

Correlation of motor evoked potentials with magnetic resonance imaging and neurologic findings in Doberman Pinschers with and without signs of cervical spondylomyelopathy

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Objective—To establish the reference ranges for motor evoked potential (MEP) latency and amplitude in clinically normal Doberman Pinschers, compare the MEPs of Doberman Pinschers with and without clinical signs of cervical spondylomyelopathy (CSM; wobbler syndrome), and determine whether MEP data correlate with neurologic or magnetic resonance imaging (MRI) findings.

Animals—16 clinically normal and 16 CSM-affected Doberman Pinschers.

Procedures—Dogs were classified according to their neurologic deficits. After sedation with acepromazine and hydromorphone, transcranial magnetic MEPs were assessed in each dog; latencies and amplitudes were recorded from the extensor carpi radialis and cranial tibial muscles. Magnetic resonance imaging was performed to evaluate the presence and severity of spinal cord compression.

Results—Significant differences in cranial tibial muscle MEP latencies and amplitudes were detected between clinically normal and CSM-affected dogs. No differences in the extensor carpi radialis MEP were detected between groups. There was a significant correlation ($r = 0.776$) between the cranial tibial muscle MEP latencies and neurologic findings. Significant correlations were also found between MRI findings and the cranial tibial muscle MEP latencies ($r = 0.757$) and amplitudes ($r = -0.453$).

Conclusions and Clinical Relevance—Results provided a reference range for MEPs in clinically normal Doberman Pinschers and indicated that cranial tibial muscle MEP latencies correlated well with both MRI and neurologic findings. Because of the high correlation between cranial tibial muscle MEP data and neurologic and MRI findings, MEP assessment could be considered as a screening tool in the management of dogs with spinal cord disease. (*Am J Vet Res* 2006;67:1613–1620)

ABBREVIATIONS

CSM	Cervical spondylomyelopathy
MR	Magnetic resonance
MEP	Motor evoked potential
SSEP	Somatosensory evoked potential
TR	Repetition time
TE	Echo time

cervical vertebral column of predominantly large- and giant-breed dogs, most commonly Doberman Pinschers and Great Danes.¹⁻⁶ In affected dogs, several pathologic processes lead to spinal cord and nerve root compression, which cause neurologic deficits and neck pain. Definitive diagnosis of CSM is achieved via imaging techniques such as myelography, computed tomography, or MR imaging.⁷⁻⁹ Magnetic resonance imaging has been considered the best imaging technique for the evaluation of cervical spondylotic myelopathy in humans.¹⁰

Although MR imaging is an excellent technique for defining anatomic lesions, it does not provide any functional information. Assessment of transcranial magnetic MEPs (more simply and widely known as MEPs) is a quick, safe, and noninvasive technique to study nerve conduction in the descending motor pathways.¹¹⁻¹³ Motor evoked potentials have been effectively used to assess the integrity of motor pathways in humans with multiple sclerosis, cervical spondylopathy, motor neuron disease, scoliosis, and cervical radiculopathy.^{12,14,15} Motor evoked potentials are more sensitive to spinal cord injury and ischemia and are better predictors of clinical outcome than SSEPs in rats and dogs.^{16,17} It is important to note that abnormalities in MEPs are not disease-specific and that results of MEP assessments should be interpreted in the context of other clinical data.¹⁸ Both SSEP and MEP assessments have been reported to be sensitive methods not

Cervical spondylomyelopathy is one of the many terms used to describe a disease that affects the

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only in the detection of spinal cord involvement in cervical spondylotic myelopathy in humans, but also in the evaluation of the location of spinal cord compression and the degree of spinal cord involvement.¹⁹ Results of several studies^{20,22} have suggested that the sensitivity and specificity of MEP assessment are superior to SSEP assessment in the evaluation of humans with cervical spondylotic myelopathy.

Motor evoked potentials have also been used in the evaluation of humans with preclinical or asymptomatic cervical spinal cord compression detected via MR imaging.^{19,21,23,24} Motor evoked potential analyses have received increasing attention in the veterinary field,²⁵⁻²⁸ and a recent investigation²⁵ in dogs assessed correlations among neurologic findings and MEP data. In humans, several studies^{20,29-31} have explored correlations between MEPs and MR image and clinical findings; however, to our knowledge, no such investigation has been performed in the veterinary field.

The objectives of the study reported here were to establish the reference ranges of MEP latency and amplitude in clinically normal Doberman Pinschers, compare the MEPs of Doberman Pinschers with and without clinical signs of CSM, and determine whether there is any correlation between MEP data and neurologic or MR image findings. The study was part of a larger investigation of the morphologic and morphometric features,³² electrophysiologic findings, diagnosis, and natural history of Doberman Pinschers with and without signs of CSM.

