Electrophysiological features in dogs with peripheral nerve sheath tumors: 51 cases (1993–2010)

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Objective—To determine the electrophysiological changes in dogs with peripheral nerve sheath tumors (PNSTs), evaluate the prevalence of these changes, assess the correlation between spontaneous activity in epaxial muscles and proximal invasion by the tumor, and evaluate whether knowledge of electrophysiological changes could be helpful in the imaging diagnosis via CT or MRI.

Design—Retrospective case series.

Animals—51 dogs with a histologic (n = 18) or a suspected (33) diagnosis of PNST.

Procedures—Clinical, postmortem, and histologic reports and details of electrodiagnostic procedures and CT or MRI reports were studied. Twenty-four CT and 6 MRI reports for dogs with PNSTs were reviewed by a single observer blinded to the diagnosis.

Results—Only 2 of the 51 dogs had no electrophysiological changes. The most commonly affected muscles were those innervated by the radial, ulnar, median, tibial-sciatic, and peroneal nerves. Abnormal spontaneous epaxial muscle activity was significantly more frequent in the group with foraminal or spinal invasion by the tumors. Knowledge of the electrophysiological changes increased diagnostic accuracy of CT.

Conclusions and Clinical Relevance—Results suggested that electrophysiological studies may be sensitive for the detection of PNST and helpful in the imaging diagnosis. Epaxial electromyographic abnormalities appeared to be predictive for intervertebral or vertebral canal invasion by PNSTs in dogs. (*J Am Vet Med Assoc* 2012;241:1194–1201)

Peripheral nerve sheath tumors in dogs are well described, but diagnosis and treatment remain challenging. These tumors may involve spinal and peripheral nerves, including those arising from the cervical and lumbosacral intumescences in particular.[1–6] Chronic lameness in 1 leg is a frequent clinical sign.[1–6] For this reason, it is difficult to differentiate between PNSTs and orthopedic conditions.[1–6] Progressive hemiparesis or tetraparesis occurs in patients with spinal invasion of the cervicothoracic region.[1] Peripheral nerve sheath tumors grow proximally and therefore tend to invade the intervertebral foramen and the vertebral canal. Peripheral nerve sheath tumors may affect 1 or several nerve roots, but it remains unclear whether they initially occur in multifocal areas or whether they spread from 1 root to another.[7]

Surgical treatment in dogs involves excision of the tumor (and nerve), limb amputation, and laminectomy, when indicated.[1–3,5,6,8] Intraoperative determination of the affected root and invasion into the foramen by the PNST remain challenging.[3] In a study of 51 histologically confirmed cases of PNST in dogs, Brehm et al[1] found that 23 (45%) tumors invaded the intervertebral foramen (the root group). This group had a disease-free interval of 1 month and a median survival time of only 5 months, even with surgical treatment.

Electromyography has been described as a sensitive tool for detecting the neuropathic changes associated with these tumors.[1,9] Nerve conduction studies[4,9–11]

Abbreviations

CMAP	Compound muscle action potential
EMG	Electromyography
MNCV	Motor nerve conduction velocity
PNST	Peripheral nerve sheath tumor

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have been described in a few cases with absent CMAPs or reduced nerve conduction velocity. Electromyography of epaxial muscles has rarely been performed in veterinary patients with PNSTs.[10] However, such techniques are theoretically of interest for identifying tumor extension into the intervertebral foramen or the vertebral canal.[12] Myelography may be useful for documenting vertebral canal invasion by the tumor.[1] In peripheral locations, this technique has been supplanted by CT and MRI. However, a lack of contrast uptake or heterogeneous enhancement (after IV contrast products injection) may make it difficult to distinguish the tumor from the surrounding tissues, making diagnosis and localization difficult.[4,11,13,14]

In the study reported here, we aimed to review our knowledge concerning the electrophysiological characteristics of PNSTs and to identify features or variables correlated with the duration of clinical signs. Our secondary objective was to determine whether any of these features were predictive of proximal invasion by the PNST. Our third objective was to evaluate whether knowledge of the electrophysiological results could be helpful in interpreting imaging findings for the diagnosis of PNSTs via CT or MRI.

Materials and Methods

Medical records from dogs admitted to the Ecole Nationale Vétérinaire d'Alfort, Université Paris Est, France, between January 1993 and July 2010 that underwent an electrophysiological procedure were reviewed. Peripheral nerve sheath tumor, neurofibrosarcoma, and schwannoma were used as keywords for searches with the clinical software of the Ecole Nationale Vétérinaire d'Alfort.[b] All cases associated with an electrophysiological report containing the term tumor in the conclusion were also reviewed. We initially retained 122 cases. All cases with clinical signs compatible with PNST and a histologic diagnosis of PNST for confirmed cases and all suspected cases for which a macroscopic evaluation (per surgical observation or postmortem examination) or a CT or MRI was performed, with the detection of thickening of or a mass on a peripheral or spinal nerve, were included. All the available epidemiological, clinical, and histologic data for these cases were obtained from the clinical software or paper reports.

