Disk-associated wobbler syndrome is one of a collection of disorders affecting the caudal cervical vertebrae and intervertebral disks of large breed dogs and is the most common underlying disorder in dogs with wobbler syndrome (cervical spondylomyelopathy). Caudal cervical spinal cord compression is typically caused by protrusion of 1 or more intervertebral disks, sometimes in combination with dorsal compression resulting from hypertrophy of the ligamentum flavum and mild vertebral body malformations. Although DAWS can affect several breeds of large breed dogs, Doberman Pinschers are overrepresented. The most common clinical appearance is a gait disturbance with ataxia, paresis, or both affecting the pelvic limbs, frequently in combination with a short, stilted gait in the thoracic limbs. This disorder can be diagnosed by a variety of imaging modalities, such as myelography, computed tomography-myelography, and MRI. Each of these techniques is associated with specific advantages and disadvantages. The transcranial magnetic stimulation (TMS) technique has been suggested as a useful alternative diagnostic tool to differentiate between clinically relevant and clinically irrelevant cervical spinal cord compression identified on MRI alone. (J Am Vet Med Assoc 2011;238:81–88)

**Objective**—To evaluate the use of transcranial magnetic stimulation for differentiating between clinically relevant and clinically irrelevant cervical spinal cord compression on magnetic resonance imaging (MRI).

**Design**—Validation study.

**Animals**—Clinically normal Doberman Pinschers without (n = 11) and with (6) spinal cord compression on MRI and 16 Doberman Pinschers with disk-associated wobbler syndrome (DAWS).

**Procedures**—After dogs were sedated, transcranial magnetic motor evoked potentials were recorded from the extensor carpi radialis muscle (ECRM) and cranial tibial muscle (CTM). Onset latencies and peak-to-peak amplitudes were measured. Magnetic resonance imaging was performed to identify spinal cord compression.

**Results**—There were significant differences in ECRM and CTM onset latencies between Doberman Pinschers with DAWS and each of the 2 groups of clinically normal dogs, but there were no significant differences in ECRM and CTM onset latencies between the 2 groups of clinically normal dogs. There were significant differences in CTM peak-to-peak amplitudes between Doberman Pinschers with DAWS and each of the 2 groups of clinically normal dogs, but there were no significant differences in ECRM peak-to-peak amplitudes among groups or in CTM peak-to-peak amplitudes between the 2 groups of clinically normal dogs. There was a significant correlation between severity of spinal cord compression and ECRM onset latency, CTM onset latency, and CTM peak-to-peak amplitude.

**Conclusions and Clinical Relevance**—Results suggested that transcranial magnetic stimulation may be a useful diagnostic tool to differentiate between clinically relevant and clinically irrelevant spinal cord compression identified on MRI alone. (J Am Vet Med Assoc 2011;238:81–88)

**ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>CTM</td>
<td>Cranial tibial muscle</td>
</tr>
<tr>
<td>DAWS</td>
<td>Disk-associated wobbler syndrome</td>
</tr>
<tr>
<td>ECRM</td>
<td>Extensor carpi radialis muscle</td>
</tr>
<tr>
<td>ISI</td>
<td>Intraspinal signal intensity</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
</tr>
<tr>
<td>ROC</td>
<td>Receiver operator characteristic</td>
</tr>
<tr>
<td>TMMEP</td>
<td>Transcranial magnetic motor evoked potential</td>
</tr>
<tr>
<td>TMS</td>
<td>Transcranial magnetic stimulation</td>
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</table>

