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CT features of primary bone neoplasia of the thoracic wall in dogs

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Abstract

Primary thoracic wall neoplasia is uncommon in dogs and the prognosis depends on tumor type. The aims of this retrospective, multi-center, observational study were to describe CT features of primary thoracic wall neoplasia in dogs and to test the hypothesis that CT features would differ among tumor types. Dogs with a diagnosis of primary thoracic wall bone neoplasia and thoracic CT study were included. CT findings recorded were as follows: dimensions, location, invasiveness, grade and type of mineral attenuation, periosteal reaction, contrast enhancement, and presence of presumed pulmonary metastases, pleural effusion, and sternal lymphadenopathy. Fifty-eight cases were included (54 ribs and four sternum). Fifty-six were malignant (sarcomas - SARC) and two were benign (chondromas - CHO). Out of the 56 malignant tumors, 41 had histological confirmation of the tumor type: 23 (56%) osteosarcomas (OSA), 10 (24%) chondrosarcomas (CSA), and eight (20%) hemangiosarcomas (HSA). The majority of rib tumors were right-sided (59%) and ventrally located (72%). Malignant masses showed severe invasiveness, mild/moderate contrast enhancement, and different grades of mineral attenuation. Sternal lymphadenopathy was significantly more frequent in dogs with OSA and HSA compared to dogs with CSA ($p = 0.004$ and $p = 0.023$). Dogs with HSA showed significantly lower mineral attenuation grades compared to dogs with OSA ($p = 0.043$). Primary thoracic wall bone neoplasias were more frequently arising from the ribs, with only a few cases of sternal masses. Findings can be used to help prioritize differential diagnoses for CT studies of dogs with thoracic wall neoplasia.

KEYWORDS
Ribs, sternum, sarcoma, CT

1 | INTRODUCTION

Tumors of the thoracic wall are uncommon in dogs; they are usually primary and most commonly malignant.[1–3] They are generally mesenchymal in origin, with osteosarcoma (OSA) and chondrosarcoma (CSA) being the most frequent tumor types reported in dogs.[3–6] Other described tumor types, detected less frequently, are fibrosarcoma and hemangiosarcoma (HSA).[2,7–11] Despite the tumor type, the treatment consists in surgical resection (en bloc excision), as the prognosis for dogs with tumors of the thoracic wall managed conservatively is poor.[2,12] Nevertheless, the median survival time of dogs with OSA after surgical resection is reported to be significantly shorter compared to dogs with CSA.[2,4,6] The radiographic appearance of malignant rib

Abbreviations: CHO, chondroma; CSA, chondrosarcoma; HSA, hemangiosarcoma; OSA, osteosarcoma; SARC, sarcoma.

neoplasia in dogs has been previously described, with findings including rib osteolysis and presence of extra and/or intrathoracic masses,[2] but detailed information about CT characteristics of these tumors in dogs is still lacking.

In human medicine, CT and MRI are considered the modalities of choice for the diagnosis and characterization of thoracic wall neoplasia.[13–15] Specific cross-sectional imaging features have been described for different tumor types in human medicine.[13–15] In particular, CT is considered an important diagnostic tool, as it allows to evaluate the mineralization in the matrix of a malignant tumor.[15] For instance, when mineralization shows arc-and-ring appearance, flocculence, or a stippled shape, CSA should be considered.[15] On the other hand, if mineralization demonstrates osteoid features (dense, cloudy, ivory-like), OSA is considered most likely.[15] Another important feature on CT in human medicine is the spatial distribution of areas of mineralization, which is located at the center of the lesion in case of OSA.[13–15]

The aims of this study were to describe the CT characteristics of primary bone thoracic wall neoplasia in dogs and test the hypothesis that CT features would differ among tumor types.

2 | MATERIALS AND METHODS

2.1 | Selection and description of subjects

For this retrospective, multi-center, observational study, the electronic medical records of all dogs that had undergone thoracic CT examination in three different institutions (Ghent University in Belgium, San Marco Veterinary Clinic and Laboratory in Italy, and University of Vienna in Austria) between January 2006 and January 2022 were reviewed. Eligibility criteria and information required were: (1) presence of keywords “rib, sternum, thoracic, neoplasia, tumor, mass” in the CT report, (2) pre- and postcontrast CT examination of the thorax available for review, (3) cytological or histological diagnosis of primary bone neoplasia of the thoracic wall available, and (4) data regarding age, sex, breed and bodyweight available. Presence of a diagnosed metastatic lesion in the thoracic wall or a generalized neoplasia (such as multiple myeloma) represented exclusion criteria, as well as non-diagnostic cytological or histological evaluation, or incomplete CT studies.

All imaging procedures were performed solely for dogs’ benefit and for standard diagnostic and monitoring purposes. Previous informed written consent was obtained from all dog owners. All the procedures performed complied with the European legislation “on the protection of animals used for scientific purposes” (Directive 2010/63/EU).

Based on the cytological or histological diagnosis, patients included were divided into two groups: dogs with malignant neoplasia, sarcoma (SARC group), and dogs with benign neoplasia, chondroma (CHO group). Dogs included in the malignant neoplasia group, when possible based on the cytological and histological information available, were subsequently subdivided based on the tumor types in: OSA, CSA, and HSA.

All decisions for dog inclusion or exclusion, and subsequent inclusion in different groups were made by a consensus of two authors, a third-year resident of European College of Veterinary Diagnostic Imaging (A.C.) and a board-certified veterinary radiologist, European College of Veterinary Diagnostic Imaging (ECVDI; E.S.).

2.2 | Data recording and analysis

The CT images were randomized and blindly analyzed using free-standing workstations (OsiriX v5.8.5 64-bit, Geneva, Switzerland) by the board-certified veterinary radiologist (E.S). The reader was aware of the aims of the study, but unaware of the final diagnosis for each dog.