Materials and Methods

Animals—Two groups of client-owned Doberman Pinschers were prospectively studied. The experiment was conducted in accordance with the guidelines of and by approval of the Animal Care Committee of the University of Guelph. Consent from the owners was obtained prior to study enrollment. The first group consisted of 16 Doberman Pinschers that were defined as clinically normal on the basis of history and results of physical and neurologic examinations, CBC, and serum biochemical analyses. Eight dogs were male and 8 were female. The mean age was 4.3 years (age range, 2 to 8 years). The second group of dogs included 16 Doberman Pinschers with clinical signs of CSM (ie, signs of neck pain or neurologic deficits consistent with cervical spinal cord disease). Nine dogs were male and 7 were female. The mean age was 6 years (age range, 3 to 8 years). Prior to study enrollment, electro- and echocardiographic assessments revealed no cardiac abnormalities in any clinically normal or CSM-affected dog.

Neurologic evaluation—All dogs had a complete neurologic examination consisting of analysis of mental status, gait, cranial nerves, postural reactions, and spinal reflexes. The range of movements of the cervical vertebral column was assessed and palpation of the epaxial musculature was performed to determine the presence of cervical or thoracolumbar hyperesthesia. By use of a grading system (modified from that of McKee et al⁴), the neurologic status of the CSM-affected dogs was graded from 1 to 5 as follows: grade 1, cervical hyperesthesia; grade 2, mild pelvic limb ataxia or paresis; grade 3, moderate pelvic limb ataxia or paresis; grade 4, marked pelvic limb ataxia with thoracic limb involvement; and grade 5, tetraparesis or inability to stand or walk without assistance. Dogs with no abnormal neurologic findings were assigned grade 0.

Transcranial magnetic stimulation—For transcranial magnetic stimulation and MEP recordings, each dog was sedated with acepromazine (0.03 mg/kg, IV) and hydromorphone (0.05 mg/kg, IV). Neither drug adversely affects MEPs.^{25,33} The sedation protocol was adjusted, when needed, according to the degree of muscle relaxation of each dog. Approximately 15 minutes after drug administration, the dogs were positioned in lateral recumbency. The technique of transcranial magnetic stimulation and MEP acquisition was based on that used in previous studies.^{25,34}

Transcranial magnetic stimulation was performed by use of a magnetic stimulator^a and a 9.5-cm focal point coil capable of producing a peak magnetic field of 2.2 T at the coil surface. Supramaximal stimulus intensity (90% stimulus; pulse width, 70 microseconds) was delivered by the magnetic coil held tangentially to the skull, with the center of the coil over the skull lateral to the vertex. The coil was kept in close contact with the skin, and the current flow within the coil ran in a clockwise direction. Four individual stimulations were delivered at approximately 1-minute intervals over the motor cortex before repeating the procedure on the opposite side.

Recording of MEPs—Electromyographic recordings were obtained with an electromyography unit.^b Twelve-millimeter (0.5-inch), disposable, noninsulated, surgical-grade, stainless steel needles were used as the exploring (active), reference, and ground electrodes.^c An exploring electrode was inserted in the muscle belly of both the extensor carpi radialis and cranial tibial muscles, whereas the reference electrode was positioned subcutaneously approximately 1 cm distal to the active electrode. The ground electrode was placed subcutaneously between the stimulated site and active electrode, in the dorsal aspect of the cervical region. The recording electrode was connected to the negative input of the preamplifier; thus, negativity of the recording electrode (with respect to the reference electrode) caused an upward deflection of the trace. The MEPs were recorded from the right and left pelvic and thoracic limbs after stimulating the respective contralateral cortex. Recorded MEP waveforms were displayed on the oscilloscope screen and saved electronically. The total recording time was 100 milliseconds with a 10-millisecond delay. The low- and high-frequency filters were set at 30 Hz and 10 kHz (both down 12 dB/octave), respectively. The sensitivity was set at 1,000 μ V/division for all recordings.

The MEP latencies and amplitudes were calculated by use of the manually directed cursors on the oscilloscope. Latencies were measured in milliseconds and calculated as the interval from the onset of the stimulus to the onset of the response. Peak-to-peak amplitudes were measured in microvolts and calculated from the peak of the negative wave to the nadir of the first positive wave. The neuronal path length of each dog was determined by use of a tape measure; the path was measured from the site of the transcranial magnetic stimulation to the active electrode located within the extensor carpi radialis or cranial tibial muscles that were contralateral to the stimulated site.