From the Departments of Small Animal Medicine and Clinical Biology (De Decker, Van Soens, Binst, Waelbers, Van Ham), Physiology and Biometrics (Duchateau), and Medical Imaging of Domestic Animals and Orthopaedics of Small Animals (Gielen, van Bree), Faculty of Veterinary Medicine, Ghent University, 9820 Merelbeke, Belgium. Dr. De Decker’s present address is Department of Clinical Services, Queen Mother Hospital for Animals, Royal Veterinary College, University of London, North Mymms, Hatfield, Hertfordshire AL9 7TA, England. Supported by the Institute for the Promotion of Innovation by Science and Technology in Flanders, Belgium. Presented in abstract form at the 22nd Annual Symposium of the European Society of Veterinary Neurology, Bologna, Italy, September 2009. Address correspondence to Dr. De Decker (sdedecker@rvc.ac.uk).
cific advantages and disadvantages.³ During the past decade, MRI has gained popularity and several previous reports⁴–⁶ have described its use to characterize a variety of neurologic disorders affecting the cervical vertebral column and spinal cord in dogs. Magnetic resonance imaging allows direct, noninvasive, multiplanar imaging and excellent soft tissue characterization with an absence of ionizing radiation.⁷ A disadvantage of MRI for evaluation of the vertebral column and spinal cord is the possibility of clinical overinterpretation. Several studies, involving human⁸–¹¹ and veterinary¹²–¹⁴ patients, have demonstrated the occurrence of cervical spinal cord compression on magnetic resonance images from clinically normal subjects. A recent study comparing results of low-field MRI in Doberman Pinschers with DAWS with results in clinically normal Doberman Pinschers and Foxhounds found that low-field MRI of the cervical vertebral column and spinal cord could lead to false-positive and false-negative assessments of suspected clinical status. In that study, 2 of 21 clinically affected dogs were erroneously categorized, on the basis of MRI findings alone, as clinically normal and 4 of 23 clinically normal dogs were categorized as clinically affected.

Transcranial magnetic stimulation is a noninvasive, painless, and sensitive technique for stimulating the cerebral cortex. It may be used to evaluate the functional integrity and conduction speed of the fastest conducting descending motor pathways in the brain and spinal cord.¹³ Magnetic motor cortex stimulation evokes synchronized descending excitatory volleys in the spinal cord pathways.¹⁶ These excitatory volleys induce muscle twitches that are recorded as potentials in the periphery. These potentials are called TMMEPs.¹⁵ In human medicine, TMS has been widely used to assess the integrity of the spinal cord in patients with various spinal cord disorders, for intraoperative monitoring, and as a prognostic tool.¹⁷–²¹ In veterinary medicine, it has been performed on healthy dogs²²–²⁷ and horses,²⁸,²⁹ to standardize the method of stimulation and to assess the effect of various anesthetic protocols on recorded TMMEPs.³⁰–³² This technique has also been used in horses with bilateral hind limb ataxia and cervical spinal cord lesions³³,³⁴ and in dogs with thoracolumbar intervertebral disk disease,³⁵ cervical spinal cord disease,³⁶ and cervical spondylomyelopathy.³⁷

The purpose of the study reported here was to evaluate the use of TMS for differentiating between clinically relevant and clinically irrelevant spinal cord compression evident on magnetic resonance images of dogs with and without DAWS. Because TMS provides objective information on spinal cord function, we hypothesized that this technique could be used to differentiate between clinically relevant and clinically irrelevant spinal cord compression as seen on MRI. Additionally, we wanted to compare our results with previously established reference values for TMMEPs in clinically normal Doberman Pinschers and assess whether there was a correlation between TMS and a published MRI compression scale.³⁷,³⁸

Materials and Methods

Animals—Thirty-three client-owned Doberman Pinschers were included in the study. The study was conducted in accordance with the guidelines of the Animal Care Committee of the University of Ghent. Written owner consent was obtained prior to study enrollment.

Three groups of dogs were studied. The first group consisted of 11 clinically normal Doberman Pinschers without MRI evidence of spinal cord compression. This group included 6 males and 5 females between 1.5 and 8 years old (mean, 4.3 years; median, 4.5 years). The second group consisted of 6 clinically normal Doberman Pinschers with MRI evidence of spinal cord compression. This group included 3 males and 3 females between 1.6 and 7.1 years old (mean, 4.0 years; median, 3.9 years). The third group consisted of 16 Doberman Pinschers with MRI evidence of spinal cord compression and clinical signs of DAWS. This group included 6 males and 10 females between 4.6 and 10 years old (mean, 8.6 years; median, 8.7 years). Clinical signs in these dogs ranged from cervical hyperesthesia only (n = 2) to ambulatory paraparesis, ataxia, or both with or without cervical hyperesthesia (5); ambulatory tetraparesis, ataxia, or both with or without cervical hyperesthesia (7); and nonambulatory tetraparesis with or without cervical hyperesthesia (2).