Three dimensions (height, length, and width) and the dimension of the lesion relative to the size of the dog (expressed in ratio between the maximum diameter of the mass and bodyweight) were measured for each lesion. Several qualitative features were subjectively assessed: location (rib or sternum); in case of ribs, lateralization (right or left), number of involved ribs, and position (dorsal, mid, or ventral). The grade of invasiveness was evaluated as mild, moderate, or severe, similarly to the grade of contrast enhancement (mild, moderate, severe). The presence of pulmonary lesions presumed to represent metastasis was recorded, together with the presence or absence of pleural effusion and lymphadenopathy of the sternal lymph nodes. Lymphadenopathy was subjectively determined to be present based on the following characteristics and the reader’s experience: subjective enlargement and/or heterogeneous contrast enhancement.

Particular attention was then placed on the evaluation of the tomographic appearance of the mineral attenuating portion(s) of the mass. Several features of the mineral attenuating regions were evaluated: grade of mineral attenuation in the lesion (subjectively evaluated as mild, moderate, or severe); localization of the tissue within the lesion (central or random); type of mineral attenuation (solid, cloudlike, ivory-like, stippled, flocculent, rings and arcs). The presence/absence of periosteal reaction was also recorded, together with the appearance (continuous/interrupted) and different types (smooth and solid, rough and solid, lamellar, brush border, palisading, spicular, sunburst, and amorphous).

2.3 | Statistics

The statistical analysis was performed by a veterinarian with PhD experience in medical data analysis. The free-software R (http://www.r-project.org/) was used for statistical analyses. Categorical variables were expressed as percentages, numerical variables as median and minimum–maximum (for data with non-normal distribution), and mean and standard deviation (for data with normal distribution). The normality of distribution of the data was evaluated based on visual inspection of histograms, the Shapiro–Wilk test, and the Q–Q plots. Differences among groups for continuous variables were evaluated using the Kruskall-Wallis test or one-way ANOVA test, depending on data

TABLE 1 Signalment of the dogs included in the three groups.

Groups	OSA (n = 23)	CSA (n = 10)	HSA (n = 8)	*P* value
Age (years)	7,5 (1-14)	9,75 (5-13)	3,75 (1.5-13.5)	0,375
Bodyweight (kg)	32,7 (8-55)	22,3 (10-44)	31,8 (15-57)	0,170
Males (N)	13 (2)	5 (2)	7 (4)	0,200
Females (S)	10 (6)	5 (4)	1 (1)	

Abbreviations: OSA, osteosarcoma; CSA, chondrosarcoma; HAS, hemangiosarcoma; N, neutered; S, spayed.*Notes*: Age and bodyweight presented as median and range (minimum-maximum).

distribution, with Bonferroni's post hoc analysis. Pairwise comparisons of the CT variables were assessed with the Fisher's exact test and Mann–Whitney *U* test. The level of significance was set at $P < 0.05$. A power analysis was not performed.

3 | RESULTS

3.1 | Subjects

A total of 58 dogs were included in the study (26 from Ghent University, 26 from San Marco Veterinary Clinic and Laboratory, and 6 from Vienna University). Of these 58, 11 (18.9%) were crossbreed dogs; other breeds included: four (6.8%) German Shepherds, four (6.8%) Rottweilers, three (5.1%) Border Collies, three (5.1%) Boxers. Two (3.4%) each of American Staffordshire Terrier, Bernese Mountain dogs, Bullmastiff, Cocker Spaniel, English Bulldog, Labrador Retriever, Golden Retriever, Irish Setter, Malinoise, and one (1.7%) each of Australian Cattle Dog, Beagle, Boerboel, Bull Terrier, Curlycoated, Dachshund, Fox Terrier, Jack Russell Terrier, Giant Schnauzer, Husky, Leonberger, Wolfdog, Pyrenese, Staffordshire Bull Terrier, and Weimaraner. Median age of the dogs included was 8 (1–14) years, and median weight was 30 (6–57) kg. The majority of the dogs included—32/58 (55%)—were males, of which 12 neutered, and 26 of 58 (45%) were females, of which 20 neutered.

3.2 | Tumor types

Based on the cytological and histological diagnoses, 56 of 58 (96%) dogs were included in the group of malignancy, and two dogs (4%) were included in the group of benign tumors, both histologically diagnosed as CHO. One was a Boxer, female intact, 8 years old, and the other a German Shepherd, female spayed, 6 years old.

All 56 tumors included in the malignancy group were diagnosed as SARC. The histological confirmation of the tumor type was available for 41 dogs, and included 23 OSA, 10 CSA, and 8 HSA.

The remaining 15 cases had a cytological diagnosis of SARC, but no definitive confirmation of the tumor type, therefore they were not included in the further division in the three described groups.

The three Border Collies included in the study were all in the CSA group, while the two American Staffordshire Terriers were both in the HSA group. Signalment of the dogs included in the three groups is summarized in Table 1. No statistically significant difference was found between the three groups, although the median age of the HSA group (3.75 years) was lower than the median age of the OSA (7.5 years) and CSA group (9.75 years). Nevertheless, out of the 10 dogs included in the study presented at young age (less than two years old), seven were in the OSA group (30% of the total of dogs with OSA) and one in the HSA group (12% of the total of dogs with HSA); two had only the cytological diagnosis of sarcoma.

3.3 | Imaging technique and CT findings

Computed tomographic data were acquired with different machines and different acquisition protocols, details are provided in Table 2. For all studies, a precontrast series of the thorax was acquired, followed by a postcontrast series acquired between 2 and 5 min after contrast injection. Dogs were all scanned in sternal recumbency on the CT table with the head first and frontlimbs extended cranially. An iodinated contrast agent (iohexol 370 mgI/mL, 2mL/kg dosage) followed by a saline flush was each time injected in a cephalic vein either manually or with single/dual barrel injector system.