In all patients, the electrophysiological procedure was performed before imaging or surgery by a board-certified neurologist or a resident in neurology. Electrophysiological procedures were performed under general anesthesia, with an EMG unit.[c,d] The anesthetic protocol involved the placement of a peripheral IV catheter, induction of anesthesia with propofol[e] (4 to 6 mg/kg [1.8 to 2.7 mg/lb], IV, to effect) or thiopental[f] (10 to 15 mg/kg [4.5 to 6.8 mg/lb], IV, to effect), and maintenance with isoflurane vaporized in oxygen. The EMG was performed with a disposable, concentric 0.45-mm needle with a 0.068-mm^2 sampling area, with the patient in a lateral recumbent position to allow complete examination of epaxial, thoracic, and pelvic limb muscles. Both the thoracic limbs or both the pelvic limbs were examined, depending on the limb affected. The epaxial muscles were explored in the area of the affected limb. Three needle passes were routinely performed in 3 areas for all of the muscles examined. Abnormal spontaneous activity such as prolonged insertional activity, positive sharp waves, and fibrillation potentials was recorded and quantified. A subjective score of 0 to 3 was attributed to each muscle tested on the basis of the frequency of spontaneous activity. A score of 0 corresponded to electrically silent muscles. A score of 1 corresponded to rare spontaneous activity recorded at few sites. A score of 2 corresponded to diffuse occasional spontaneous activity or frequent spontaneous activity recorded at few sites. A score of 3 corresponded to diffuse abundant spontaneous activity in the muscle. The degree of appendicular EMG changes was calculated for each affected limb by summing the scores for all the muscles within this limb.

All motor nerve conduction and late latency action potential (H-reflex and F-waves) studies were performed with polytetrafluoroethylene-coated, stainless steel monopolar needles with 3-mm bare tips for stimulations and recordings, with supramaximal stimuli of 0.1 milliseconds' duration delivered at a rate of 1 Hz. Motor nerve conduction studies of the radial and ulnar nerves were performed if the clinical signs concerned a thoracic limb. Peroneal and tibial nerves were evaluated if the clinical signs involved a pelvic limb.[15] M-wave latency, distal CMAP amplitudes, and nerve conduction velocities were evaluated. In all patients, the operator obtained the maximum amplitude of the CMAPs at supramaximal stimulation. The distal points of stimulation were used to obtain long latency potentials for each nerve. H-waves were recorded for tibial and ulnar nerves, and F-waves were recorded for the peroneal and ulnar nerves. The intensity of stimulation was gradually increased from 1 V to the supramaximal voltage to obtain H-waves and from the supramaximal voltage to > 100 V to obtain F-waves. The shortest latency obtained was taken as the H- or F-wave latency. All the electrophysiological data were reexamined by the first author (MLC) with the software supplied with the electrophysiological device. Published values were used to interpret the electrophysiological data[15] except for late latency action potentials. For each nerve studied, CMAP amplitudes were considered abnormal if they were lower than a published reference range.[15] Motor nerve conduction velocities were also considered abnormal if they were lower than a published reference range.[15] A conduction block was considered in instances of a > 50% decrease in the proximal to distal CMAP amplitude ratio without notable temporal dispersion and polyphasia.[16] To abolish the limb length effect, the ratio of right side H- or F-wave latency for one nerve to left side H- or F-wave latency for the same nerve was calculated for each nerve studied. This value was compared with a reference range we established for the purpose of this study. Values of H- and F-wave latency for dogs examined in our institution were used for this purpose. All these dogs underwent an electrophysiological procedure because of chronic lameness. They all had a final diagnosis of orthopedic disease. Ten dogs were used to determine the ratio of the ulnar H-waves latencies. Ten were used to determine the ratio of the radial F-waves latencies. Seventeen were used to determine the ratio

of the tibial H-waves latencies. Fourteen were used to determine the ratio of the peroneal F-waves latencies. A patient in the present study was considered to have normal late latency action potentials if both the H- and F-waves of the affected limb had a normal latency (ie, within the above determined reference range) or if one had a normal latency and the other was not determined.

Computed tomography and MRI were considered advanced imaging procedures in this study. Computed tomographic scans were performed with 4 scanners over the study period.[g–j] Images were obtained before and after contrast agent injection IV.[k] The lesions were described in terms of contrast enhancement and differentiation from the surrounding tissues. Magnetic resonance imaging was performed with a 0.2-T MRI unit[l]. T1-weighted images, T2-weighted images, and T1-weighted images after IV contrast agent injection[m] were performed in all patients that underwent MRI. Short T1 inversion recovery sequences were performed in some patients. The images were acquired in sagittal, transverse, and dorsal sequences. On CT and MRI, the contrast enhancement was subjectively described as good, moderate, weak, or absent. If present, it was subjectively described as homogeneous, heterogeneous, or rim enhancement. The distinction from the surrounding tissues was subjectively described as good, moderate, or difficult. The tumor's aspect was described as a mass, a nerve thickening, or both, and muscle atrophy was noted. Moreover, on MRI, the lesion was described regarding its intensity with respect to the surrounding tissues and the distinction from surrounding tissues was noted on T1-weighted images after contrast agent injection, T2-weighted images, and short T1 inversion recovery images. Twenty-six of the 28 CT scans and 6 of the 7 MRI scans were examined by the first 2 authors (MLC and JLT) together and with the knowledge of the electrophysiological procedures. The images of 3 CT and 1 MRI examinations were not accessible, so the information was retrieved from written reports.

To evaluate the influence of the electrophysiological procedure on the diagnostic imaging interpretation, 24 CT and 6 MRI examinations were reviewed by a single board-certified radiologist (JL). The 3 CT and the MRI examinations lacking were not reviewed, and another CT examination was not accessible to the reviewer at the time of the blinded reviewing process. In addition to the PNST cases, the observer had to review 30 other CT (n = 14) and MRI (16) examinations from dogs affected by a unilateral lameness or a lower motor neuron disorder. This individual was not aware of the clinical signs for the cases. For each study, the presence or absence of peripheral nerve abnormalities was indicated with either a high or low level of confidence.