All dogs underwent complete physical and neurologic examinations at the time of enrollment in the study. In addition, a CBC, serum biochemical analysis, echocardiographic examination, and standardized measurement of musculoskeletal bleeding time were performed. All clinically normal Doberman Pinschers underwent follow-up physical and neurologic examinations between 16 and 18 months after the initial evaluation to determine whether any recorded MRI or TMS abnormalities could be regarded as truly clinically unimportant or rather as indicative of early onset of disease prior to development of clinical signs. Neurologic examinations of all dogs were performed by a single individual (SDD).

TMS—Motor cortex magnetic stimulation was performed by use of a commercially available magnetic stimulator³ with a circular coil 45 mm in external diameter that generated a peak magnetic field of approximately 4 T. Maximal (ie, 110%) stimulator output was used to ensure identifiable TMMEPs. The magnetic coil was placed tangentially to the skull and in contact with the skin, with the center of the coil placed over the vertex (Figure 1),
as described. To activate each hemisphere preferentially, a clockwise inducing current flow was used to stimulate the right motor cortex and a counterclockwise flow was used to stimulate the left motor cortex. Although stimulation should be painless in dogs, mild discomfort can be associated with the evoked muscle contractions, and the noise of stimulation can agitate some dogs. Therefore, dogs were sedated with acepromazine (0.03 mg/kg [0.014 mg/lb], IV) and morphine (0.2 mg/kg [0.09 mg/lb], IV), as described in a previous study involving Doberman Pinschers. Administration of this drug combination reportedly does not influence measured values for TMMEPs in dogs.

Recording of TMMEPs—Recordings were obtained by use of an electromyography unit. Magnetic motor evoked potentials were recorded successively from the left thoracic, right thoracic, left pelvic, and right pelvic limbs with monopolar needle electrodes inserted in the muscle belly of the ECRM in the thoracic limbs and the CTM in the pelvic limbs. The tip of the recording electrode was positioned in the middle of the muscle belly, just cranial to the lateral humeral epicondyle for the ECRM and slightly lateral to the distal end of the tibial crest for the CTM. The reference electrode was a subdermal needle electrode positioned subcutaneously over tendons at the level of the carpal and the tarsal joints for the ECRM and the CTM, respectively. The ground electrode was placed subcutaneously over the olecranon of the thoracic limb or over the patella of the pelvic limb. The low- and high-frequency filters were set at 20 Hz and 10 kHz, respectively. Sensitivity was set at 10 mV/division but was increased if the peak-to-peak amplitude was low. Analysis time was 100 milliseconds following the stimulus.

Measurements of the TMMEP onset latency and peak-to-peak amplitude were made manually by use of the cursors on the oscilloscope. Onset latency was measured as the shortest time between the trigger point and the takeoff of the initial phase (negative or positive); peak-to-peak amplitude was measured between the 2 largest peaks of opposite polarity. Individual stimulations were delivered until 2 reproducible TMMEPs were recorded. Magnetic motor evoked responses were considered absent if 4 consecutive stimulations consistently failed to elicit a reproducible TMMEP. In dogs with absent TMMEPs, onset latency was regarded as infinite and peak-to-peak amplitude was recorded as 0 mV. The neuronal path length of each dog was measured from the vertex to the contralateral active electrode located within the ECRM or CTM with a tape measure placed on the surface of the skin.

MRI—A permanent 0.2-T magnet was used to perform MRI in all dogs, as described. Dogs were anesthetized, and T1-weighted spin echo and T2-weighted fast spin echo studies were performed in all dogs in the sagittal (C2 to C7), dorsal (C2 to C7), and transverse (C4 to C7) planes. Slice thickness was 4 mm in the sagittal and dorsal images and 3 mm in the transverse images with no interslice gap.