Of the 58 dogs included in the study, 54 presented a neoplasia arising from the ribs, while in four cases the mass was originating from the sternum (Figure 1). In 32 of 54 (59%) cases, the lesion was right-sided, and in 22 of 54 (41%) was left-sided. The majority of the rib lesions were located in the ventral aspect (39/54, 72%), in nine of 54 (17%) were at the dorsal aspect and in six of 54 (11%) in the mid portion of the rib. In 23 of 54 (42%) cases, more than one rib was involved in the mass lesion. The rib most frequently involved was the seventh (13 cases, 24%), followed by the fifth and the eleventh, 11 cases each (20%). The different CT characteristics regarding size, invasiveness, contrast enhancement, and presence of pleural effusion, presumed pulmonary metastasis and sternal lymphadenopathy in the two dogs with benign lesions (CHO) and in the 56 dogs with malignant lesions (SARC) are summarized in Table 3, and two examples are shown in Figure 2. Due to the presence of only two cases in the group of benign lesions, statistical evaluation was not performed between these two groups.

TABLE 2 Description of imaging equipment and technical parameters used for CT scanning at the three different institutions in this 15-years period.

Institution	N of cases	Imaging equipment	Technical parameters
Ghent University	21	4-row MDCT unit, Lightspeed Qx/I, General Electric Medical Systems	Helical modality, 120 kVp, 140 mAs, image matrix 512 × 512, 1.25 mm slice thickness
Ghent University	5	320-row MDCT unit, Aquilion One, Toshiba Medical Systems, Otawara, Japan	Helical modality, 120 kVp, 200 mAs, image matrix 512 × 512, 0.5 mm slice thickness
San Marco Veterinary Clinic	8	16-row MDCT unit, Lightspeed 16, GE Medical Systems, Milan, Italy	Helical modality, 120 kVp and 200 mAs, detector configuration 16 × 1.25 mm (50% overlap), pitch 0.562:1, and 0.7 s rotation times
San Marco Veterinary Clinic	18	Dual-source CT (128 × 2 or 192 × 2 DSCT) (Somatom Definition Flash or Force; Siemens, Erlangen, Germany)	Helical modality, one tube,120 kVp, 400 mAs/rot (0.28 s), collimation 128/192 × 0.6 mm
Vienna University	1	Single slice unit (Pace^{TM}, General Electric, Milwaukee, WI, USA)	120 kVp, 100 mAs, image matrix 512 × 512
Vienna University	5	16-row MDCT unit (SOMATOM Emotion 16, Siemens Healthcare, Erlangen, Germany)	Helical modality, 130 kVp, 80–200 mAs, image matrix 512 × 512

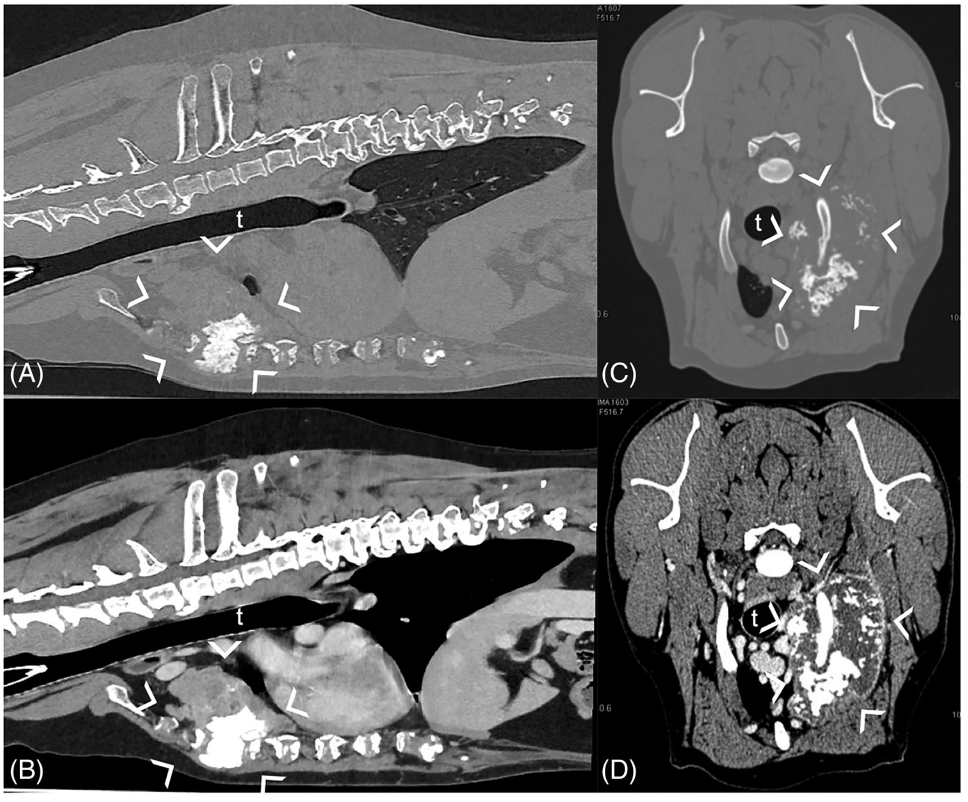

FIGURE 1 Examples of neoplasia arising from the sternum (A, B) and from the rib (C,D). A,B, Sagittal reconstruction of the thorax of a dog with sternal OSA (between arrowheads), bone window (A) and post-contrast soft tissue window (B) showing a large, heterogeneous mass, with mineralized and soft tissue components, occupying the cranial aspect of the thoracic cavity. C,D, Transverse plane in bone window (C) and post-contrast soft tissue window (D) of the cranial thorax of a dog with OSA of the second left rib (between arrowheads), characterized by mixed attenuation, with large mineralized portions, and invasion of the thoracic cavity. *t* = trachea. Helical modality, 120 kVp, 200 mAs, image matrix 512 × 512, 0.5 mm slice thickness.

