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1 **Abstract**

2 Objectives. To estimate the prevalence of subclinical abnormalities reported in thoracic CT scans of

3 cats and to test associations between respiratory signs and CT signs.

4 Methods. Retrospective review of signalment, indications, respiratory signs and reported CT findings

5 in a series of cats having thoracic CT scans. Associations between patient variables, respiratory signs

6 and CT signs were tested using multivariable regression methods.

7 Results. Records of 352 consecutive cats were reviewed. Abnormalities affecting thoracic structures

8 were reported in CT scans of 138/179 (77%) cats without respiratory signs. The most prevalent CT

9 findings in cats without respiratory signs were pulmonary collapse (41%), signs of bronchial disease

10 (24%) and space-occupying lesions (21%). Dyspnoea, cough and tachypnoea were associated with

11 space-occupying lesions. Dyspnoea was also associated with pulmonary consolidation and

12 atelectasis. Increasing body weight was associated with pulmonary atelectasis and increasing age

13 was associated with signs of bronchial disease.

14 Clinical significance. Abnormalities are reported frequently in thoracic CT scans of cats without

15 respiratory signs. The most prevalent abnormality, pulmonary atelectasis, is probably a temporary

16 effect of sedation or anaesthesia for CT. A high prevalence of subclinical abnormalities and limited

17 correlations between clinical signs and CT findings will complicate diagnosis.

18 **Introduction**

19 Computed x-ray tomography (CT) is used increasingly to investigate cats with thoracic conditions

20 (Henninger 2003; Cohn et al. 2004; Oliveira et al. 2011; Aarsvold et al. 2015). Being a cross-sectional

21 imaging modality, CT eliminates the problem of superimposition that affects radiography and

22 therefore enables clearer depiction of internal anatomy and morphological abnormalities that alter

23 anatomy. As a result CT has a higher sensitivity for pulmonary disease than radiography (Nemanic et

24 al. 2006). In general, higher sensitivity is advantageous, but one of the drawbacks of using more

25 sensitive diagnostic tests is that more of the abnormalities detected may represent clinically silent

26 conditions and, potentially, incidental findings (Aspinall et al. 2013). For example, previous CT

27 studies have documented the tendency for lung collapse in anaesthetised cats (Henao-Guerrero et

28 al. 2012). It is the authors' impression that other abnormalities, such as signs of bronchial disease,

29 are observed frequently in cats having thoracic CT for reasons unrelated to respiratory signs.

30 Clinicians interpreting diagnostic images must always consider the possible relationship between

31 imaging signs and clinical signs in order to assess the likely meaning of the images (Wood, 1999). For

32 example, it is generally accepted that coughing in cats is more associated with bronchial lesions

33 whereas dyspnoea is more associated with cardiac disease or space-occupying lesions, such as a

34 pulmonary mass or pleural fluid (Moise et al. 1989; Corcoran et al. 1995; Dye et al. 1996; Sauve et al.

35 2005; Swift et al. 2009; Foster & Martin 2011; Johnson & Vernau 2011; Sigrist et al. 2011); however,

36 such associations are not pathognomonic, so it can be difficult to judge if the imaging signs in an

37 individual patient fully explain their clinical signs. Particularly in patients with non-specific or vague

38 clinical signs, it can be difficult to decide if an imaging finding represents a clinical or subclinical

39 condition, and whether to treat it or employ further diagnostic tests.

40 The aims of the present study were to estimate the prevalence of subclinical abnormalities reported

41 in thoracic CT scans of cats and to test the associations between clinical signs and CT signs.

42

Methods

43

44   For this retrospective cross-sectional study, electronic medical records of cats referred to the Queen

45   Mother Hospital for Animals (QMHA) between September 2013 and September 2015 were

46   reviewed. The only inclusion criterion was CT imaging of the thorax. The signalment, body weight,

47   body condition score, indication for CT and respiratory signs (if any) were extracted from

48   contemporaneous clinical notes by one investigator (IDJ). Indications for CT were categorised as

49   follows: suspected respiratory condition, metastasis check, trauma, comprehensive medical work-

50   up, other. Respiratory signs were categorised as follows: none, cough, upper respiratory signs

51   (stertor, change of voice, nasal discharge, nasal obstruction, dyspnoea), dyspnoea not associated

52   with upper airway signs, tachypnoea, hyperpnoea, other.

