). In a study of 35 cats with cardiomyopathy based on angiographic or necropsy findings (Moise and others 1986), only seven (20 per cent) had radiographic evidence of pulmonary oedema, which suggests that the majority did not have cardiac failure or were already receiving treatment when radiographed.

The aim of this study was to describe in more detail the radiographic appearance of pulmonary oedema in a series of cats with cardiac failure.

METHODS

The medical records of a first opinion veterinary practice in the period 2002 to 2007 were searched for cats that had thoracic radiography and echocardiographic diagnosis of myocardial disease within the same period of hospitalisation. Diagnosis of cardiac disease was based on echocardiographic measurement of the left atrium septum-to-free wall dimension at end systole (LAD_s) in short-axis M-mode images obtained from a right parasternal window. LAD_s: aorta diameter ratio equal to or greater than 1·7 was considered abnormal (Maerz and others 2006). Echocardiography was performed by C. R. L. or N. M.

Radiographs were made using a detail (200 speed) film-screen system. All cats were conscious for radiography. Cats without a two-view radiographic study (lateral and ventrodorsal or dorsoventral), cats with radiographs in which the lungs appeared normal, cats that had previously received a diuretic or drugs to treat cardiac disease and cats with radiographic signs of more than a slight pleural effusion were excluded. For the purposes of this study, slight pleural effusion was defined as less than 2 mm separation of the lung edges from the thoracic wall and interlobar fissures less than 2 mm wide. Radiographs were reviewed by two board certified radiologists (L. B. and C. R. L.) with knowledge of the echocardiographic diagnosis. For each case, a consensus by discussion was reached about the radiographic appearance of the lungs. Abnormal pulmonary opacity was classified as bronchial, vascular, interstitial and/or alveolar. The distribution of abnormal opacity was classified as diffuse if the entire lung appeared abnormal and focal or multifocal if parts of the lung appeared normal. Cats with diffusely increased pulmonary opacity were subdivided into those with either a uniform or a non-uniform distribution. Abnormal opacity was also classified as regional (dorsal, ventral, cranial, caudal, hilar and peripheral) or lobar, if applicable. Vertebral heart score was measured on the lateral radiographs using the method of Litster and Buchanan (2000).

RESULTS

Records of 23 cats that satisfied the inclusion criteria were found. Nineteen were domestic shorthair cats and four were oriental breeds. There were 17 males and six females. Median (range) age was nine years (one to 20 years). On admission, all cats had respiratory signs: 21 (91 per cent) had increased respiratory rate and 16 (70 per cent) were dyspnoeic. Median respiratory rate was 60 breaths/min (range 30 to 120 breaths/min), and median heart rate was 204 beats/min (range 120 to 240 beats/min). Eight cats had a systolic murmur, five had a gallop rhythm and two had dysrhythmia. In five cats, the heart sounds were described as muffled by breath sounds. All cats had left atrial enlargement. Median LAD_s was 21 mm (range 16 to 26 mm) and median LAD_s: aorta diameter ratio was 2·4 (range 1·7 to 3·0). Two cats had pericardial fluid. One cat had an aortic thrombus. Five cats had hyperthyroidism (serum thyroxine $>$60 nmol/l), including two that were already receiving treatment for hyperthyroidism before presenting with signs of cardiac failure. Twenty (87 per cent) cats had reduced severity of respiratory signs after treatment with furosemide. The remaining three cats died soon after diagnosis, but necropsy was not performed.

The radiographic appearance of the lung was characterised by an increased opacity associated with a range of mixed patterns and variable distribution. All cats had evidence of a reticular or granular interstitial pattern that reduced clarity of margins of the pulmonary vessels and cardiac silhouette (Fig 1). Interstitial pattern was observed in combination with alveolar pattern in 19 (83 per cent) cats, including six with air bronchograms (Fig 2). Interstitial pattern was observed in combination with increased diameter of pulmonary vessels in 16 (70 per cent) cats (Fig 3). Ring shadows compatible with bronchial wall thickening or peribronchial infiltrates were observed in 14 (61 per cent) cats (Fig 4). Of 13 cats in which one type of pulmonary pattern was considered predominant, it was an alveolar pattern in 12 and an interstitial pattern in one.