TABLE 3 CT findings in the two main groups of dogs included in the study.

	CHO group (= 2)	SARC group (= 56)
Length (cm)	3.25 (2.9–3.6)	9.2 (2.3–25.3)
Width (cm)	1.9 (1.6–2.2)	7.9 (1.8–20.1)
Height (cm)	3.5 (3.3–3.7)	8.9 (3.2–19.4)
Maximum diameter mass/bodyweight	0.11 (0.09–0.13)	0.38 (0.1–1.08)
Invasion thoracic cavity	Mild 2/2 (100%)	Mild 9/56 (16%) Moderate 22/56 (39%) Severe 25/56 (45%)
Contrast enhancement	Mild 2/2 (100%)	Mild 24/56 (43%) Moderate 27/56 (48%) Severe 5/56 (9%)
Pleural effusion	0	27/56 (48%)
Presumed pulmonary metastasis	0	18/56 (32%)
Sternal lymphadenopathy	0	21/56 (38%)

Data are reported as frequency and percentage on total cases. Measurements (length, width, and height) are reported as median and range (minimum–maximum).
CHO, chondroma; SARC, sarcoma

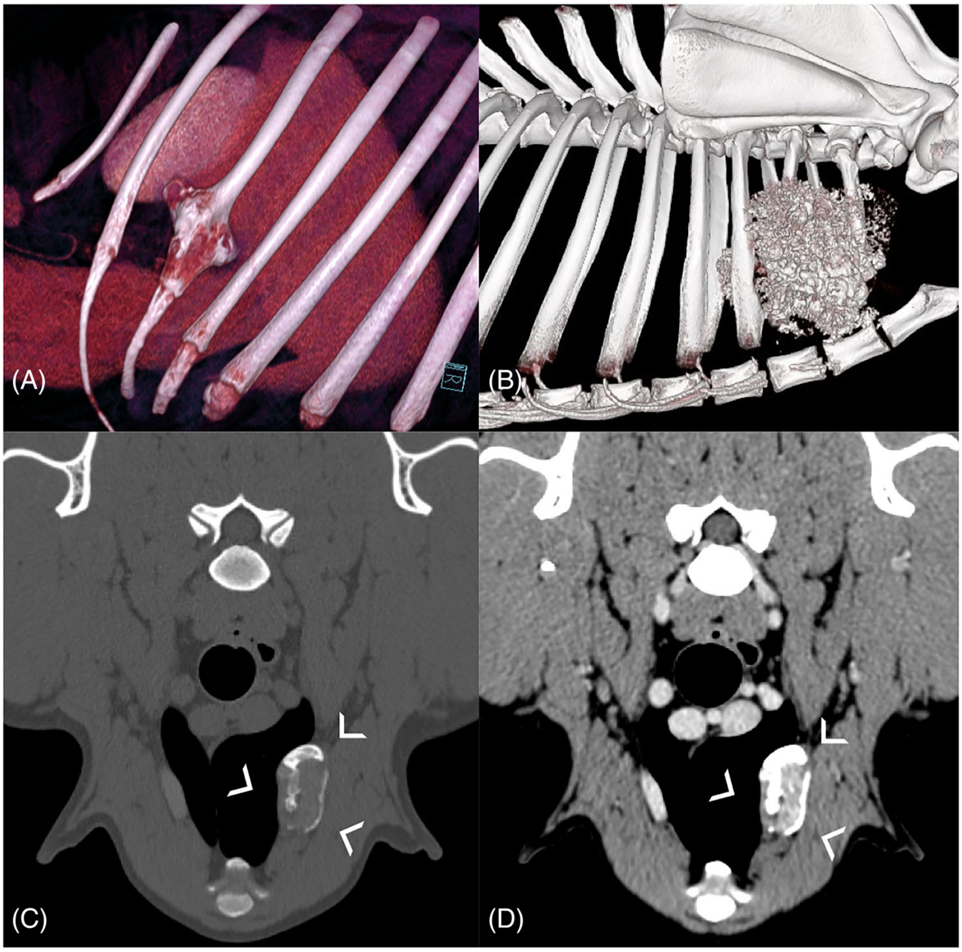

FIGURE 2 Differences between benign and malignant rib tumors. A,B, Examples of two different three dimensional (3D) volume rendering (VR) images: A, VR in a right lateral perspective (head is on the right of the image) of a dog with a CHO of the ninth right rib; B, VR in a right lateral perspective of a dog with CSA of the second right rib. Note the reduced volume of A (benign) compared to B (malignant). C,D, Example of CHO. Transverse CT images, bone window (C), and in postcontrast soft tissue window (D), of a dog with confirmed rib CHO (between arrowheads). Helical modality,120 kVp, 400 mAs/rot (0.28 s), collimation 128/192 × 0.6 mm. [Color figure can be viewed at wileyonlinelibrary.com]