MR imaging—For MR imaging, the dogs were anesthetized with propofol and isoflurane and positioned in dorsal recumbency. Magnetic resonance imaging was performed with a 1.5-T magnet^d and a circular, polarized, cervical vertebral column array coil. The field of view was constant for all dogs (25 cm in the sagittal plane and 16 cm in the transverse plane). Two acquisitions (number of excitations [Nex]) were obtained for each imaging sequence. A matrix size of 256 \times 256 voxels was used for all sections, and the slice thickness was 3 mm with no interslice space for all sequences. Settings used for sagittal and transverse MR imaging were as follows: T1 weighted (TR = 600 milliseconds; TE = 20 milliseconds),

turbo spin echo-T2 weighted (TR = 4,620 milliseconds; TE = 120 milliseconds), proton density weighted (TR = 4,620 milliseconds; TE = 20 milliseconds), and inversion recovery weighted (TR = 2,200 milliseconds; TE = 14 milliseconds). In the sagittal plane, T1-, T2-, inversion recovery-, and proton density-weighted images were acquired, whereas in the transverse plane, T1-, T2-, and proton density-weighted images were acquired. To avoid variations in image interpretation, all images were printed with a laser film printer at a magnification of 1.25X. The printout films had 20 images (4 images/row; 5 images/column) in the transverse plane and 12 images (4 images/row; 3 images/column) in the sagittal plane.

The severity of the spinal cord compression was assessed on the sagittal and transverse T2- and T1-weighted images and classified according to the degree of spinal cord deformation, displacement, and parenchymal changes into 4 stages in the spinal cord location that was most severely affected³⁰ as follows: grade 0, no evidence of cord compression; grade 1, mild indentation of the spinal cord with a dorsoventral cord diameter that is not less than two thirds of the expected cord diameter; grade 2, notable spinal cord indentation with a dorsoventral cord diameter that is less than two thirds of the expected cord diameter, but not associated with MR signal changes within the cord; grade 3, notable spinal cord indentation associated with MR signal changes within the spinal cord, namely hyper- or hypointensity (compared with the areas of normal spinal cord signal intensity cranial and caudal to the abnormality) in T2- or T1-weighted images, respectively.

Data analysis—Statistical analyses were performed by use of an ANCOVA to analyze the MEP latency and amplitude as well as the effects of side, location (extensor carpi radialis or cranial tibial muscles), and group (clinically normal or CSM-affected) and their interaction, while controlling for neuronal path length. Significant differences were established by use of a Tukey test at a value of $P < 0.05$, if the overall F test was significant. A multivariate ANOVA was used to investigate the correlation of the latencies and amplitudes with the neurologic status and severity of spinal cord compression as assessed by MR imaging, controlling for group, neuronal path length, and group-length interaction. A general linear model was applied to allow the data to be fitted to a curve. Logarithmic transformation was applied to the data that were not normally distributed, as determined by the Shapiro-Wilk test, for both ANCOVA and multivariate ANOVA. Analyses were performed by use of computer software.⁵

Results

Neurologic findings—Sixteen dogs were considered neurologically normal. For the 16 clinically affected Doberman Pinschers with CSM, the neurologic status was assessed as grade 1 (cervical hyperesthesia) in 3 dogs; grade 2 (mild ataxia) in 2 dogs; grade 3 (moderate ataxia) in 4 dogs; grade 4 (severe ataxia) in 6 dogs; and grade 5 (nonambulatory) in 1 dog. A thoracic limb posture with elbow abduction and internal rotation of digits (so-called toe-in posture) was evident in 7 CSM-affected and in 8 clinically normal dogs.

MR image findings—In the clinically normal group, 12 dogs had no spinal cord compression (grade 0). Four dogs had mild spinal cord compression (grade 1) caused by intervertebral disk protrusion; the compression was located at intervertebral disk C5-6 in 2 dogs and at C6-7 in the other 2 dogs. In the group of CSM-affected dogs, 1 dog had no spinal cord compression

(grade 0), 3 dogs were classified as grade 1 (mild spinal cord compression), 3 dogs were classified as grade 2 (notable spinal cord compression), and 9 dogs were classified as grade 3 (notable spinal cord compression with spinal cord MR signal changes; Figure 1). The cause of clinical signs in the 16 affected dogs was assumed to be disk related in 14 dogs and a result of foraminal stenosis in 1 dog (causing cervical hyperesthesia only) and articular facet impingement (causing bilateral spinal cord compression) in another dog. In all dogs with spinal cord signal changes, hyperintensity was evident in the T2-weighted images. Only 1 dog had hypointensity in the T1-weighted images as well as hyperintensity in T2-weighted images. The main compression was located at intervertebral disk level C5-6 in 5 dogs and C6-7 in 10 dogs. Three dogs had more than 1 site of spinal cord compression; the additional compressions in these 3 dogs were located in the caudal cervical spine and were less severe than the main compression. A detailed description of the MR image findings of these dogs is presented elsewhere.³²