The distribution of pulmonary oedema was considered to be diffuse/uniform in

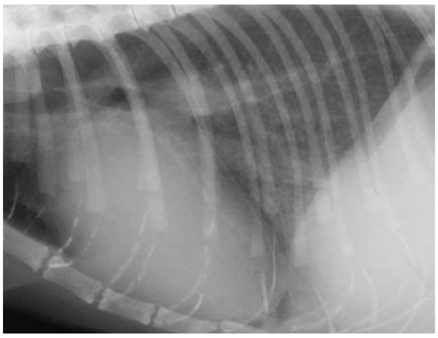

FIG 1. Example of interstitial pattern. There is an ill-defined reticular opacity affecting the caudal lung lobes that reduces visibility of pulmonary vessels and the caudal vena cava

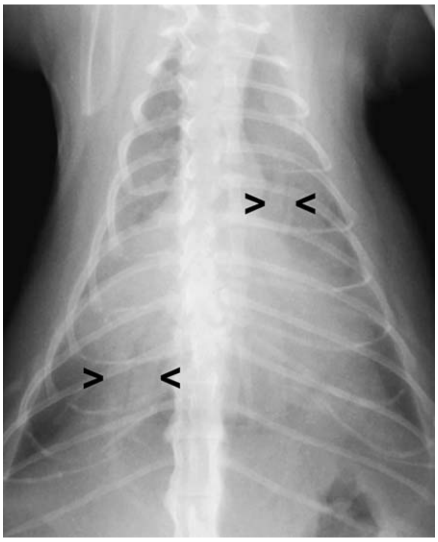

FIG 3. Example of vascular pattern. The left cranial lobar and the right caudal lobar vessels have increased diameter (between arrowheads). Although enlarged, these vessels are not easily recognised in this case because of the increased opacity of the adjacent lung

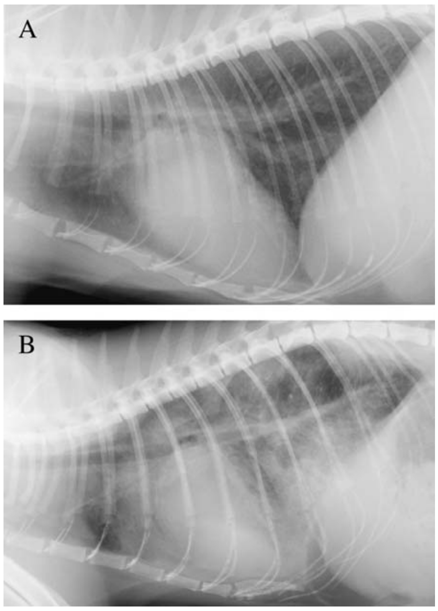

FIG 5. Examples of the variable distribution of pulmonary oedema: (A) diffuse and uniform interstitial pattern (and enlargement of some pulmonary vessels). (B) diffuse, non-uniform alveolar pattern

four (17 per cent) cats (Fig 5A), diffuse/non-uniform in 14 (61 per cent) cats (Fig 5B), multi-focal in four (17 per cent) cats (Fig 6) and focal in the remaining one (4 per cent). Each of the cats with diffuse/uniform pulmonary opacity was considered to have a mixed interstitial and bronchial pattern. Nine (39 per cent) cats were considered to have a regional distribution of oedema, including five (22 per cent) with a ventral distribution (Fig 7A), three (13 per cent) with a caudal distribution (Fig 7B) and one (4 per cent) cat with a hilar distribution (Fig 8). No cats had signs of oedema affecting a single lung lobe. The distribution of pulmonary opacities was bilaterally symmetrical in five (22 per cent) cats. Follow-up radiographs in three cats showed resolution of pulmonary lesions within 36 hours (Fig 8C), but no suitable follow-up radiographs were available for the remaining cats.