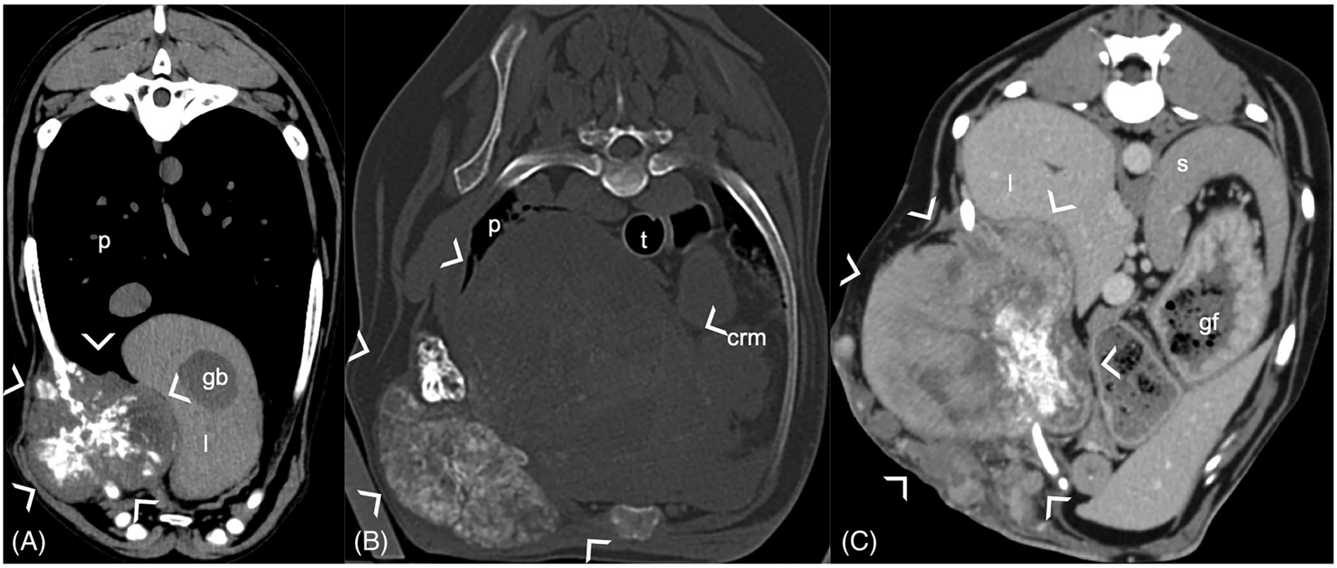

FIGURE 3 Examples of OSA. Transverse CT images, in postcontrast soft tissue window (A,C), and bone window (B) of three dogs with confirmed rib OSA. Note the large masses (between arrowheads) invading the thoracic and/or abdominal cavities, causing displacement and compression of the adjacent structures. Different types of mineral attenuating tissue within the lesion are shown: high grade of mineral attenuation, centered, cloud-like (A) high grade of mineral attenuation, centered, ivory-like (B), moderate grade of mineral attenuation, centered, flocculent; the grade of enhancement (A,C) was considered moderate. p = pulmonary parenchyma; l = liver; gb = gallbladder; t = trachea; crm = cranial mediastinum; gf = gastric fundus; s = spleen. Helical modality, 120 kVp, 200 mAs, image matrix 512 × 512, 0.5 mm slice thickness.

3.4 | Comparison of CT findings in different tumor types

No statistically significant differences were found between the tumor types regarding the lateralization of the mass, dorsal, mid or ventral location, and rib affected. Interestingly, the difference between the tumor types in involvement of one or multiple ribs was statistically significant ($P = 0.04$); in particular, at pairwise comparison, OSA was more frequently involving a single rib compared to CSA ($P = 0.05$), while no statistically significant differences were found between CSA and HSA ($P = 0.43$) and OSA and HSA ($P = 1$).

The CT findings in dogs with OSA (Figure 3), CSA (Figure 4), and HSA (Figure 5) are summarized in Table 4. The presence of sternal lymphadenopathy (Figure 6A) as detected at CT examination was the only feature reaching statistical significance ($p = 0.011$). In particular, sternal lymphadenopathy was significantly more frequent in dogs with OSA and HSA compared to dogs with CSA ($P = 0.004$ and $P = 0.023$, respectively). No difference was found in the frequency of sternal lymphadenopathy between dogs with OSA and HSA ($P = 1$). Frequency of presumed pulmonary metastasis (Figure 6B) was similar between the three groups ($P = 0.869$), while pleural effusion (Figure 6C) was more frequent in dogs with HSA, although not statistically significant ($P = 0.298$).

Several features of the mineral attenuating portions, including the grade of mineral attenuation, type of mineral attenuation, and periosteal reaction were evaluated. The finding with the difference closest to significance among the three groups was the grade of mineral attenuation ($P = 0.080$). In pairwise comparisons, dogs with HSA showed a significantly lower grade of mineral attenuation compared to dogs with OSA ($P = 0.043$). Grade of mineral attenuation did not differ between dogs with OSA and CSA ($P = 0.489$) and dogs with HSA and CSA ($P = 0.438$). No statistically significant differences were found regarding the localization of the ossified tissue, type of mineral attenuation, and periosteal reaction between the three groups.

4 | DISCUSSION

Findings partially supported our hypothesis in that malignant neoplasia (SARC) was more frequently observed, with lesions being more commonly ventrally located and showing severe invasion of the thoracic cavity. Benign lesions (chondroma) appeared subjectively smaller and non-invasive. Findings that did not support our hypothesis were minimal differences in the mineral attenuation among the tumor types in the included population (in contrast with previous reports in human medicine).