Assessment of MEPs—The MEP waveform had a polyphasic characteristic in most clinically normal and

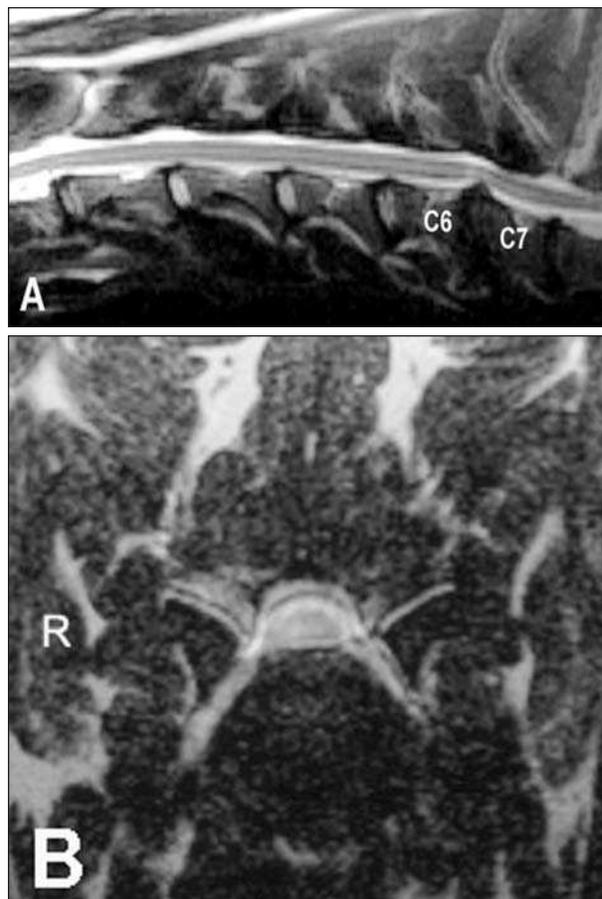


Figure 1—Magnetic resonance images at the cervical level of the vertebral column of a 5-year-old male Doberman Pinscher with nonambulatory tetraparesis (grade 5). A—Sagittal T2-weighted MR image. Notice the severe spinal cord compression at the C6-7 intervertebral disk region with spinal cord hyperintensity (grade 3). B—Transverse T2-weighted MR image. In the C6-7 intervertebral disk region, spinal cord compression and MR signal hyperintensity are evident. R = Right side.

all CSM-affected dogs (Figures 2 and 3). However, in clinically normal dogs, only 3 to 5 waveforms were detected, whereas in the CSM-affected dogs, more than

5 phases were usually evident. The first recording usually contained the least polyphasic configuration.

The mean \pm SD neuronal path length of the clinically normal Doberman Pinschers was 78.4 ± 5.9 cm for the thoracic limbs and 124.9 ± 8.4 cm for the pelvic limbs. Dogs with CSM had a mean neuronal path length of 78.6 ± 5.9 cm for the thoracic limbs and 125.3 ± 7.7 for the pelvic limbs. Neuronal path lengths did not differ between left and right sides, so the overall mean values for the thoracic and pelvic limbs were each used in the analysis. There was a significant ($P = 0.042$) increase in latency with longer neuronal path lengths. Neuronal path length had no effect on amplitude ($P = 0.192$).

On analysis of the MEP latencies and amplitudes, there was a significant difference in cranial tibial muscle MEP latencies ($P < 0.001$) and amplitudes ($P = 0.036$) between the clinically normal and CSM-affected groups (Table 1). There was no significant difference in extensor carpi radialis muscle MEP latencies ($P = 0.104$) and amplitudes ($P = 0.647$) between groups.

In the group of clinically normal dogs, 2 of the 4 dogs with spinal cord compression had MEP latencies and amplitudes that were similar to those of the other clinically normal dogs. Compared with the clinically normal group, the 2 other dogs with spinal cord compression had decreased cranial tibial muscle MEP amplitudes (250 and 592 μ V, respectively), and 1 of these dogs also had prolonged cranial tibial muscle MEP latency (29.1 milliseconds). The MEP latencies and amplitudes of the 4 clinically normal Doberman Pinschers with mild spinal cord compression were compared with MEP findings for the other dogs in the group. No difference ($P = 0.335$) was identified in cranial tibial muscle latencies; however, cranial tibial muscle amplitudes were different ($P = 0.042$). In the CSM-affected group, MR image findings related well to latency