Pulmonary oedema obscured the margins of the cardiac silhouette in eight cats.

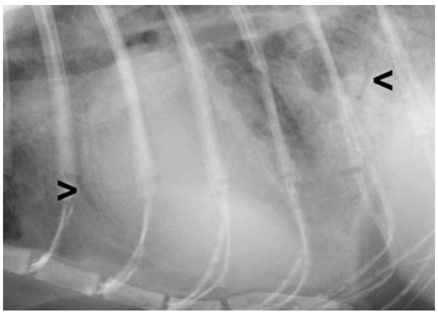

FIG 2. Example of alveolar pattern with air bronchograms (arrowheads) affecting the ventral parts of the lungs. The cardiac and diaphragmatic borders are obscured

In the remaining 15 cats, median (range) vertebral heart scale was 9·6 (8·3 to 10·8). A left atrial bulge was identified in 11 (48 per cent) cats. No correlation was found between vertebral heart scale and echocardiographic measurements.

DISCUSSION

This study included 23 cats that were presented with respiratory signs secondary to pulmonary lesions associated with echocardiographic signs of cardiac disease. Variations were observed in the cardiac chamber dimensions of cats in this study, which reflect the heterogeneity of feline cardiac diseases (Bright and others 1992, Peterson and others 1993, Bonagura and Luis Fuentes 2000, Ferasin and others 2003), but all cats had left atrial enlargement according to the relatively conservative criterion employed. Of the various methods that may be used to measure the left atrium in cats, the LAD_s: aorta diameter ratio measured in short-axis M-mode images obtained from a right parasternal window has the highest specificity (Maerz and others 2006), which makes it the optimal method to use when attempting to avoid inclusion of cats with false-positive diagnosis. In addition, 70 per cent cats in this series were dyspnoeic, as may be expected based on previous reports (Lord and others 1974) and 87 per cent cats had reduced severity of respiratory signs after treatment with furosemide. These features support our assertion that these cats had cardiac failure and pulmonary oedema. The lack of definitive (histological) diagnosis allows the possibility that we inadvertently included some cats with other pulmonary conditions, such as bronchopneumonia or haemorrhage; however,

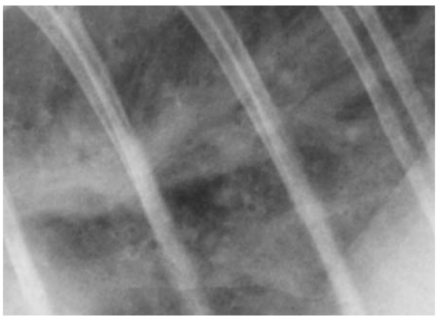

FIG 4. Example of bronchial pattern. Numerous small thick ring shadows are visible. In this instance, there is also enlargement of pulmonary vessels and a diffuse uneven alveolar pattern. The appearance of thickened bronchial walls in cats with cardiac failure may reflect fluid in the peribronchial tissues rather than thickening of the true bronchial wall (see text)