53   CT scans were acquired using a multi-detector row CT scanner (MX 8000 IDT, Philips Medical

54   Systems, Cleveland, USA). CT images were obtained using helical acquisition, 120kVp, 200mAs, 16 x

55   1.5mm collimation, 0.688 pitch, 2mm slice thickness, 150-300mm field of view, 512x512 matrix

56   (pixel size 0.3-0.6mm). All cats had separate CT series to examine the lung and the thoracic soft

57   tissues, respectively. Images of the lung were reconstructed using a high frequency (lung enhanced)

58   algorithm whereas images of the thoracic soft tissues were reconstructed using a sharp

59   reconstruction algorithm. When indicated, post-contrast CT images of the thoracic soft tissues were

60   obtained 60s after the start of rapid intravenous injection of 2ml/kg bolus of iohexol (Omnipaque

61   300, GE Healthcare, Oslo, Norway). Use of sedation or anaesthesia for CT was recorded.

62   Abnormalities in CT scans, as reported individually at the time of clinical work-up by the six Board-

63   certified radiologists employed at the QMHA in this period, were extracted from imaging reports by

64   another investigator (CRL) without reference to the clinical information. Experience of small animal

65   CT in this group of radiologists ranged from 5 to 26 years. CT signs were categorised as follows:

66   space-occupying lesions (pulmonary mass, other intrathoracic mass, pleural fluid, pneumothorax,

67   pneumomediastinum), pulmonary nodules (solid, subsolid, cavitary, bulla/cyst), consolidation

68 (sublobar, lobar, bronchocentric, multifocal), atelectasis/collapse (sublobar, lobar, bronchocentric,

69 multifocal), ground-glass opacities (focal, multifocal, diffuse), air-trapping (focal/lobar, multifocal,

70 diffuse, interstitial emphysema), bronchial lesions (wall thickening, bronchiectasis, mucus plugging,

71 "tree-in-bud," foreign body, broncholith), other (honeycombing, septal lines, parenchymal bands,

72 adenopathy, vascular congestion) and thoracic wall lesions (rib fractures, barrel-chested

73 conformation, pectus excavatum, peritoneopericardial diaphragmatic hernia, other). The "tree-in-

74 bud" pattern applies to centrilobular branching structures that resemble a budding tree.

75 Terminology followed recommendations for thoracic imaging by the Fleischner Society (Hansell et al.

76 2008).

77 Calculation based on the need to estimate a prevalence of 30% to within +/-5% indicated a sample

78 size equal to 322 cats (Eng 2003). Associations between respiratory signs and reported CT signs were

79 tested using multinomial logistic regression with respiratory signs as the dependent variable.

80 Associations between age, body weight, body condition score, use of sedation or anaesthesia and

81 atelectasis were tested using binary logistic regression. The association between age and bronchial

82 lesions was also tested using binary logistic regression. Statistical testing was done using SPSS

83 Statistics, version 22 (IBM Corporation, Chicago, IL). Results with $p<0.05$ were considered significant.

84

85 **Results**

86 Records of 352 consecutive cats were reviewed. No cats were excluded. There were 195 (55%) male

87 cats (186 neutered) and 157 (45%) females (150 neutered). The most prevalent breeds were

88 Domestic Short Hair (n=213, 61%), Domestic Long Hair (34, 10%), British Short Hair (14, 4%), Siamese

89 (14, 4%) and Maine Coon (12, 3%). There were 21 other feline breeds with less than 10 individuals.

90 Age was known in 350 cats. Median (range) age of cats was 9.5y (4m – 18y). Body weight was

91 recorded in 311 cats and body condition score was recorded in 202 cats. Median body weight was

92 4.4kg (range 1.2 – 13.1kg) and median body condition score was 4 (range 1 – 9).