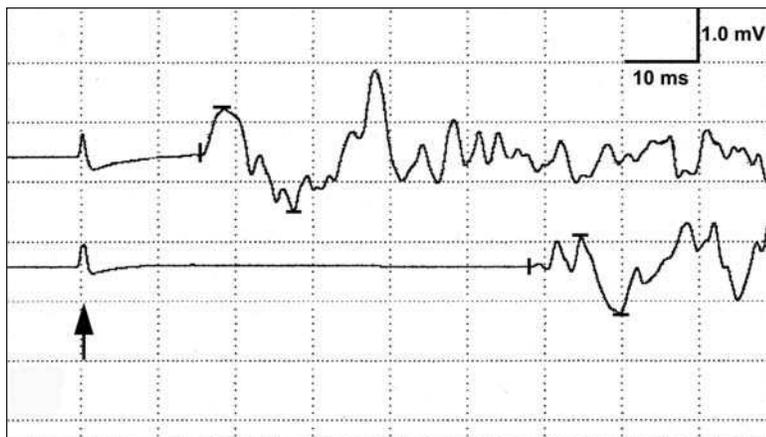


Figure 2—Motor evoked potential recording from the extensor carpi radialis muscle (upper trace) and the cranial tibial muscle (lower trace) of the dog in Figure 1. Notice the polyphasic wave with adequate latency and reduced amplitude in the extensor carpi radialis muscle (compared with the MEP recorded from a clinically normal dog [Figure 3]). The cranial tibial muscle MEP has prolonged latency and polyphasic configuration. The arrow indicates the stimulus artifact. Vertical bars indicate onset latency and horizontal bars indicate peak-to-peak amplitude.

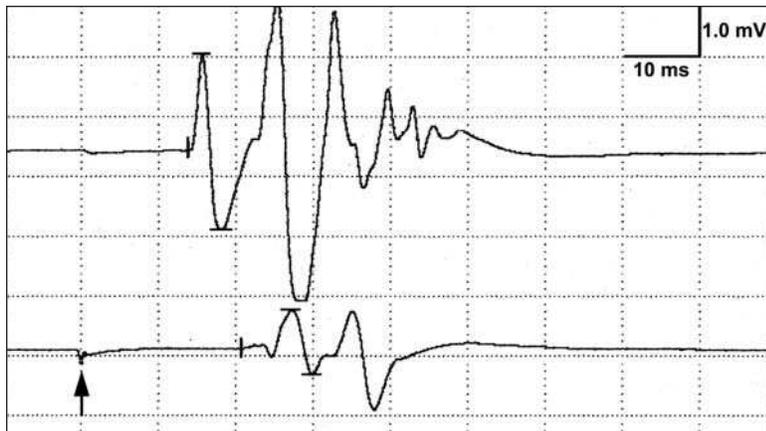


Figure 3—Motor evoked potential recording from the extensor carpi radialis muscle (upper trace) and the cranial tibial muscle (lower trace) of a 2-year-old spayed female clinically normal Doberman Pinscher. The latency and amplitude are within the range for clinically normal Doberman Pinschers, but a polyphasic configuration is detectable in the 2 traces. The arrow indicates the stimulus artifact. Vertical bars indicate onset latency, and horizontal bars indicate peak-to-peak amplitude.

Table 1—Mean \pm SE latencies and amplitudes of MEPs recorded from the extensor carpi radialis and cranial tibial muscles of clinically normal Doberman Pinschers ($n = 16$) and Doberman Pinschers with clinical signs of CSM (16).

Muscle	Latency (ms)		Amplitude (μ V)	
	Clinically normal group	CSM group	Clinically normal group	CSM group
Extensor carpi radialis	14.3 ± 0.4^a	14.5 ± 0.6^a	$2,975.7 \pm 305.1^a$	$2,534.2 \pm 319.1^a$
Cranial tibial	21.8 ± 0.6^a	34.1 ± 2.0^b	$1,416.3 \pm 170.0^a$	947.7 ± 229.5^b

^{a,b}Within each row, different superscript letters represent a significant difference ($P < 0.05$) between groups.

changes. Most dogs (7/9) with spinal cord compression and spinal cord MR signal changes had markedly prolonged (> 40 milliseconds) latencies in the cranial tibial