Magnetic resonance images were examined for evidence of spinal cord compression, defined as complete subarachnoid space compression with deviation or distortion of the spinal cord. In dogs with spinal cord compression, the severity of compression was scored on a scale from 0 to 3 at the level of the spinal cord that was most severely affected. Scores were assigned on the basis of degree of spinal cord deformation and displacement and severity of ISI changes, as described. Grade 0 indicated no evidence of cord compression, grade 1 indicated mild indentation of the spinal cord with a dorsoventral cord diameter that was not less than two-thirds of the expected cord diameter, grade 2 indicated notable spinal cord indentation with a dorsoventral cord diameter that was less than two-thirds of the expected cord diameter but not associated with ISI changes within the cord, and grade 3 indicated notable spinal cord indentation associated with ISI changes. The expected spinal cord diameter was defined as the cord diameter adjacent to the site of spinal cord compression. Changes in ISI were evaluated on the basis of relative increase in signal on T2-weighted images, decrease in signal on T1-weighted images, or both, compared with the surrounding spinal cord parenchyma.

Data analysis—For all TMMEP variables (ie, onset latency, peak-to-peak amplitude, and neuronal path length for the ECRM and for the CTM), values recorded in each dog for the left and right limbs were averaged to obtain a single value for each variable for the ECRM and the CTM for each dog. Statistical analyses were performed on the basis of nonparametric, rank-based methods with a commercial software package. Nonparametric methods were used because the data could not be assumed to be normally distributed and because no values for onset latency were obtained in some instances, and a value of infinity was assumed.

Kruskall-Wallis 1-way ANOVA was used to compare values for onset latency and peak-to-peak amplitude among the 3 clinical groups, with values of \( P < 0.05 \) considered significant. Pairwise comparisons were performed with the 2-sided Wilcoxon rank sum test. Because of the multiple comparisons, a Bonferroni adjustment was made to the cutoff for significance, with values of \( P < 0.017 \) considered significant. Kendall correlation coefficients were calculated between onset latency and neuronal path length and between spinal compression score and onset latency and peak-to-peak amplitude. The signed rank test was used to compare values for onset latency and peak-to-peak amplitude recorded from the left and right limbs, with values of \( P < 0.05 \) considered significant.

Receiver operator characteristic curves (calculated with a commercial software program) were created for use of ECRM and CTM onset latencies and peak-to-peak amplitudes to distinguish between clinically normal Doberman Pinschers and Doberman Pinschers with DAWS. In general, ROC curves can be used to identify the optimal cutoff between normal and abnormal values for diagnostic tests, with each value on an ROC curve representing a tradeoff between sensitivity (ability to detect an affected dog) and specificity (ability to detect an unaffected dog). Tests that combine high sensitivity with high specificity are best at discriminating between affected and unaffected dogs. The area under an ROC curve quantifies the overall ability of the
test to discriminate between affected and unaffected dogs. A useless test (no discrimination) will have an area under the curve of 0.5; a perfect test will have an area under the curve of 1.0.

Results

Median values and ranges for onset latency, peak-to-peak amplitude, and neuronal path length for the 3 groups of Doberman Pinschers were calculated (Table 1) from recorded TMMEPs. In 11 of the 16 Doberman Pinschers with clinical signs of DAWS, TMMEPs could not be recorded in either pelvic limb. In 3, TMMEPs could be recorded in 1 pelvic limb. No response was recorded in the remaining 11 dogs. Onset latency was regarded as infinite and peak-to-peak amplitude was recorded as 0 mV if TMMEPs were absent.

Table 1—Median onset latencies, peak-to-peak amplitudes, and neuronal path lengths for TMMEPs recorded from the ECRM and CTM in clinically normal Doberman Pinschers without (group 1; n = 11) and with (group 2; 6) spinal cord compression on MRI and 16 Doberman Pinschers with DAWS (group 3).