All the surgical procedures were performed by a board-certified surgeon or resident in surgery. The postmortem examinations were performed by one of the authors (MLC, JLT, or SB) or by a board-certified pathologist.

The imaging, surgical, postmortem, and histologic procedures were used to classify the tumors into 2 groups on the basis of their most proximal location. The proximal group included all the tumors invading the intervertebral foramen or the vertebral canal; this group was very similar to the root group of Brehm et al.[1] The peripheral group included all the tumors invading only a plexus or a peripheral nerve.

Data for the weight of the animal were missing in some cases. For group comparisons, dogs were arbitrarily classified as weighing from 1 to 15 kg (2.2 to 33 lb) or > 15 kg, according to breed. Even with this method, we were unable to classify 3 dogs on the basis of size because these individuals were crossbreeds of unknown size.

A Mann-Whitney test was used to evaluate the statistical difference between the proximal and peripheral groups in terms of the duration of clinical signs. A linear regression analysis was performed to evaluate the correlation between the degree of appendicular EMG changes and the percentage decrease of ulnar, radial, tibial, and peroneal CMAPs and the duration of clinical signs. A Fisher exact test was performed to compare the proportions of abnormal CMAPs, MNCVs, and H- and F-wave latencies between the histologically confirmed and suspected cases. The Fisher exact test was also used to compare the proportions of abnormal F-waves. The χ^2 test was also used to compare the proportions of abnormal H-waves. The Kolmogorov-Smirnov test was used to assess the normality of the distribution of the right-to-left side ratio of the H- and F-waves in the dogs with orthopedic disease. Finally, logistic regression was used to compare the proportion of cases with spontaneous activity in epaxial muscles between proximal and peripheral tumors. Values of $P < 0.05$ were considered significant. All statistical analyses were performed with a commercial software suite.[n]

Results

Epidemiological data—Fifty-one cases met the inclusion criteria. The distribution of breeds was as follows: 7 Labrador Retrievers, 2 Golden Retrievers, 6 Poodles, 5 Rottweilers, 5 German Shepherd Dogs, 3 Fox Terriers, 3 Yorkshire Terriers, 2 American Staffordshire Terriers, 2 Siberian Huskies, 2 Brittany Spaniels, 1 Shetland Sheepdog, 2 Collies, 1 Gordon Setter, 1 French Bulldog, 1 Dachshund, 1 Pyrenean Shepherd Dog, 1 Lhassa Apso, 1 Boxer, and 5 crossbreed dogs. Seventy-one cases were excluded. Sixty-one of these 71 cases had no further exploration following the electrophysiological procedure or the data were unavailable at the time of the study. Two cases involved a histologic diagnosis of PNST, and 1 had compatible MRI images but data concerning electrophysiology were lacking. Another patient had a normal CT and no histologic exploration. Four cases had no imaging procedures and the following histologic diagnosis: lymph node metastasis of a mammary gland carcinoma in 2 cases, Wallerian degeneration in 1 case, and lymphangioma in 1 case. One dog had a mass invading the right cranial thorax and the right brachial plexus without histologic diagnosis. One case involved thickening of a nerve root on CT images and a histologic diagnosis of neuritis.

The study included 17 dogs weighing < 15 kg and 31 weighing > 15 kg. Three dogs could not be assigned to 1 of these 2 size classes. Thirty-five of the dogs were male, and 14 were female. Sex was unknown in 2 cas-

es. The median age of the affected dogs was 8.5 years (range, 5.5 to 16 years).

Clinical signs—The owners reported chronic lameness in 41 (80%) cases, paresis or weakness of 1 limb in 7 (14%), hyperesthesia of the limb (expressed as excessive licking) in 1 (2%), and the presence of a subcutaneous mass at the level of the elbow in 1 (2%). The main clinical sign was not known in 1 (2%) case. The median duration of clinical signs for all dogs was 120 days (range, 14 to 549 days). The clinical signs in dogs with a thoracic limb tumor (n = 40) included muscular atrophy (33); paresis or lameness (12); proprioceptive deficits (35); hyporeflexia (31); thoracic limb hyperesthesia (14), hypoesthesia (6), or both (5); pain on brachial plexus palpation (14); a mass lesion detected in the brachial plexus area (2); anisocoria (5); and some cutaneous trunci reflex absence on the side of the suspected tumor (9). The clinical signs in dogs with a pelvic limb tumor (n = 11) included muscular atrophy (11), paresis or lameness (2), proprioceptive deficits (8), hyporeflexia (8), and pelvic limb hyperesthesia (1) or hypoesthesia (4).

Lesion location—The limb affected was thoracic in 40 dogs and pelvic in 11. In 18 cases, PNST was confirmed histologically, and PNST was suspected on the basis of results of cytologic testing in 1 additional case. The histologically confirmed and suspected case animals did not differ significantly in terms of sex (P = 0.35), age (P = 0.71), or size of the dog (P = 0.29).