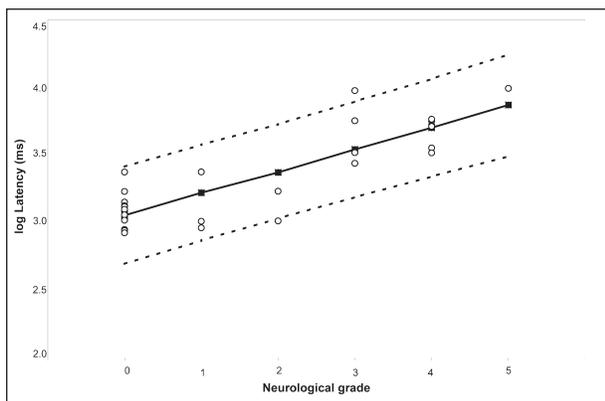


Figure 4—Linear regression analysis (solid line with solid squares) of the relationship between the log of onset latency of the MEP recorded from the cranial tibial muscle and clinical findings in 32 Doberman Pinschers that were classified according to their ranked neurologic status. Actual datum points (open circles) and upper and lower 95% confidence limits (dashed lines) are shown. There is a significant linear correlation ($r^2 = 0.756$; $P < 0.001$) between the severity of neurologic findings and latency (predicted latency [Y] = $0.1623[\text{neurologic findings}] + 0.00072[\text{neuronal path length for the pelvic limb}] + 2.962$). The neurologic grades were as follows: grade 0, normal neurologic examination findings; grade 1, cervical hyperesthesia; grade 2, mild pelvic limb ataxia or paresis; grade 3, moderate pelvic limb ataxia or paresis; grade 4, marked pelvic limb ataxia with thoracic limb involvement; and grade 5, tetraparesis or inability to stand or walk without assistance.

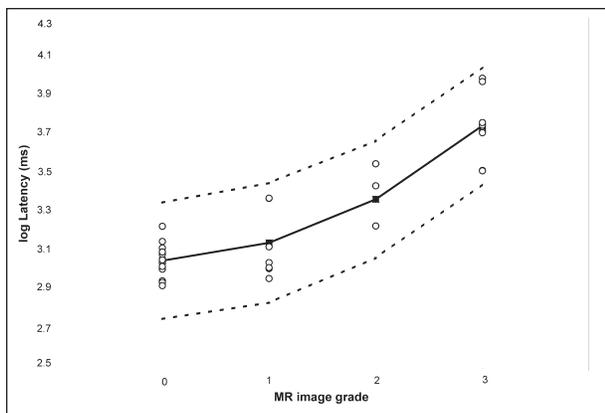


Figure 5—Quadratic regression analysis (solid line with solid squares) of the relationship between the log of onset latency of the MEP recorded from the cranial tibial muscle and the ranked MR image findings (classified according to severity of spinal cord compression) in 32 Doberman Pinschers. Actual datum points (open circles) and 95% confidence limits on predicted values (dashed lines) are shown. There is a significant quadratic correlation ($r^2 = 0.837$; $P = 0.009$) between the severity of MR image findings and latency (predicted latency [Y] = $0.0012[\text{MR image findings}] + 0.00772[\text{MR image findings} \times \text{MR image findings}] + 0.0033[\text{neuronal path length for the pelvic limb}] + 2.63$). Magnetic resonance image grades were as follows: grade 0, no evidence of cord compression; grade 1, mild indentation of the spinal cord with a dorsoventral cord diameter that is not less than two thirds of the expected cord diameter; grade 2, notable spinal cord indentation with a dorsoventral cord diameter that is less than two thirds of the expected cord diameter, but not associated with MR signal changes within the cord; grade 3, notable spinal cord indentation associated with MR signal changes within the spinal cord, namely hyper- or hypointensity in T2- or T1-weighted images, respectively.

muscle. The only CSM-affected dog without spinal cord compression had MEP latencies and amplitudes for the cranial tibial and extensor carpi radialis muscles that were similar to mean values for the clinically normal dogs.

Overall, there was a relationship between the severity of clinical signs and the MEP latencies in the cranial tibial muscle. Of the 3 dogs with cervical hyperesthesia and no neurologic deficits, 2 dogs had normal MEP findings. In the other dog, mean latency of the cranial tibial muscle MEP was mildly prolonged (27 milliseconds); however, the MEP amplitude was severely decreased (300 μV). The most severely affected dog (with nonambulatory tetraparesis) had the most prolonged cranial tibial muscle latency (Figure 2). Interestingly, even in a dog with severe thoracic limb ataxia and weakness (abrasive wounds were present on the dorsal aspect of both thoracic limb feet), the extensor carpi radialis muscle MEP latencies remained unaffected (mean latency, 13.1 milliseconds), although its extensor carpi radialis muscle amplitudes were markedly reduced (mean amplitude, 482 μV).

A significant correlation was identified between the cranial tibial muscle MEP latencies and the neurologic findings ($r = 0.776$; $P < 0.001$; Figure 4). A correlation also existed between cranial tibial muscle MEP latencies and the severity of spinal cord compression, as determined by MR imaging ($r = 0.757$; $P < 0.001$; Figure 5). The cranial tibial muscle MEP amplitudes were also significantly correlated with MR image findings ($r = -0.453$; $P = 0.011$; Figure 6), but not with neurologic findings ($r = -0.275$; $P = 0.140$). The extensor carpi radialis muscle MEP latencies were not correlated with neurologic status ($r = 0.006$; $P = 0.97$) or MR image findings ($r = -0.037$; $P = 0.834$). In addition, no correlation was identified between the extensor carpi radialis muscle MEP amplitudes and neurologic ($r = -0.272$; $P = 0.144$) or MR image findings ($r = -0.30$; $P = 0.107$).