<table>
<thead>
<tr>
<th>Group</th>
<th>Onset latency (ms)</th>
<th>Peak-to-peak amplitude (mV)</th>
<th>Neuronal path length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ECRM</td>
<td>13.75 (12.25–16.95)</td>
<td>7.52 (1.86–19.45)</td>
</tr>
<tr>
<td></td>
<td>CTM</td>
<td>21.75 (18.65–37.1)</td>
<td>5.52 (0.81–12.50)</td>
</tr>
<tr>
<td>2</td>
<td>ECRM</td>
<td>13.62 (12.75–15.90)</td>
<td>6.00 (2.66–15.72)</td>
</tr>
<tr>
<td></td>
<td>CTM</td>
<td>20.9 (19.55–29.6)</td>
<td>7.50 (0.42–16.70)</td>
</tr>
<tr>
<td>3</td>
<td>ECRM</td>
<td>17.72 (13.25–26.4)</td>
<td>4.06 (0.098–11.98)</td>
</tr>
<tr>
<td></td>
<td>CTM</td>
<td>∞ (31.7–∞)</td>
<td>0* (0–2.74)</td>
</tr>
</tbody>
</table>

Data are reported as median (range).

*In 2 of the 16 clinically affected Doberman Pinschers, TMMEPs could be elicited in both pelvic limbs, and in 3, TMMEPs could be elicited in 1 pelvic limb. No response was recorded in the remaining 11 dogs. Onset latency was regarded as infinite and peak-to-peak amplitude was recorded as 0 mV if TMMEPs were absent.
For both the ECRM and the CTM, onset latencies for clinically affected Doberman Pinschers were significantly different from values for both of the 2 groups of clinically normal dogs (Table 2), but there were no significant differences in ECRM or CTM onset latencies between the 2 groups of clinically normal dogs. There were no significant differences for ECRM peak-to-peak amplitude among the 3 groups. However, CTM peak-to-peak amplitudes for clinically affected Doberman Pinschers were significantly different from values for both of the 2 groups of clinically normal dogs. There was no significant difference in CTM peak-to-peak amplitudes between the 2 groups of clinically normal dogs.

Threshold values for ECRM and CTM onset latencies and CTM peak-to-peak amplitudes were identified from the ROC curves. A value of 16 milliseconds for ECRM onset latency corresponded with a sensitivity of 0.75 and specificity of 0.9 when used to discriminate between clinically normal and clinically affected dogs (Figure 5). A value of 32 milliseconds for CTM onset latency corresponded with sensitivity and specificity of approximately 0.9 when used to discriminate between clinically normal and clinically affected dogs (Figure 6). A value of 1 mV for CTM peak-to-peak amplitude corresponded with sensitivity and specificity of approximately 0.9 when used to discriminate between clinically normal and clinically affected dogs (Figure 7). No threshold value with a combined high sensitivity and high specificity could be identified for ECRM peak-to-peak amplitude (Figure 8). The ROC curve for ECRM peak-to-peak amplitude also had a small area under the curve, compared with areas associated with ROC curves for the other variables. When compared with these threshold values, 2 clinically normal dogs without MRI evidence of spinal cord compression had prolonged ECRM onset latencies and another dog from this group had a prolonged CTM onset latency. Three clinically affected dogs had normal ECRM onset latencies, and another dog from this group had a normal CTM onset latency. One clinically normal dog without MRI evidence of spinal cord compression had low CTM peak-to-peak amplitudes. One clinically affected dog had a normal CTM peak-to-peak amplitude.

Table 2—Results of comparison of onset latencies and peak-to-peak amplitudes for TMMEPs recorded from the ECRM and CTM in the 3 groups of dogs in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall</th>
<th>Group 1 vs 2</th>
<th>Group 1 vs 3</th>
<th>Group 2 vs 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset latency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECRM</td>
<td>&lt; 0.001</td>
<td>0.80</td>
<td>0.003</td>
<td>0.009</td>
</tr>
<tr>
<td>CTM</td>
<td>&lt; 0.001</td>
<td>0.40</td>
<td>&lt; 0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Peak-to-peak amplitude</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECRM</td>
<td>0.22</td>
<td>0.65</td>
<td>0.10</td>
<td>0.37</td>
</tr>
<tr>
<td>CTM</td>
<td>&lt; 0.001</td>
<td>0.96</td>
<td>&lt; 0.001</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Data represent P values. Because of the multiple comparisons, values of P < 0.017 were considered significant.
None of the 3 groups had significant differences in onset latencies or peak-to-peak amplitudes between the left and right limbs. When all dogs were considered as a single group, the only significant correlation between onset latency and neuronal path length that was identified was between ECRM onset latency and neuronal path length for the right thoracic limb (r = 0.26; P = 0.043).