93   The principal indications for thoracic CT were respiratory signs (n= 144, 41%), comprehensive

94   medical work-up (107, 30%), search for metastasis (64, 18%) and trauma (37, 11%). Respiratory signs

95   were present in 173 (49%) cats, including upper respiratory signs in 78 (22%) cats, dyspnoea not

96   associated with upper airway signs in 42 (12%) cats, combinations of two or more other categories

97   of respiratory signs in 20 (6%) cats, tachypnoea in 17 (5%) cats and cough in 16 (4%) cats. There were

98   no cats in which hyperpnoea was recorded as the sole respiratory sign.

99   Two hundred and thirty-seven (67%) cats were anaesthetised for CT and the remainder were

100   sedated. Cats were positioned in sternal recumbency for CT, except for four cats with suspected

101   vertebral fractures, which were placed in lateral recumbency. Abnormalities affecting thoracic

102   structures were reported in CT scans of 138 (77%) cats without respiratory signs, 65 (83%) cats with

103   upper respiratory signs and 91 (96%) cats with other respiratory signs (p=0.0004). CT scans were

104   interpreted as normal in 58 (16%) cats.

105   Abnormalities reported in CT scans of the 179 cats without respiratory signs are summarised in table

106   1. The most prevalent abnormalities in these cats were pulmonary atelectasis (reported in 41%) and

107   signs of bronchial disease (24%). No abnormalities were reported in 23% cats without respiratory

108   signs. Of the 57 cats without respiratory signs in which the indication for CT was to search for

109   metastasis, 50 (88%) had a cellular diagnosis of neoplasia and, of these, 15 (30%) had pulmonary

110   nodules and 9 (18%) had pleural fluid reported on CT. Of the 28 cats without respiratory signs in

111   which the indication for CT was trauma, 9 (32%) had space-occupying lesions, including

112   pneumomediastinum in 5 (18%) and pneumothorax in 4 (14%). The 92 cats without respiratory signs

113   in which the indication for CT was the need for a comprehensive medical work-up included a wide

114   range of conditions. The most prevalent of these were 21 cats subsequently shown to have

115   neoplasia. Of these, 5/21 (24%) had space-occupying lesions (3 pulmonary mass, 1 mediastinal cyst,

116   1 pleural effusion) and 4/21 (19%) had pulmonary nodules on CT. The second most prevalent group

117   were 15 cats with uncontrolled diabetes mellitus (including 11 with hypersomatotropism). Of these,

118   only one diabetic cat had a CT abnormality related to its condition, which was pleural effusion

119   secondary to metastatic adrenal carcinoma.

120   The frequencies of reported CT abnormalities CT in cats with different respiratory signs are

121   summarised in table 2 and the results of statistical testing are summarised in table 3. Air-trapping

122   and thoracic wall lesions were excluded from the statistical analysis because of the small number of

123   affected individuals. The strongest association found between respiratory signs and CT abnormalities

124   was between dyspnoea and space-occupying lesion (odds ratio 8.7, 95% confidence interval 3.6-

125   21.1) (p=0.00002). Cough and tachypnoea were also significantly associated with a CT report of a

126   space-occupying lesion. Space-occupying lesions reported in 99 cats in this series were pulmonary

127   mass in 25%, other thoracic mass in 27%, pleural fluid in 53%, pneumothorax in 18% and

128   pneumomediastinum in 11% cats. Masses and pleural fluid occurred together in 17% cats with

129   space-occupying lesions. Dyspnoea was also significantly associated with a CT report of pulmonary

130   consolidation or atelectasis. Upper respiratory tract signs were significantly associated with a CT

131   report of bronchial lesions and inversely associated with space-occupying lesions or ground-glass

132   opacities.

133   Overall, pulmonary atelectasis/collapse was the most frequent reported CT abnormality, affecting

134   159 (45%) cats in this series. The most frequently collapsed lobes, in descending order were the right

135   middle (collapsed in 53% affected cats), left cranial (45%), right cranial (39%), left caudal (16%),

136   accessory (11%) and right caudal (9%). All lobes had some degree of atelectasis in 8% affected cats.