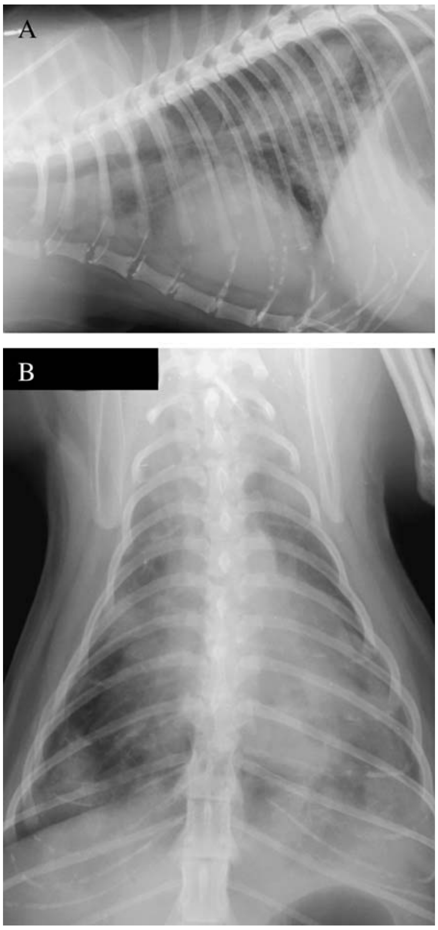

FIG 6. Example of multi-focal pulmonary oedema. (A) lateral; (B) dorsoventral. The distinction between a multi-focal and a diffuse, non-uniform distribution is based on the observation that certain parts of the lung (here the cranial aspect of the right caudal lobe) appear to be unaffected. This distinction is intended purely for the purposes of description; no significant clinical or pathological difference is implied

obtaining the lung biopsies necessary for definitive diagnosis is not warranted – and could be considered contraindicated – when managing an acute respiratory condition. Furthermore, when that condition proves to be rapidly reversible, at least in the majority of cases, the result of a subsequent biopsy is unlikely to represent accurately the state of the lung at the time of radiography. The acute and labile nature of pulmonary oedema together with the frequent need for immediate treatment of animals presented to first opinion practices place significant constraints on studies of this condition. These constraints are reflected in our methods and exclusion criteria and limit the confidence that can be

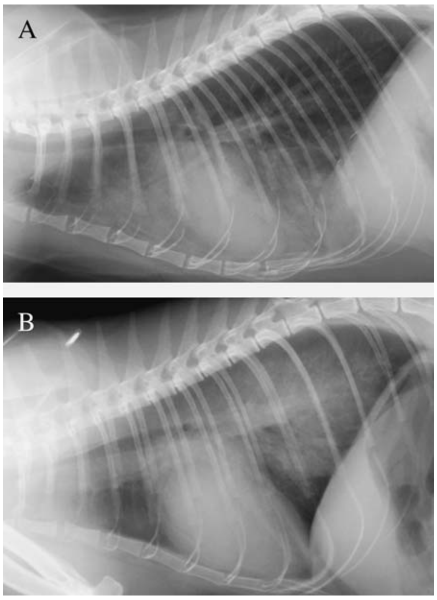

FIG 7. Examples of regional distribution of alveolar patterns associated with pulmonary oedema: (A) ventral distribution; (B) caudal distribution

attached to our results. Clinical researchers in practices with a large acute caseload and multiple cardiologists (to reach a consensus about the diagnosis of cardiomyopathy) who consistently obtain follow-up radiographs showing rapid resolution of lesions compatible with pulmonary oedema may be able to obtain data that support more authoritative conclusions about this condition.

It is perhaps surprising that such a well-recognised and prevalent condition as feline cardiac failure has not already been the subject of detailed radiographic studies. Radiographs apparently showing pulmonary oedema have been included in numerous textbooks and review articles, but there is a need for additional primary case material to complement that provided by pioneers in feline cardiology, such as Lord and others (1974). Our aim was to study cats seen in first opinion practice to produce results that would be most meaningful to veterinarians managing cats with acute cardiac failure, but numerous potential subjects had to be excluded because they did not satisfy our criteria. The requirement for a two-view radiographic study excluded many cats in cardiac failure that had either a single lateral or a dorsoventral view, including those in which radiography was deliberately limited to a single dorso-

FIG 8. Example of hilar distribution of pulmonary oedema. (A) lateral; (B) dorsoventral. The heart is obscured by a marked alveolar pattern but the peripheral parts of the lung are affected less. (C) repeat lateral radiograph of the same cat obtained the following day after treatment with furosemide. The lungs appear normal. The rapid resolution of pulmonary lesions supports retrospective diagnosis of oedema (see text)

ventral view as a means of minimising stress in an acute patient. To optimally examine the lung, it was considered necessary to exclude cats with more than a minimal volume of pleural fluid. As has been reported previously (Fox and others 1997, Ferasin and others 2003), the majority of cats with cardiac failure have pleural effusion, which meant that a large number of potential candidates for the present study had to be excluded. Also, to avoid variations in the radiographic appearance of the lung occurring as a result of drugs used to treat pulmonary oedema, cats that had received a diuretic or other drug to treat cardiac disease before radiography were excluded.