All 11 clinically normal Doberman Pinschers without MRI evidence of spinal cord compression had grade 0 spinal cord compression. Of the 6 clinically normal Doberman Pinschers with MRI evidence of spinal cord compression, 5 had grade 1 spinal cord compression and 1 had grade 2 spinal cord compression. Of the 16 Doberman Pinschers with DAWS, 5 had grade 1 spinal cord compression, 2 had grade 2 spinal cord compression, and 9 had grade 3 spinal cord compression. There were significant correlations between spinal cord compression score and ECRM onset latency (r = 0.42; P = 0.002), CTM onset latency (r = 0.41; P = 0.003), and CTM peak-to-peak amplitude (r = −0.41; P = 0.003).

Of the 17 clinically normal Doberman Pinschers, 15 were available for complete physical and neurologic examinations between 16 and 18 months after the MRI and TMS examinations. These examinations revealed no abnormalities. The 2 remaining dogs were euthanatized for reasons unrelated to this study. According to the owners, they never demonstrated signs suggestive of cervical hyperesthesia or cervical myelopathy.

**Discussion**

In the present study, there were significant differences in ECRM and CTM onset latencies between the Doberman Pinschers with DAWS and 2 groups of clinically normal dogs. In addition, there were significant correlations between severity of spinal cord compression and ECRM onset latency, CTM onset latency, and CTM peak-to-peak amplitude. These results suggest that TMS can be used as a diagnostic tool to differentiate between clinically relevant and clinically irrelevant cervical spinal cord compression in dogs.

Previous studies have demonstrated the application of TMS as a valuable diagnostic tool in dogs with cervical spondylomyelopathy and other spinal cord disorders. However, data on TMS findings in dogs with clinically irrelevant spinal cord compression are scarce. Median values for clinically normal Doberman Pinschers for both ECRM and CTM onset latency in the present study were comparable with mean values reported by da Costa et al.

In the present study, values for onset latency were particularly useful to differentiate between clinically relevant and clinically irrelevant spinal cord compressions seen on magnetic resonance images, and values for peak-to-peak amplitude were less useful for this purpose. Recorded peak-to-peak amplitudes were also associated with large differences between minimum and maximum values, and values obtained in the present study were different from reported reference values for clinically normal Doberman Pinschers. Therefore, in agreement with results of earlier studies, values for peak-to-peak amplitude may be assumed to be of limited clinical value. Peak-to-peak amplitude is influenced by the number of fibers recruited by the stimulus, the number of motor neurons excited by the descending impulses, the characteristics of the target muscle, and alterations in the position of the magnetic stimulating coil over the surface of the cranium. The variability in these factors appears to be spontaneous, and its cause is unknown.

When compared with the threshold values obtained from the ROC curves, 2 clinically normal dogs without MRI evidence of spinal cord compression in the pres-
ent study had prolonged ECRM onset latencies and another dog from this group had prolonged CTM onset latency. Abnormal TMMEPs in human patients without signs of myelopathy have also been described.\textsuperscript{30,31} None of the clinically normal Doberman Pinschers with MRI evidence of spinal cord compression in the present study had abnormal onset latencies.

The finding that TMMEP abnormalities were more pronounced in the pelvic limbs compared with the thoracic limbs in the present study is in agreement with several veterinary\textsuperscript{32–34} and human\textsuperscript{15,35} studies evaluating the use of TMS in patients with cervical spinal cord disease. In human medicine, it is believed that TMMEP abnormalities provide direct evidence of corticospinal tract dysfunction.\textsuperscript{15,35} Studies of humans with cervical spondylotic myelopathy suggest that the corticospinal tracts are affected early and that the lateral corticospinal tracts are affected first in patients with minor spinal cord compression.\textsuperscript{49} Corticospinal and other cervical spinal cord tracts to the thoracic limbs are located medially and fibers to the pelvic limbs are located more laterally in the somatotopic arrangement of the cervical spinal cord.\textsuperscript{15} These factors may help explain the more pronounced pelvic limb TMMEP abnormalities in patients with progressive cervical spinal cord compression. However, the specific spinal cord pathways stimulated during TMS are currently not known.\textsuperscript{46} In human medicine, it has been assumed that it is mainly the corticospinal tracts that are stimulated by TMS.\textsuperscript{46} However, experimental studies\textsuperscript{57–59} in cats and rats concluded that activation of several descending pathways that converge on common spinal interneurons and motor neurons contribute to magnetic motor evoked potentials, implying that TMMEPs are not only mediated by the corticospinal tract, but also by extrapyramidal pathways. The relative contribution of pyramidal and extrapyramidal pathways may differ between species.\textsuperscript{49}