Following imaging, surgical, postmortem, and histologic descriptions, 29 dogs were classified in the proximal group and 18 in the peripheral group. The exact location of the most proximal part of the tumor was not determined in 4 cases. The proximal and peripheral groups did not differ significantly in terms of sex (P = 0.74), age (P = 0.47), or size of the dogs (P = 0.08). No significant (P = 0.27) difference in the duration of clinical signs was found between the proximal and peripheral group. The affected spinal roots were determined when possible; C5 was affected in 2 dogs, C6 in 7, C7 in 19, C8 in 24, T1 in 13, T2 in 2, T3 in 2, L4 in 2, L5 in 1, L6 in 3, L7 in 3, S1 in 2, S2 in 1, and S3 in 1.

Appendicular EMG results—Abnormal spontaneous activity was found in at least 1 muscle of the affected limb in 49 of 51 cases. In animals with affected thoracic limbs, the extensor carpi radialis and triceps brachialis muscles had EMG changes in 29 of 40 cases. Interosseous and the group of flexor carpi and digitorum muscles had EMG changes in 26 and 22 of 40 cases. In the 11 animals with affected pelvic limbs, interosseous (n = 9), tibialis cranialis (8), gastrocnemius (7), and semimembranosus or tendinosus (6) muscles most commonly had EMG changes. We found no association between the degree of appendicular EMG changes and the duration of clinical signs (P = 0.23).

Epaxial muscle EMG results—The results of epaxial muscle EMG were available in 30 cases. Abnormal epaxial muscle activity was observed in the area of the affected limb in 12 cases. Eleven of these 12 cases belonged to the proximal group. The epaxial muscles were electrically silent in 18 dogs, of which 8 were from the proximal group.

The frequency of abnormal spontaneous epaxial muscles activity differed significantly (P = 0.048) between the proximal and peripheral groups. The sensitivity of this EMG finding for the prediction of an intervertebral or spinal invasion by the PNST was 53%, and its specificity was 91%. This technique had a specificity of 100% if we considered only the thoracic limbs.

Motor nerve conduction studies—The CMAP amplitudes from at least 1 nerve of the affected limb were below normal values in 32 of 40 cases. The 8 dogs with unaltered CMAP amplitudes were affected on a thoracic limb. No significant (P = 0.7) difference in the numbers of abnormal CMAP amplitudes was found between the histologically confirmed (14/16) and suspected (26/32) cases. A conduction block was diagnosed in 3 cases. In all these patients, a radial nerve was affected.

The CMAP amplitude of the nerves in the affected limb, expressed as a percentage of that for the contralateral limb, was not associated with the duration of clinical signs (P = 0.053 for the ulnar nerves, P = 0.63 for the radial nerve, P = 0.24 for the peroneal nerve, and P = 0.55 for the tibial nerve). The MNCV was abnormal for at least 1 nerve in 32 of 40 cases. The MNCV abnormalities did not differ significantly (P = 1) between confirmed (13/16) and suspected (25/32) cases.

Late latency action potential—We established the following reference ranges for right-to-left side ratio for the of H- and F-waves latencies on the basis of testing patients examined at our hospital for other conditions (ie, orthopedic disease) and without evidence of PNSTs. All these ratios were normally distributed, and the reference ranges are expressed as mean ± 2SD, with the number of animals tested indicated in parentheses. The reference range for the ulnar nerves H-wave latencies ratio was 1.03 ± 0.182 (n = 10). It was 0.931 ± 0.0744 (10) for the radial nerves F-waves latencies ratio, 0.998 ± 0.104 (17) for the tibial nerves H-waves latencies ratio, and 0.965 ± 0.230 (14) the peroneal nerves F-waves latencies ratio. The latency of late latency action potentials for the affected limb was abnormal in 34 of 38 patients with PNSTs. No significant difference was found between the proximal and peripheral groups in terms of abnormalities of H- (12/21 and 8/13, respectively; P = 0.800) or F-waves (18/19 and 10/10, respectively; P = 1). There was also no difference between the suspected and confirmed cases in terms of abnormalities of H- (16/26 and 5/11, respectively; P = 0.475) and F-waves (24/25 and 7/7, respectively; P = 1).

Advanced imaging—On CT images, the contrast enhancement was good in 5 of 28 cases, moderate in 9, and weak in 8. Rim enhancement was noticed in 9 of 28 cases. The data concerning enhancement was not available in 6 of 28 cases. The distinction from the lesion to surrounding tissue was good in 6 of 28 cases, moderate in 8, and difficult in 12. These data were not available in 2 of 28 cases. Obvious muscle atrophy was noticed in 15 of 28 cases. No muscle atrophy was observed in 10 of 28 cases. The muscle could not be evaluated or was not mentioned in reports in 3 of 28 cases.

On MRI sequences, 6 of 7 lesions were isointense to the nervous tissue and 1 was hyperintense on T1-weighted images. On T2-weighted images, 7 of 7 lesions

were hyperintense to the nervous tissue. Because they were located in the plexus area, 4 were also evaluated in comparison with the fat. Three were hypointense to the fat, and 1 was isointense (**Figure 1**). Short T1 inversion recovery sequences were obtained in 5 of the 7 dogs. In all 5 dogs, the lesion was hyperintense. After IV injection of gadolinium, the contrast enhancement was good in 3 of 7 cases, weak in 2, and absent in 2. It was also homogeneous in 2 of 5 cases and heterogenous in 2; the information regarding the homogeneity of the contrast enhancement was not available in 1 of 5 cases. A rim enhancement was noticed in 1 case. The distinction to surrounding tissue was good in 4 of 7 cases, moderate in 2, and not given in 1 on T2-weighted images. It was good in 2 of 7 cases, moderate in 3, and absent in 2 on T1 postcontrast images. It was good in 5 of 5 cases on short T1 inversion recovery images. The lesions were a nerve thickening in 4 of 7 cases, a mass in 2, and both in 1. Muscle atrophy was noticed in 6 of 7 cases and was not mentioned in the report in 1.