Despite the relatively small number of subjects that satisfied our criteria, it is possible to conclude that feline cardiogenic pulmonary oedema has a highly variable radiographic appearance (McKlveen and Moon 1999). It is important that veterinarians managing cats presented with acute respiratory signs are aware of the range of radiographic appearances compatible with oedema to avoid misdiagnosis. Pulmonary oedema must be differentiated from bronchopneumonia in cats with an alveolar pattern affecting the ventral lung fields and from chronic bronchitis in cats with bronchial or bronchointerstitial patterns. Once the possibility of pulmonary oedema has been recognised, appropriate treatment can be started and followed up with more specific diagnostic tests when the patient is in a more stable condition. The labile nature of pulmonary oedema facilitates relatively rapid retrospective diagnosis if a marked reduction in lesion severity is observed in repeat radiographs obtained after 12 to 24 hours diuresis and cage rest (Lord and others 1974, Lord and Zontine 1977, Lamb 2002).

The variations in the radiographic appearance of pulmonary oedema observed in the present study may reflect different stages in the development of the lesion at the time of radiography. These stages have been described in experimental dogs with hydrostatic pulmonary oedema (Staub and others 1967, Conhaim 1989, Forster and others 1992, Scillia and others 2004). Initially, oedema fluid leaks into the loose tissue around pulmonary vessels and bronchi, and its radiographic appearance may mimic bronchial wall thickening. There is a tendency for oedema to collect first at the hilus, although this may be difficult to recognise radiographically because of the increased opacity occurring as a result of superimposition of enlarged vessels and the left atrium. Only one cat in the present study had a pulmonary lesion with a distribution we considered to be hilar. Oedema fluid then accumulates in the alveolar and interlobular septa, which become thicker, so producing a hazy or reticular interstitial pattern. Finally, fluid leaks through the epithelium of the alveolar ducts and floods the alveoli. If sufficient alveoli are flooded, the lung appears consolidated, sometimes with air bronchograms, and hence is classified radiographically as an alveolar pattern (Kittleson and Kienle 1998, Lord and Suter 1999). Anecdotal evidence suggests that air bronchograms are visible in relatively few cats with alveolar patterns. In the present study, air bronchograms were recognised in six of 19 (32 per cent) cats with alveolar patterns.

Although the pathophysiology described above is likely to be equally applicable to dogs and cats, and helps explain why different radiographic patterns occur in animals with cardiac failure, it remains unclear why the distribution of pulmonary oedema is so much more variable in cats than in dogs.

Pulmonary oedema tends to obscure the heart and pulmonary vessels (McKlveen and Moon 1999), making their radiographic evaluation more difficult. Pulmonary oedema obscured the margins of the cardiac silhouette in eight cats in the present study. In all those in which it was possible to identify the cardiac borders, the vertebral heart scale measurement exceeded the published normal range (6·9 to 8·1) (Litster and Buchanan 2000). The lack of correlation between vertebral heart scale and echocardiographic measurements may reflect various factors: standard echocardiographic examination does not include measurement of total external cardiac dimensions; some cats had pericardial fluid; small volumes of pleural fluid or pulmonary lesions may have obscured the true cardiac border leading to erroneous radiographic measurements. We did not attempt to correlate results of vertebral heart scale with the radiographic appearance of the lung. In a previous study, there was no apparent relationship between the degree of pulmonary oedema and heart size (Lord and others 1974).

Acknowledgement

We thank Philippa Davis, Hospital Manager at Goddard Veterinary Group, for her help in searching medical records.

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