In the present study, normal onset latencies were recorded for the thoracic limbs in only 3 of the 16 affected dogs. This is in contrast to results of a prior study,\textsuperscript{57} in which the TMMEPs of Doberman Pinschers with and without clinical signs of cervical spondylomyelopathy were compared. In that study,\textsuperscript{57} even in dogs with notable thoracic limb involvement, no significantly different ECRM latencies or amplitudes were noted. The reason for these conflicting results is unclear. Other veterinary studies\textsuperscript{15,34} have demonstrated the occurrence of abnormal TMMEPs of the thoracic limbs in patients with cervical spinal cord disorders.

In several affected dogs in the present study, no TMMEPs could be elicited from the pelvic limbs. This finding is in agreement with previous studies involving humans\textsuperscript{30,42} and animals.\textsuperscript{33,35} The reason for this phenomenon is unknown; however, in previous studies\textsuperscript{45–52} involving animals in which TMMEPs were recorded simultaneously from the epidural space and the peripheral nerves, the recorded TMMEPs were abnormal or absent at the peripheral nerve level before changes were noticed in the epidural space. It is possible that the propagating impulse, although present in the spinal cord distal to the lesion, may not be strong enough to increase the postsynaptic membrane potential of the motor neuron to its threshold. Therefore, the impulse will not be present in the peripheral nerve.

Although TMS is a painless, noninvasive, and sensitive technique to assess the functional integrity of the spinal cord, this technique is also associated with limitations and contraindications.\textsuperscript{35} To perform a TMS study, cooperation of the patient is needed. This can sometimes be difficult to accomplish in canine patients. Further, the TMMEPs abnormalities are not specific for a certain disease entity, and the results should be interpreted in the context of clinical data and results of imaging studies. Although TMS is considered to be safe, patients with a history of epilepsy, electrical implants such as cardiac pacemakers, or affixed magnetic bodies such as intracranial surgery clips should be excluded.\textsuperscript{35,39}

In the present study, there was a significant correlation between severity of spinal cord compression on magnetic resonance images, as determined with a published scale,\textsuperscript{37,38} and the onset latencies for ECRM and CTM and the peak-to-peak amplitude for CTM. Our results confirmed those obtained by da Costa et al\textsuperscript{37} in a study of Doberman Pinschers with cervical spondylomyelopathy and can probably at least in part be explained by our finding of a grade 3 spinal cord compression only in clinically affected dogs. Therefore, further studies are warranted to investigate whether this result truly suggests that TMS findings correlate with degree of spinal cord compression seen on MRI or only illustrates the difference between rather severe clinically relevant and rather minor clinically irrelevant spinal cord compression.

The present study was limited by the small number of dogs that were included. This was especially true for the clinically normal dogs with MRI evidence of spinal cord compression. This hampered the formulation of reliable reference ranges for onset latency and peak-to-peak amplitude values for the various groups of Doberman Pinschers. For this reason, ROC curves were constructed to identify threshold values for the measured variables. Our findings should encourage further exploration of the use of TMS in veterinary medicine for the assessment of spinal cord disorders in various breeds of dogs.

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b. Sapphire, Acertys Healthcare, Aartselaar, Belgium.

c. Monopolar needle electrode, Acertys Healthcare, Aartselaar, Belgium.

d. Subdermal needle electrode, Acertys Healthcare, Aartselaar, Belgium.

e. Magnet, Airis Mate, Hitachi, Chiba, Japan.


g. StatXact 9, Cytel Inc, Witzenhausen, Germany.