Five of the 24 blinded reviewed CT scans were excluded because the postcontrast slices were no longer available. On CT, 5 of 19 lesions were not detected on the initial blinded evaluation. No concurrent visible muscle atrophy was present on these 5 CT series. In 3 of 5 cases, peripheral nerve abnormalities in the form of moderate thickening of the presumed affected nerves were detected on the second review, after knowledge of the electrophysiological results (**Figure 2**). In 2 of 5 cases, the reviewer was not confident for the exclusion of a PNST and recommended MRI examination. In these cases, peripheral nerve changes were only sus-

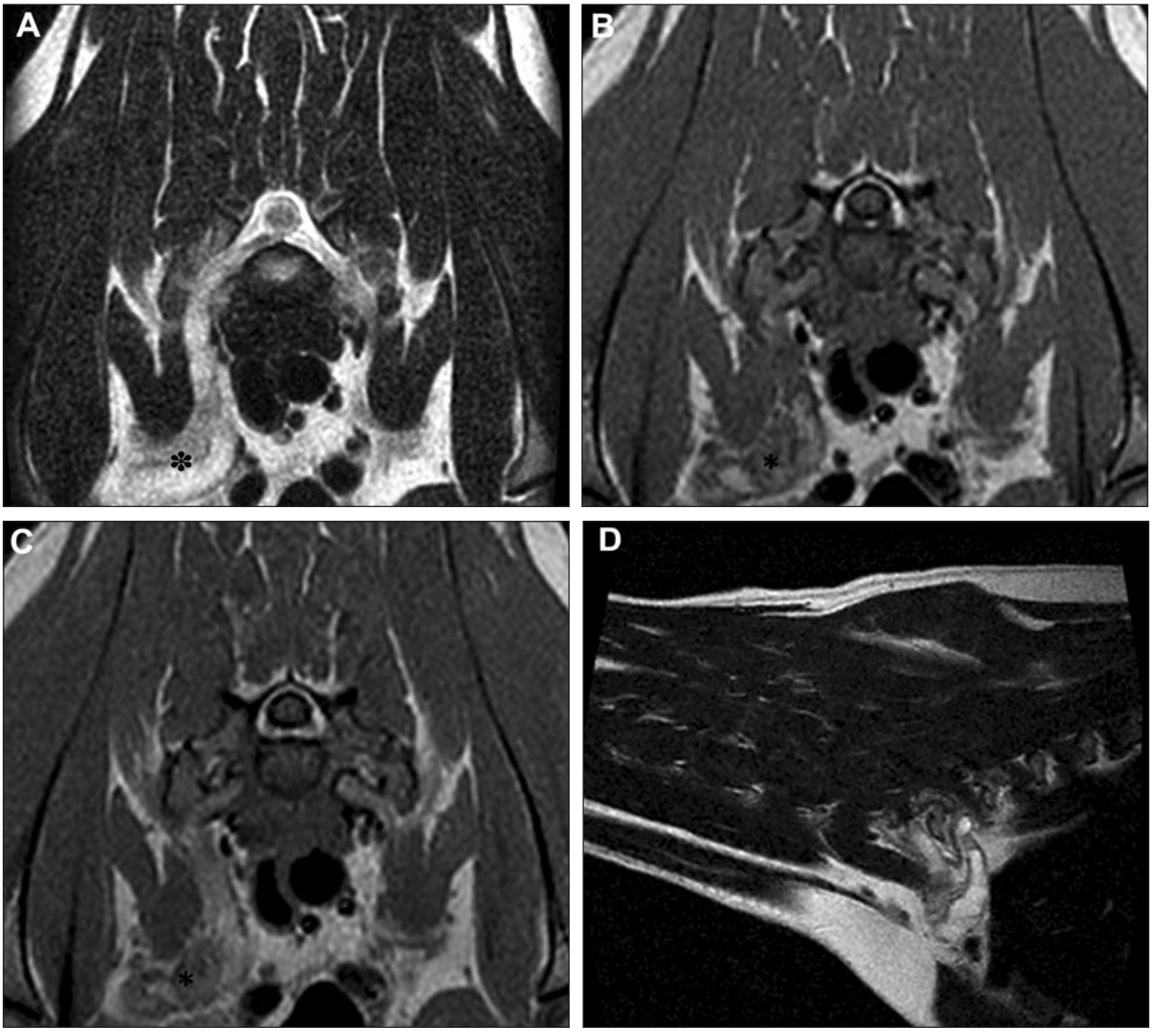

Figure 1—Transverse T2-weighted MRI image (A), T1-weighted image (B), and T1-weighted image obtained after gadolinium injection (C), and parasagittal T2-weighted image (D) from an 8.5-year-old male Golden Retriever with a confirmed PNST extending from the C5-6 intervertebral foramen to the brachial plexus. Images were obtained from C1 to T2. A—On the T2-weighted image, the tumor (black asterisk) is heterogeneous and isointense to the fat. B and C—On the T1-weighted images, the tumor (black asterisk) is heterogeneous and isointense to the nervous tissue and shows mild heterogeneous contrast enhancement. D—On the parasagittal image, the PNST is invading 2 consecutive spinal roots. On all images, there is severe thickening of the nerves and mild muscular atrophy on the side of the lesion. These images illustrate the classical features of PNSTs in a dog.