Median age of the dogs included in this study was 8 years, similar to previously described,[3–6] but a relatively large number (10) of dogs younger than 2 years old were also present, partially in accordance with previous studies.[2,7] No breed, sex, or sexual status predilection was detected in this study nor in previous reports.[2–6]

In accordance to previous literature, in our study tumors of the thoracic wall were most commonly malignant and mesenchymal in origin.[1–6] Similarly to previously described, in the current study, OSA was the most frequent tumor type, accounting for more than half of the tumors histologically diagnosed.[2–4,6] Compared to previous literature, in which the CSA was the second most common tumor type, in our study population the number of dogs with primary rib CSA

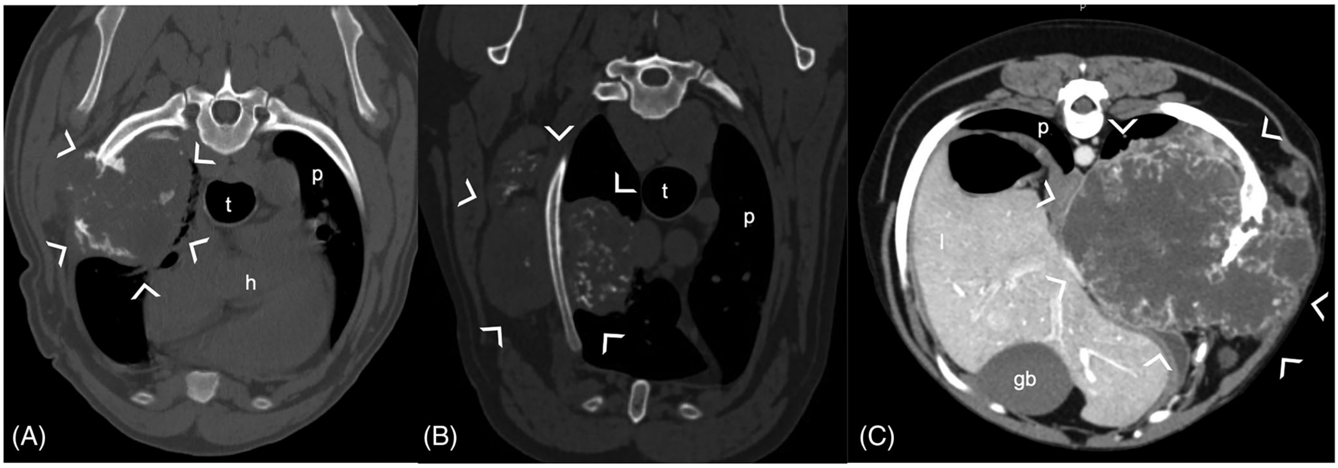

FIGURE 4 Examples of CSA. Transverse CT images, in bone window (A,B) and post-contrast soft tissue window (C), of three dogs with confirmed rib CSA. Note also in these cases the large masses (between arrowheads) invading the thoracic and/or abdominal cavities, causing displacement and compression of the adjacent structures. Different types of mineral attenuating tissue within the lesion are shown: mild grade of mineral attenuation, random, flocculent (A) and moderate grade of mineral attenuation, random, ring-and-arcs (B); the grade of enhancement (C) was considered moderate. p = pulmonary parenchyma; t = trachea; h = heart; l = liver; gb = gallbladder. Helical modality,120 kVp, 400 mAs/rot (0.28 s), collimation 128/192 × 0.6 mm.

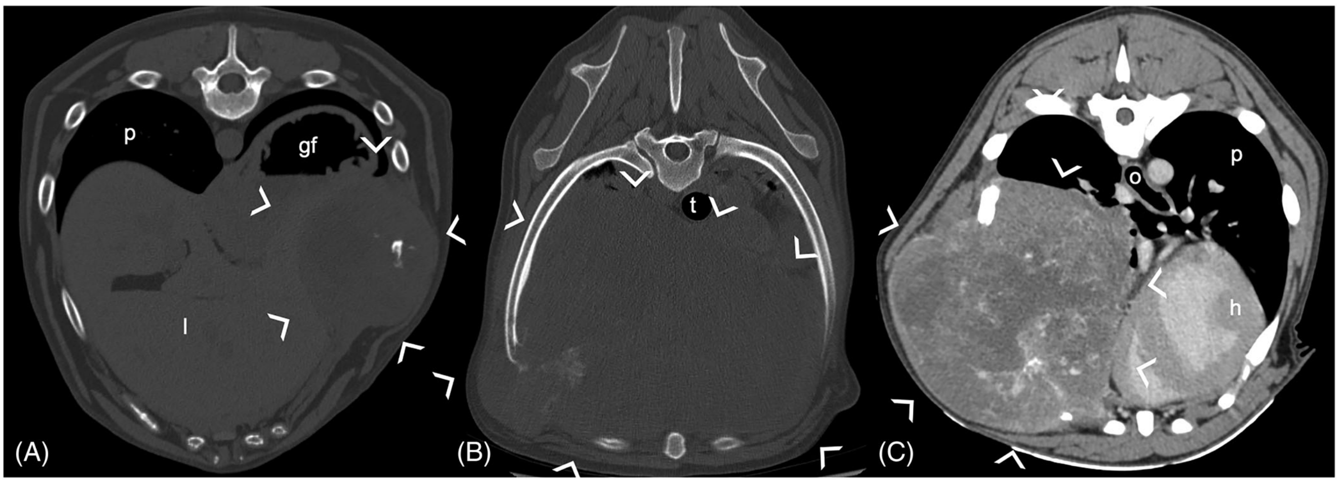

FIGURE 5 Examples of HSA. Transverse CT images, in bone window (A,B) and post-contrast soft tissue window (C), of three dogs with confirmed rib HSA. Note also in these cases the masses (between arrowheads) invading the thoracic and/or abdominal cavities, causing displacement and compression of the adjacent structures. The grade of mineral attenuation in these three cases was mild, with central, stippled (A) and central, flocculent (B) appearance; the grade of enhancement (C) was considered moderate. p = pulmonary parenchyma; l = liver; gf = gastric fundus; t = trachea; h = heart; o = oesophagus. Helical modality, 120 kVp, 200 mAs, image matrix 512 × 512, 0.5 mm slice thickness.

was similar to the number of dogs with HSA, the latter only sporadically described to date.[2–4,6] Benign neoplasia of the thoracic wall are rare in dogs, with few cases of chondroma described in the veterinary literature.[1,3,16] In our study, the two cases with CHO showed smaller size relative to the size of the patients compared to SARC, and no other thoracic abnormalities (pleural effusion, lymphadenopathy, presumed pulmonary metastasis) were seen. In a previous report, the CT features of a large rib chondroma were described, including thoracic invasion, displacement, and compression of the mediastinal organs, as well as chylothorax.[16] None of these features were seen in the two chondromas included in the current study, possibly because they have been detected at CT examination in an earlier stage.