137   The predominant distribution of atelectasis was sub-lobar, which was reported in 71% lobes affected

138   by atelectasis. Other reported distributions of pulmonary atelectasis were lobar (19%),

139   bronchocentric (5%) and multifocal (5%) (Figure 1). There was an association between body weight

140   and CT signs of pulmonary atelectasis (odds ratio 1.2, 95% confidence interval 1.0-1.5) (p=0.02).

141   Neither body condition score (p=0.8) nor use of anaesthesia (p=0.08) were significantly associated

142   with pulmonary atelectasis.

143   Bronchial abnormalities were reported in CT scans of 103 (29%) cats in this series. Reported

144   bronchial abnormalities were thickened bronchial walls in 91%, mucus plugging in 14%, tree in bud

145   in 5%, bronchiectasis in 3% and broncholithiasis in 1% instances (Figure 2). Signs of thickened

146   bronchial walls and mucus plugging occurred together in 12% cats with bronchial lesions. There was

147   an association between age and CT signs of bronchial disease (odds ratio 1.12, 95% confidence

148   interval 1.07-1.19) (p=0.0003).

149

150   **Discussion**

151   These results support the conclusion that the prevalence of abnormalities reported in thoracic CT

152   scans is high (77%) in cats having CT for reasons other than to investigate respiratory signs. A high

153   prevalence of potentially subclinical abnormalities is problematical because it will complicate

154   diagnosis and tend to undermine the correlations between clinical signs and CT findings that are

155   normally used as a basis for interpretation of findings.

156   Although the high prevalence of lung atelectasis observed in the present study is probably a

157   temporary effect of the routine use of sedation or anaesthesia for CT, signs of bronchial disease and

158   space-occupying lesions were also reported frequently in cats without respiratory signs. Previous

159   studies have found that cats with infectious pneumonia may lack respiratory signs (Macdonald et al.

160   2003) and that histological lesions affecting the lung of cats with diabetes mellitus may be

161   unassociated with respiratory signs (Mexas et al. 2006). These findings may correspond with the

162   widely-held belief that the cat – like the sheep – is a species able to hide signs of disease, with the

163   result that by the time an owner recognises their pet is unwell, its condition may be advanced;

164   however, the present study provides no information about the possibility that certain subclinical

165   lesions may eventually become serious. Only a cohort study with long term follow-up of patients

166   could determine the extent to which that occurs. Alternatively, many of the abnormalities reported

167   in the thoracic CT scans in this series may represent static conditions that will never cause clinical

168   signs. If so, labelling affected cats carries the potential for overdiagnosis (Moynihan et al. 2012).

169   In this study, respiratory signs were significantly associated with abnormal findings on CT but there

170   were few significant associations between specific respiratory signs and CT-detected abnormalities.

171   Dyspnoea, cough and tachypnoea were associated with space-occupying lesions. Dyspnoea was also

172   associated with pulmonary consolidation and atelectasis. A previous study found that cardiac

173   disease is the most frequent cause of dyspnoea in cats (Swift et al. 2009). This finding is applicable to

174   a referral population of cats, but the present study underrepresented this group of patients because

175   relatively few cats with cardiac disease are considered candidates for CT. Cough was a relatively

176   infrequent clinical sign in this study and was not significantly associated with bronchial abnormalities

177   on CT. An association between expiratory dyspnoea and lower airway disease in cats has been

178   reported (Sigrist et al. 2011), but a similar association was not evident in the present study.

179   Bronchial abnormalities, mainly thickened bronchial walls and signs of mucus plugging, were

180   observed in many cats with no respiratory signs or signs referable to the upper respiratory tract,

181   hence the clinical significance of these findings is uncertain. One of the limitations of the present

182   study is that the severity of radiographic signs cannot be assessed on the basis of CT reports, hence

183   it is unclear if – for example –signs of bronchial disease were more marked in cats with cough than

184   cats without respiratory signs.