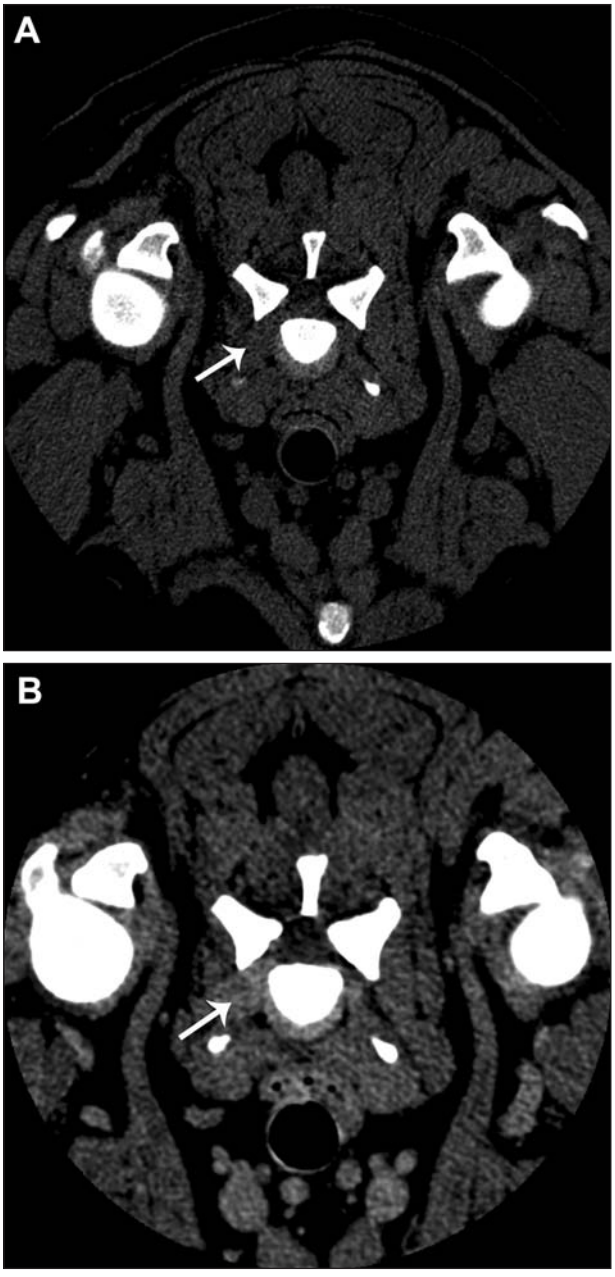

Figure 2—Transverse CT images of a 7-year-old male Rottweiler with a histologically confirmed PNST invading the right C5-6 intervertebral foramen. This lesion was overlooked during initial review of the CT images by a board-certified radiologist who was blinded to the diagnosis. Images were obtained from C1 to T2. A—On the precontrast image, there is only a very mild widening of the intervertebral foramen (arrow). B—The tumor appears weakly enhanced after contrast agent injection (arrow). No concurrent muscular atrophy is evident on either image.

pected because of the presence of muscle atrophy. On MRI, all cases (6/6) of PNSTs were diagnosed with a high level of confidence.

Discussion

The results of the present study demonstrate that EMG remains a sensitive diagnostic technique to detect the neuropathic changes associated with confirmed and suspected PNSTs in dogs. Moreover, electrophysiologic studies are helpful for radiologists during the interpretation of CT in these patients. Additionally, we suggest that epaxial muscle EMG study may predict proximal extension of PNSTs in dogs.

Forty-nine of the 51 (96%) dogs studied had abnormal spontaneous muscle activity on EMG. Brehm et al[1] reported similar findings, with abnormal activity detected in all 23 dogs examined. One of the 2 dogs in the present study with a normal EMG examination had a tumor that infiltrated all the fascicles but not the axons. This may account for the normal EMG results obtained for this dog, despite the presence of clinical signs for 138 days. However, some caution is required. Even if the PNST is restricted to the perineurium and does not contain axons, it could displace the nonaffected portion of the nerve[17] and could compress the vessels, reducing vascular flow to the distal parts of the nerve and thereby triggering axonal lesions. The CMAPs and MNCVs changes were heterogeneous. The results of testing in some patients involved a decrease in CMAPs amplitudes with normal MNCVs, whereas some patients had normal CMAPs amplitudes with a decrease in MNCVs. If we considered these results together, only 3 dogs had normal CMAP amplitudes and MNCVs. However, EMG seems sufficient to detect the neuropathic changes associated with PNSTs, even at early stages of the disease.

In the present study, abnormal EMG results were most frequently obtained for the interosseous, flexor carpi and digitorum, extensor carpi radialis, and triceps brachialis muscles for thoracic limbs and for the tibialis cranialis, interosseous, gastrocnemius, semimembranosus, and tendinosus muscles for pelvic limbs. These muscles are innervated by the radial, ulnar, median, peroneal, and tibial-sciatic nerves. The abnormal results obtained for these muscles are not surprising, given that the most commonly affected nerve roots were C8, T1, and C7 for thoracic limbs and L6 and L7 for pelvic limbs. Bradley et al[3] reported a similar distribution of affected nerve roots. These data suggest that the roots should be meticulously investigated during diagnostic imaging or surgical exploration.