Most of the SARC included in the current study were originated from the ribs, with only four cases of sternal neoplasia. As previously reported,[3] the ventral aspect of the rib was the most commonly affected, and in our population in approximately half of the cases more than one rib was involved. No predilection for a particular rib was noticed in the current study, but the most frequently involved was the seventh rib, and 60% of the lesions were right-sided. Previous reports described the right side affected twice as often as the left

TABLE 4 Comparison of CT findings in the three groups of dogs with sarcomas included in the study.

CT findings	OSA group (n = 23)	CSA group (n = 10)	HSA group (n = 8)	*P* value
Height (cm)	8.70 (3.20-19.40)	7.75 (3.80-13.50)	7.50 (5.40-12.70)	0.736
Length (cm)	9.50 (2.90-25.30)	9.15 (4.50-15.00)	6.90 (3.50-11.40)	0.214
Width (cm)	8.80 (2.50-20.10)	6.70 (2.60-13.60)	6.80 (3.30-11.90)	0.618
Grade of invasiveness	Mild 5 (22%) Moderate 8 (35%) Severe 10 (43%)	Mild 2 (20%) Moderate 4 (40%) Severe 4 (40%)	Mild 1 (12%) Moderate 3 (38%) Severe 4 (50%)	0.981
Contrast enhancement	Mild 9 (39%) Moderate 12 (52%) Severe 2 (9%)	Mild 3 (30%) Moderate 6 (60%) Severe 1 (10%)	Mild 4 (50%) Moderate 4 (50%) Severe 0 (0%)	0.856
Presumed pulmonary metastasis	8 (35%)	3 (30%)	2 (25%)	0.869
Pleural effusion	11 (48%)	4 (40%)	6 (75%)	0.298
Sternal lymphadenopathy	12 (52%)	0 (0%)	4 (50%)	0.011
Grade of mineral attenuation	Mild 5 (22%) Moderate 15 (65%) Severe 3 (13%)	Mild 4 (40%) Moderate 4 (40%) Severe 2 (20%)	Mild 6 (75%) Moderate 2 (25%) Severe 0 (0%)	0.080
Localization of the ossified tissue	Central 15 (65%) Random 8 (35%)	Central 4 (40%) Random 6 (60%)	Central 3 (38%) Random 5 (62%)	0.243
Type of mineral attenuation	Cloud/ivory-like 7 (30%) Flocculent/Stippled/ Rings and arcs 16 (70%)	Cloud/ivory-like 1 (10%) Flocculent/Stippled/ Rings and arcs 9 (90%)	Cloud/ivory-like 1 (12%) Flocculent/Stippled/ Rings and arcs 7 (88%)	0.281
Appearance of the periosteal reaction	Continuous 6 (26%) Interrupted 17 (74%)	Continuous 4 (40%) Interrupted 6 (60%)	Continuous 1 (12%) Interrupted 7 (88%)	0.422
Type of periosteal reaction	Solid 5 (22%) Spiculated/Sunburst 4 (17%) Amorphous 14 (61%)	Solid 4 (40%) Spiculated/Sunburst 2 (20%) Amorphous 4 (40%)	Solid 0 Spiculated/sunburst 3 (38%) Amorphous 5 (62%)	0.327

Measurements (height, length, and width) are reported as median (minimum-maximum). Other data are reported as frequency and percentage of total cases.
A $P < 0.05$ was considered significant (underlined findings).
OSA, osteosarcoma; CSA, chondrosarcoma; HAS, hemangiosarcoma.

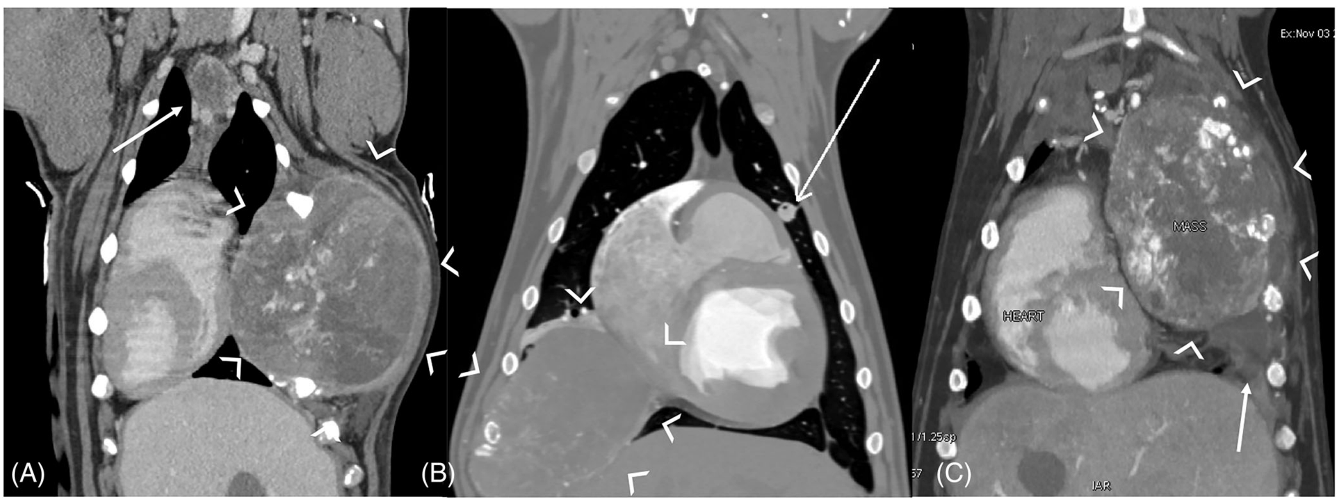

FIGURE 6 Examples of sternal lymphadenopathy (A), presumed pulmonary metastasis (B), and pleural effusion (C) in three dogs with thoracic wall bone neoplasia. Dorsal reconstruction, post-contrast soft tissue windows. The thoracic wall masses are shown between arrowheads, and arrows are pointing at an enlarged and heterogeneous sternal lymph node (A), a soft-tissue pulmonary nodule, compatible with metastatic process (B), and moderate pleural effusion (C) respectively. Helical modality, 120 kVp, 140 mAs, image matrix 512 × 512, 1.25 mm slice thickness.