185   The tendency for lung atelectasis in anaesthetised cats has been reported previously (Henao-

186   Guerrero et al. 2012). In dogs, use of high inspired pO2 during anaesthesia has been associated with

187   a higher prevalence of lung atelectasis than moderate inspired pO2 (Staffieri et al. 2007). The same

188   effect may apply to cats, although this was not evident in the present study because cats having CT

189   under general anaesthesia were no more likely to have lung atelectasis than those having CT under

190   sedation. Avoiding lung atelectasis may be expected to aid interpretation of CT images and to

191   increase sensitivity for lesions that could be obscured by lung atelectasis. A reduced tendency for

192   lung atelectasis may be an advantage of conscious CT for cats (Oliveira et al. 2011). Hence, CT

193   scanning of conscious cats or cats under anaesthesia with positive pressure ventilation may be

194   preferred; however, a recent study of anaesthetised dogs and cats that had brief hyperventilation

195   and CT scan during the subsequent expiratory pause (which is the technique usually employed in the

196   authors' hospital), found that ability to detect pulmonary nodules or bulla was not significantly

197   different than when images were acquired with the lungs inflated by positive pressure ventilation

198   (Simone et al. 2016). Cats in ventral or dorsal recumbency are probably affected less by lung

199   atelectasis than those in lateral recumbency, although this cannot be tested in the present study

200   because at the authors' hospital only cats presented after trauma that are considered at risk of being

201   repositioned have CT scans in lateral recumbency (Figure 1D).

202   In this study, lung atelectasis was associated with increasing body weight, likely reflecting the

203   tendency for reduced lung volume in cats with accumulation of intrathoracic fat. Body condition

204   score is used widely as a method of estimating obesity (Laflamme 1997), and would be expected to

205   be correlated with likelihood of lung atelectasis under anaesthesia, possibly better than body

206   weight, but that was not observed. The lack of recorded body condition score in a large proportion

207   of cats will have reduced statistical power and may at least partly explain this negative result.

208   The most frequently collapsed lung lobes in cats in the present study were the right middle and the

209   left and right cranial lobes. The right middle lobe is most prone to collapse in the cat (and dog)

210   (Robinson 1982) and is frequently found to be collapsed in cats with bronchial disease because of

211   mucus or exudate obstructing the airways (Moise et al. 1989). The association found between CT

212   signs of bronchial disease and patient age may reflect progressive disease that is initially feline

213   asthma. Asthma is thought to the result of an allergic response triggered by inhaled allergens that

214   leads to bronchial smooth muscle constriction and airway narrowing (Trzil & Reinero 2014). Many

215   cats with asthma have minimal radiographic signs other than pulmonary overinflation (Gadbois et al.

216   2009); however, chronic antigenic stimulation in affected cats leads to permanent bronchial luminal

217   narrowing and wall thickening because of smooth muscle hyperplasia, goblet cell and submucosal

218   gland hypertrophy and hyperplasia, epithelial erosion and eosinophilic infiltration (Padrid et al. 1995;

219   Reinero et al. 2004) and these pathological changes are more likely to become visible

220   radiographically.

221   It should be emphasised that this study was not designed to estimate the accuracy of CT for thoracic

222   lesions in cats or to estimate the reliability of observers. Our principal aim was to estimate the

223   prevalence of subclinical abnormalities reported in thoracic CT scans of cats and this is probably best

224   achieved by extracting data from imaging reports produced in a consecutive series of patients by

225   radiologists working according to their normal routine in a clinical environment. As a result, the

226   authors' data include variability occurring as a result of patients (all were included regardless of

227   indication or diagnosis) and radiologists (including hawks and doves, working with clinical histories of

228   varying quality). Other methods, such as limiting the study to cats in which there is a certain final

229   diagnosis, or employing a panel of observers to reach a consensus about the CT findings without

230   knowledge of the clinical history, would produce results less representative of clinical practice.