A large number of false negatives (5/19) were present in this study after blinded CT imaging evaluation. With knowledge of the EMG results, PNSTs were detected in 3 of 5 cases and characterized only by minimal peripheral nerve thickening in the absence of visible muscular changes. On MRI, PNSTs were diagnosed with a high level of confidence in all cases (6/6). Because they were not used in the same patients, we cannot state that MRI is superior to CT. However, our results may indicate the lack of sensitivity of the CT, compared with the sensitivity of MRI, for the detection of PNSTs, especially in the absence of visible muscular atrophy. This is supported by the current human literature.[14,18] Moreover, the data of the present study suggested that electrophysiological results can be used to guide radiologists in identifying more subtle lesions.

Given that the poor outcome for patients with PNSTs is determined by their proximal growth, there is a call for predictive markers of this invasion. In the present study, data showed that abnormal epaxial muscle EMG is suggestive of such an invasion. The

specificity for this diagnostic test was 91%. However, its sensitivity was poor (53%). Axon sparing could variably occur along the longitudinal axis of the infiltrated nerve and may account for this finding. Indeed 5 of the 8 concerned cases involved decreases in CMAPs. This might be explained by axon sparing at the level of the intervertebral foramen, whereas axonal degeneration could occur distally. The organization of epaxial muscle layers may also contribute to this lack of sensitivity. In the cervical area, the splenius muscle is innervated by the cervical nerves and the serratus dorsalis is innervated by the intercostales nerves. At deeper levels, the longissimus and transversospinalis systems are innervated by the cervical nerves and the iliocostalis system is innervated by the thoracic nerves.[19] Therefore, the nerves tested by EMG vary with the depth of the muscle layer. Each area must be carefully explored at different depths. Finally, the retrospective nature of this study may account for variability in the precision of this procedure. A limitation in the group incorporation is the use of the advanced imaging, surgical, or postmortem observations to identify the proximal margin of the tumor. Magnetic resonance imaging has been identified as the first-choice imaging method for human patients,[18] but its accuracy for tumor margin detection is not known in dogs.[14] Computed tomography was considered good for the evaluation of tumor limits in 1 report[11] dealing with only 3 cases of confirmed PNSTs. The value of surgical exploration is also yet to be established. Although some authors described long-term survival after surgical resection, high rates of recurrence suggest less than complete accuracy in the surgical evaluation of tumor margins.[1,3,20] This inaccuracy could have led to misclassification of proximal tumors in the peripheral group in the present study. Thus, we could have overestimated its sensitivity. However, the specificity would have remained unchanged. As a result, the use of epaxial muscle EMG studies is still considered of value.

The histologic diagnosis was lacking in 33 cases in this study. This drawback is due to the retrospective nature of the study and to the poor prognosis of plexus masses. Owners often rejected surgical exploration or amputation. Moreover, many of the suspected case animals were euthanized by the referring veterinarian without histologic analysis. Isolated lameness associated with the thickening of a nerve or the presence of a mass on a nerve were considered sufficient grounds for the inclusion of cases. However, other conditions may mimic these signs: nerve abscess or granuloma, foreign bodies,[21] lymphoma,[22] hypertrophic neuropathy,[23] brachial plexus neuritis,[24,25] or hypertrophic neuritis.[o,p] All of these conditions are extremely rare, and some of them affect a specific breed or several limbs. Nerve thickening associated with foraminal stenosis could be considered in 2 cases without histologic analysis.[q] However, the advanced imaging ruled out foraminal stenosis. Among the patients that had an imaging procedure and a histologic diagnosis, hypertrophic neuritis was encountered at a frequency of 1 of 14. This suggests the prevalence of this disease is very low. Therefore, PNST remains the most likely diagnosis.

This study suggests that electrophysiological procedures are sensitive to detect the neuropathic changes associated with PNSTs. Abnormal spontaneous epaxial activity tends to be associated with invasion of the intervertebral foramen or the vertebral canal. Our results suggest that electrophysiological exploration should be performed carefully, in all muscle layers, to maximize its sensitivity. The occurrence of abnormal spontaneous epaxial activity should prompt clinicians to investigate the intervertebral foramen in detail on CT or MRI. Findings of both abnormal results on electrodiagnostic tests and advanced imaging may lead to a stronger suspicion of diagnosis of PNST.

a. le Chevoir M, Thibaud JL, Blot S. Electromyography and electroneurography, a standard but current technique in the diagnosis of peripheral nerve sheath tumors: retrospective study of 39 cases, in *Proceedings*. 23rd Annu Symp Eur Soc Vet Neurol Eur Coll Vet Neurol 2010;56.
b. CLOVIS, clinical software of the national schools of Veterinary Medicine of Alfort, Lyon, Nantes and Toulouse, Computing Department, Ecole Nationale Vétérinaire de Lyon, Marcy-l'Étoile, France.
c. Nicolet Viking Select, Viasys Healthcare, Madison, Wis.
d. Nicolet Viking IV P, Viasys Healthcare, Madison, Wis.
e. Rapinovet, Schering-Plough/Merck, Whitehouse Station, NJ.
f. Nesdonal, Mérial, Lyon, France.
g. CE 10000, General Electric, Milwaukee, Wis.
h. CT Pace, General Electric, Milwaukee, Wis.
i. Hispeed Dual Xtream, General Electric, Milwaukee, Wis.
j. Brightspeed, General Electric, Milwaukee, Wis.
k. Telebrix, Guerbet, Villepinte, France.
l. Signa Profile, 0.2 T, General Electric, Milwaukee, Wis.
m. Dotarem, Guerbet, Villepinte, France.
n. Statistics Data Analysis, version 9.1, StataCorp, College Station, Tex.
o. Platt SR, McConnell JF, Dennis R, et al. Chronic canine hypertrophic neuritis mimicking nerve sheath tumours on advanced imaging, 3 cases (abstr). *J Vet Intern Med* 2006;21:1145–1146.
p. Walmsley G, Mantis P, Cappello R. Magnetic resonance imaging of focal radiculopathy (abstr). *J Vet Intern Med* 2006;21:1162.
q. Matiasek K, Steffen F, Schmahl W, et al. Back to the roots: radicular pathology in foraminal stenosis (abstr). *J Vet Intern Med* 2007;22:514.