side,[2] and ribs between the fourth or fifth rib to eighth or ninth rib most commonly affected,[2,4,6] although other studies led to conflicting results.[3,5,7]

The radiographic features of malignant rib neoplasia in dogs included rib osteolysis, and presence of extra and/or intrathoracic masses, with mineralized areas.[2] According to our results, mesenchymal tumors of the thoracic wall appeared in CT as large masses (with maximum diameter measuring in some cases more than 20 cm) and with secondary moderate to severe invasion of the thoracic cavity in most of the cases. The grade of mineral attenuation (as subjectively assessed) within the masses was variable, and contrast enhancement was overall considered mild or moderate in almost all cases. Presumed pulmonary metastasis were detected at CT examinations in 32% of the cases with diagnosed malignant neoplasia. In previous studies, the percentage of dogs with presumed pulmonary metastasis ranged from approximately 10% to more than 50% of the cases,[2,3,5] but the different modalities of detection of the metastasis (radiographic or CT study, surgery, necropsy) makes the comparison between studies difficult. Similarly, approximately half of the cases with SARC presented with pleural effusion at CT examination, and almost 40% of them showed enlargement of the sternal lymph nodes: these percentages are higher as previously reported, probably also due to different modalities of detection of the effusion and lymphadenopathy.[2,3]

The treatment of all types of neoplasia of the thoracic wall consists of surgical resection.[2,12] Nevertheless, the identification of different tumor types is important, as survival times differs between tumor type, with CSA carrying better prognosis compared to OSA and HSA.[3,4,6] For this reason, in this study, we evaluated the factors that could potentially help in the differentiation of the tumor types. Although no statistically significant difference was proved regarding the median age between the three groups, very young dogs (<2 years old) were most commonly affected by OSA, while no dogs younger than 5 years old were present in the CSA group. This is similar to human medicine, in which CSA is described to occur more commonly in patients older than 50 years, and OSA to be seen more commonly in children and adolescents.[14]

The involvement of a single rib was more frequent in dogs diagnosed with OSA compared to other tumor types; this finding is in accordance with the tendency of OSA to be monostotic in nature, as reported for appendicular OSA.[8–10]

In human medicine, different CT characteristics have been described in order to distinguish rib OSA from CSA: the central localization of the mineral tissue within the lesion, together with osteoid features (dense, cloudy, ivory-like appearance), are indicative of OSA, while CSA is more likely to present with arc-and-ring appearance, flocculent or stippled shape [15]. In the present study, no similar results were found, with no significant difference in localization or type of mineral attenuation and periosteal reaction between the three tumor types. Interestingly, in our study the grade of mineral attenuation, as subjectively evaluated, significantly differed between dogs with HSA and OSA, with a mild grade of mineral attenuation suggesting the presence of a HSA and moderate to high grades of mineral attenuation more likely to be OSA.

The sternal lymph nodes were enlarged in half of the cases diagnosed with OSA and HSA, and in none of the dogs with CSA, suggesting that lymph node involvement at CT examination could be considered a useful tool in distinguishing thoracic wall CSA from other tumor types in dogs.

This study has several limitations. Due to the retrospective nature of the study, the large period of inclusion (15 years), and the multicentric design, the CT technique has not been standardized. For the same reasons, the histological evaluation was not present in all cases, and data regarding the treatment, follow-up, and survival times were lacking. Furthermore, due to the rarity of these tumors in dogs, the number of included cases was relatively low, and the groups were not homogeneously represented, with subsequent low statistical power that could have influenced the results. Prospective further studies are therefore needed in order to correlate CT findings with histological diagnosis.

In conclusion, mesenchymal thoracic wall bone neoplasia appeared as large masses, invading the thoracic cavity in this sample of dogs. Relatively frequent findings were presumed pulmonary metastasis and pleural effusion, however these did not differ among tumor types. The presence of sternal lymphadenopathy was more frequent in dogs with rib OSA and HSA, and a low grade of mineral attenuation within the lesion was suggestive of HSA.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

a. Conception and Design: Cordella, Stock
b. Acquisition of Data: Cordella, Strohmayer, Dalla Serra
c. Analysis and Interpretation of Data: Cordella, Stock, Bertolini, Saunders

Category 2

a. Drafting the Article: Cordella
b. Revising Article for Intellectual Content: Stock, Bertolini, Strohmayer, Saunders, Dalla Serra

Category 3

a. Final Approval of the Completed Article: Cordella, Stock, Saunders, Bertolini, Strohmayer, Dalla Serra

Category 4

a. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Cordella, Stock, Saunders, Bertolini, Strohmayer, Dalla Serra

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CONFLICT OF INTEREST DISCLOSURE

The authors have declared no conflict of interest.

DATA ACCESSIBILITY STATEMENT

Contact corresponding author to access original data.

PREVIOUS PRESENTATION DISCLOSURE

The preliminary results of this study were presented at the ECVDI online conference in September 2021.

REPORTING CHECKLIST DISCLOSURE

The study followed the STROBE-VET reporting guidelines.

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