Table 1. Abnormalities reported in CT scans of 179 cats without respiratory signs

| Indication for CT | CT abnormalities | | | | | | | | | |
	None	Space-occupying lesion	Pulmonary nodules	Consolidation	Atelectasis	Ground glass opacity	Air-trapping	Bronchial lesions	Other	Thoracic wall lesion
Suspected respiratory condition[a] n=1	0	1 (100%)	0	0	1 (100%)	0	0	0	1 (100%)	0
Metastasis check n=57	11 (19%)	10 (18%)	17 (30%)	4 (7%)	21 (37%)	7 (12%)	0	12 (21%)	7 (12%)	2 (4%)
Trauma n=28	6 (21%)	9 (32%)	1 (4%)	0	16 (57%)	0	0	3 (11%)	3 (11%)	2 (7%)
Comprehensive medical work-up n=92	24 (26%)	18 (20%)	11 (12%)	9 (10%)	35 (38%)	8 (9%)	0	27 (29%)	10 (11%)	1 (1%)
Other[b] n=1	0	0	0	0	1 (100%)	0	0	1 (100%)	0	0
Totals	41 (23%)	38 (21%)	29 (16%)	13 (7%)	74 (41%)	15 (8%)	0	43 (24%)	21 (12%)	5 (3%)

[a] Reduced lung sounds on auscultation, subsequently shown to be secondary to pleural effusion

[b] Pre-operative assessment of suspected vascular ring anomaly

Table 2. Associations between respiratory signs and abnormalities reported in CT scans of 352 cats

Respiratory signs	CT abnormalities None	Space-occupying lesion	Pulmonary nodules	Consolidation	Atelectasis	Ground glass opacity	Air-trapping	Bronchial lesions	Other	Thoracic wall lesion
None n=179	41 (23%)	38 (21%)	29 (16%)	13 (7%)	74 (41%)	15 (8%)	0	43 (24%)	21 (12%)	5 (3%)
Cough n=16	0	8 (5%)	2 (13%)	1 6(%)	10 (62%)	2 (13%)	1 (6%)	7 (44%)	0	0
Upper respiratory n=78	13 (17%)	8 (10%)	12 (15%)	5 (6%)	34 (44%)	2 (3%)	0	33 (42%)	4 (5%)	1 (1%)
Dyspnoea n=42	1 (2%)	30 (71%)	3 (7%)	8 (19%)	28 (67%)	3 (7%)	2 (5%)	9 (21%)	9 (21%)	6 (14%)
Tachypnoea n=17	3 (18%)	7 (53%)	4 (24%)	3 (18%)	4 (24%)	0	0	3 (18%)	4 (24%)	0
Combination of respiratory signs n=20	0	6 (30%)	4 (20%)	4 (20%)	9 (45%)	2 (10%)	0	8 (40%)	2 (10%)	0
Totals	58 (17%)	99 (28%)	54 (15%)	34 (10%)	159 (45%)	24 (7%)	3 (1%)	103 (29%)	40 (11%)	12 (3%)

Table 3. Significant associations between respiratory signs and abnormalities reported in CT scans of 352 cats

| Respiratory signs | CT abnormalities | | | | | | |
	Space-occupying lesion	Pulmonary nodules	Consolidation	Atelectasis	Ground glass opacity	Bronchial lesions	Other
Cough	4.1 (1.3-13.3) p=0.017	NS	NS	NS	NS	NS	NS
Upper respiratory	0.4 (0.17-0.98) p=0.04	NS	NS	NS	0.2 (0.04-0.8) p=0.03	2.0 (1.1-3.8) p=0.04	NS
Dyspnoea	8.7 (3.6-21.1) p=0.00002	NS	5.0 (1.5-17.0) p=0.009	3.5 (1.4-8.9) p=0.009	NS	NS	NS
Tachypnoea	3.8 (1.1-13.3) p=0.03	NS	NS	NS	NS	NS	NS
Combination of respiratory signs	NS	NS	NS	NS	NS	NS	NS

Values are odds ratio (95% confidence interval)