References

1. Brehm DM, Vite CH, Steinberg HS, et al. A retrospective evaluation of 51 cases of peripheral nerve sheath tumors in the dog. *J Am Anim Hosp Assoc* 1995;31:349–359.
2. Targett MP, Dyce J, Houlton JEF. Tumours involving the nerve sheaths of the forelimb in dogs. *J Small Anim Pract* 1993;34:221–225.
3. Bradley RL, Withrow SJ, Snyder SP. Nerve sheath tumors in the dog. *J Am Anim Hosp Assoc* 1982;18:915–921.
4. Abraham LA, Mitten RW, Beck C, et al. Diagnosis of sciatic nerve tumour in two dogs by electromyography and magnetic resonance imaging. *Aust Vet J* 2003;81:42–46.
5. Montoliu P, Pumarola M, Zamora A, et al. Femoral mononeuropathy caused by a malignant sarcoma: two case reports. *Vet J* 2008;178:298–301.
6. Harcourt-Brown TR, Granger N, Smith PM, et al. Use of a lateral surgical approach to the femoral nerve in the management of two primary femoral nerve sheath tumours. *Vet Comp Orthop Traumatol* 2009;22:229–232.
7. Koestner A, Higgins RJ. Tumors of the nervous system. In: Meuten DJ, eds. *Tumors in domestic animals*. 4th ed. Iowa: Blackwell Publishing Co, 2002;697–738.
8. Steinberg HS. Brachial plexus injuries and dysfunctions. *Vet Clin North Am Small Anim Pract* 1988;18:565–580.
9. Carmichael S, Griffiths IR. Tumours involving the brachial plexus in seven dogs. *Vet Rec* 1981;108:435–437.
10. Chrisman CL. Electromyography in the localization of spinal cord and nerve root neoplasia in dogs and cats. *J Am Vet Med Assoc* 1975;166:1074–1079.

11. McCarthy RJ, Feeney DA, Lipowitz AJ. Preoperative diagnosis of tumors of the brachial plexus by use of computed tomography in three dogs. *J Am Vet Med Assoc* 1993;202:291–294.
12. Kimura J. Examination of non limb muscles. In: Kimura J, eds. *Electrodiagnosis in diseases of nerve and muscle: principles and practice*. 3rd ed. New York: Oxford University Press Co, 2001;370–383.
13. Rudich SR, Feeney DA, Anderson KL, et al. Computed tomography of masses of the brachial plexus and contributing nerve roots in dogs. *Vet Radiol Ultrasound* 2004;45:46–50.
14. Kraft S, Ehrhart EJ, Gall D, et al. Magnetic resonance imaging characteristics of peripheral nerve sheath tumors of the canine brachial plexus in 18 dogs. *Vet Radiol Ultrasound* 2007;48:1–7.
15. Walker TL, Redding RW, Braund KG. Motor nerve conduction velocity and latency in the dog. *Am J Vet Res* 1979;40:1433–1439.
16. Cuddon PA. Electrophysiology in neuromuscular diseases. *Vet Clin North Am Small Anim Pract* 2002;32:31–63.
17. Summers BA, Cummings JF, de Lahunta A. Neoplasia and the peripheral nervous system. In: Summer BA, ed. *Veterinary neuropathology*. St Louis: Mosby-Year Book, 1995;472–481, 499–501.
18. Thyagarajan D, Cascino T, Harms G. Magnetic resonance imaging in brachial plexopathy of cancer. *Neurology* 1995;45:421–427.
19. Hermanson JW, Evans HE. The muscular system. In: Evans HE, ed. *Miller's anatomy of the dog*. 3rd ed. Philadelphia: WB Saunders Co, 1993;258–384.
20. Bailey CS. Long-term survival after surgical excision of a schwannoma of the sixth cervical spinal nerve in a dog. *J Am Vet Med Assoc* 1990;196:754–756.
21. Walmsley G, Scurrell E, Summers B, et al. Foreign body induced neuritis masquerading as a canine brachial plexus nerve sheath tumour. *Vet Comp Orthop Traumatol* 2009;22:427–429.
22. Rosin A. Neurologic disease associated with lymphosarcoma in ten dogs. *J Am Vet Med Assoc* 1982;181:50–53.
23. Cummings JF, Cooper BJ, de Lahunta A, et al. Canine inherited hypertrophic neuropathy. *Acta Neuropathol* 1981;53:137–143.
24. Cummings JF, Lorenz MD, de Lahunta A, et al. Canine brachial plexus neuritis: a syndrome resembling serum neuritis in man. *Cornell Vet* 1973;63:589–617.
25. Alexander JW, de Lahunta A, Scott DW. A case of brachial plexus neuropathy in a dog. *J Am Vet Med Assoc* 1974;10:515–517.