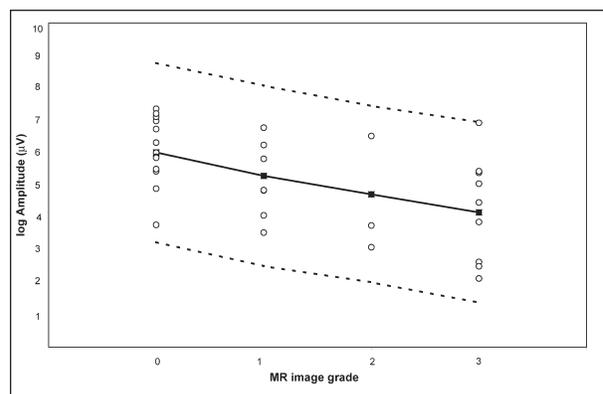


Figure 6—Linear regression analysis (solid line with solid squares) of the relationship between the log of the amplitude of the MEP recorded from the cranial tibial muscle and the ranked MR image findings (classified according to severity of spinal cord compression) in 32 Doberman Pinschers. Actual datum points (open circles) and upper and lower 95% confidence limits on predicted values (dashed lines) are shown. There is a significant linear correlation ($r^2 = 0.285$; $P = 0.002$) between the severity of MR image findings and amplitude (predicted amplitude [Y] = $-0.4369[\text{MR image findings}] - 0.01067[\text{neuronal path length for the pelvic limb}] + 9.269$). See Figure 5 for key.

Discussion

In the present study in Doberman Pinschers, a correlation between neurologic status and the MEP latency (but not amplitude) of the cranial tibial muscle was identified. This finding has also been confirmed in dogs with thoracolumbar spinal cord compression secondary to intervertebral disk disease.³⁴ In contrast, results of another study²⁵ indicated that there was a linear association of both latency and amplitude with neurologic deficits in dogs with cervical spinal cord disease. When MEPs were evaluated in horses with cervical or thoracolumbar myelopathies, no correlation was identified between MEP latency or amplitude and severity of neurologic dysfunction.^{26,27}

Latency reflects total motor conduction time from the cortex to the target muscle, and it is affected by the size of the fibers, the abundance of myelin, and the number of synapses that the impulse must cross.³⁴ Prolonged latency reflects desynchronization, temporal dispersion, conduction block, or even axonal degeneration in the fastest conducting fibers.^{30,35} Amplitude is influenced by the number of fibers recruited by the stimulus, the number of motor neurons excited by the descending impulses, the central excitatory state of the motor neuron pool, and characteristics of the target muscle.³⁴ Amplitude can be severely attenuated as a result of spinal cord compression (independent of neurologic status) and has a high intra- and interindividual variability.³⁴ Amplitude can be affected by factors such as coil position over the cortex, changes in the position of the recording electrode, variation in the current fluxes induced by magnetic stimulations, variations in the level of excitability and stress level of the patient, and patient age.^{13,33,34,36,37} With such a variety of factors influencing amplitude results, it is possible to appreciate why it is not as reliable as latency.

In our study, the cranial tibial muscle MEP latencies and amplitudes correlated with MR image findings. Most dogs with severe spinal cord compression and signal changes (ie, hyperintensity in T2-weighted images) had very prolonged latencies and reduced amplitudes, compared with the clinically normal dogs. This has also been identified in humans, and in some individuals, no MEP was recorded even though patients were ambulatory.³⁰ Several pathologic changes such as edema, inflammation, vascular ischemia, spongiform changes, myelomalacia, gliosis, cystic necrosis, and motor neuron loss have been implicated as a cause of spinal cord MR signal changes.³⁸⁻⁴¹ Overall, spinal cord MR signal changes reflect severe structural cord damage that affects the gray and white matter. These changes could affect the fastest conducting motor fibers and the motor neurons through one of the aforementioned mechanisms and result in prolonged latencies and reduced amplitudes. The correlation between MEP and MR image findings in humans was considered excellent by some investigators^{29,30} and less obvious by others.²⁰