NS, non-significant, p>0.05

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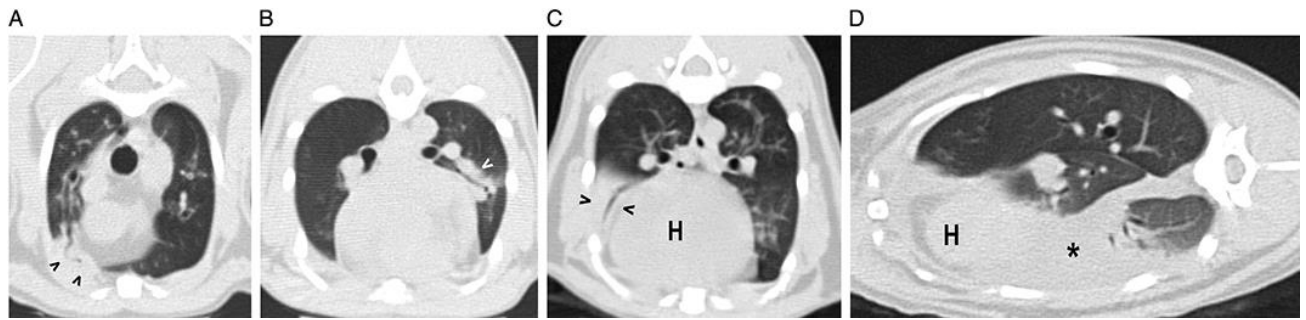
Legends

Figure 1. Examples of CT images reported as showing signs of pulmonary atelectasis. All are transverse images displayed with window 1500HU and centre -500HU. A) Sub-lobar atelectasis affecting the tip of the right cranial lobe (arrowheads) in a cat with chronic cough. There is mediastinal shift to the right. Other images showed signs of bronchial disease. B) Bronchocentric atelectasis affecting the left cranial lobe (arrowhead) in a cat with metastatic adenocarcinoma and no history of respiratory signs. C) Lobar atelectasis affecting the right middle lobe (between arrowheads) in a cat with chronic cough. The heart (H) is displaced to the right. Other images showed signs of bronchial disease. D) Unilateral left lung atelectasis (*) in an anaesthetised cat that had CT scan in left lateral recumbency because of trauma and suspected spinal fracture. The heart (H) is displaced to the left.
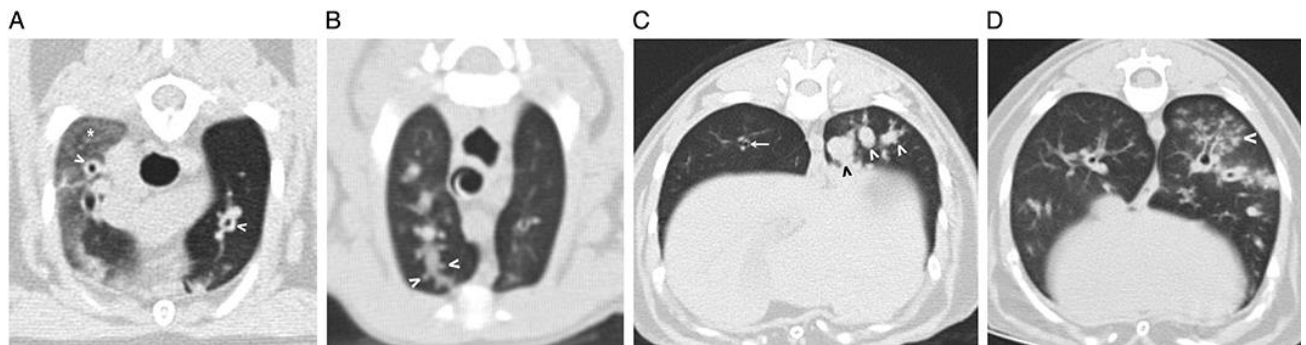
Figure 2. Examples of CT images reported as showing signs of bronchial disease. All are transverse images displayed with window 1500HU and centre -500HU. A) Thickened bronchial walls (arrowheads) in a cat with a suspected vertebral neoplasm and no history of respiratory signs. There is also ground-glass opacity (*) affecting the right cranial lobe. B) Mucus plugging of the right cranial lobar bronchus (between arrowheads) in a cat with chronic cough and tachypnoea. C) Mucus plugging of dilated bronchi (arrowheads) at the periphery of the left caudal lobe in a cat with multiple cutaneous mast cell tumours and no history of respiratory signs. The diameters of each of these bronchi grossly exceed the diameter of the bronchus in the right caudal lobe (arrow) compatible with bronchiectasis. D) Tree-in-bud sign (arrowhead) in the left caudal lobe of a cat with chronic cough.