With the advent of MR imaging, asymptomatic or so-called clinically silent cervical spinal cord compression has been identified in many humans.⁴²⁻⁴⁴ In clinically silent spinal cord compression, questions arise as to whether this compression causes any functional

cord involvement and whether this involvement is predictive of an unfavorable clinical course and, thus, justifies clinical and imaging follow-up evaluations or early surgical decompression before manifestation of neurologic deficits.²⁴ Via electrophysiologic methods, the presence and even the extent of asymptomatic cervical cord dysfunction can be determined in humans.²⁴ In the present study, 4 of the 16 clinically normal dogs had spinal cord compression on MR images. Of these dogs, only 1 had prolonged cranial tibial muscle latency, whereas 2 had decreased cranial tibial muscle amplitude. Studies^{21,22,45} in humans have revealed that most clinically asymptomatic patients with spinal cord compression have normal MEPs. However, other investigators have detected abnormalities in SSEPs or MEPs in 50% of asymptomatic patients (MEPs were abnormal in 36.7%); interestingly, none of the patients with normal SSEPs or MEPs developed clinical signs of myelopathy during a 2-year follow-up, whereas a third of the patients with initial MEP or SSEP abnormalities developed clinical signs.¹⁹ In another study,²³ 65% of patients with radiculopathy but no evidence of myelopathy had abnormal MEPs; however, the abnormality was mostly in the form of decreased amplitude and not prolonged latency. For the reasons previously discussed, decreased amplitude is not considered to be a strong evidence of myelopathy,²² and some researchers even suggest it has limited clinical value in the evaluation of patients with cervical spondylotic myelopathy.⁴⁶ A recent study²⁴ to establish criteria to predict the natural course of asymptomatic spinal cord compression in humans with cervical spondylotic myelopathy revealed that MEP abnormalities did not predict an unfavorable clinical course (even though there were MEP abnormalities in 19.7% of patients), although electromyographic and SSEP changes did.²⁴ Considering our findings, it appears that assessment of MEP latency is a highly sensitive test that reflects spinal cord function well. Our data also suggest that MR image findings do not always have clinical importance. In cases where questions arise about the importance of an MR image abnormality, assessment of MEP latency could be used to provide a sensitive assessment of spinal cord function.

The normal MEP configuration in dogs, horses, and humans has been reported^{125,28,34,47} to be a biphasic or triphasic wave. In the present study, MEP configuration in most dogs assumed a polyphasic characteristic. The MEP configuration was markedly polyphasic in the CSM-affected dogs and less polyphasic in the clinically normal dogs, usually with < 5 waves in the latter. In clinically normal horses, MEPs from the extensor carpi radialis muscle were predominantly biphasic or triphasic, whereas MEPs from the cranial tibial muscle were more polyphasic.²⁸ Although signal dispersion and polyphasic configuration would be expected from longer neural paths, > 5 phases is considered abnormal when evaluating hand muscles in humans; however, it is acceptable in more proximally located muscles of the arm and leg.⁴⁷ The polyphasic configuration identified in clinically normal dogs in our study could be explained by a state of muscle contraction and the high stimulus intensity.⁴⁷ In other work by our group, we

determined that the MEPs recorded at lower stimulus intensity (30% to 50%) from clinically normal dogs of breeds other than Doberman Pinschers usually had a biphasic characteristic, which became progressively more complex as the stimulus intensity was increased. In the present study, the first recorded MEP was also the least polyphasic, suggesting that after the first stimulus, the dogs expected the subsequent stimulus and that anxiety increased the muscle tension, leading to a more polyphasic waveform. Dogs and horses with myelopathy have been reported to have polyphasic MEPs.^{26,34} The marked polyphasic configuration detected in animals with compressive myelopathy is attributed to demyelination or axonal disruption, both of which cause delays in the propagating stimulus. Such delays will result in increased latencies and staggered impulses, which cause asynchronous activation of the peripheral neurons and motor units and thereby generate a polyphasic waveform.³⁴

Although we used dogs of 1 breed with fairly uniform body size in the present study, the neuronal path length proved to be an important variable for the latency analysis. Previous studies^{48,f} in humans and dogs also revealed that the neuronal path length was highly correlated with latency.

As previously determined by one of the authors,^f MEP latencies and amplitudes of the extensor carpi radialis muscle were not significantly different between the clinically normal and CSM-affected dogs, but the MEP configuration of CSM-affected dogs was consistently more polyphasic than that of the clinically normal dogs. The extensor carpi radialis and tibial cranial muscles produce the most reliable MEP recordings from the thoracic and pelvic limbs, respectively.^{33,i} In humans, there is disagreement regarding whether arm or leg MEPs are more sensitive.^{23,31} However, most studies^{20,47} report similar incidence of abnormal findings for arm and leg latencies. In horses with cervical myelopathy, the extensor carpi radialis muscle MEP was consistently abnormal.²⁶ The reported cases of cervical myelopathy in horses and humans had clinical signs in all 4 limbs secondary to compression within the C1 through C5 spinal cord region. Interestingly, all dogs in our study had a caudal cervical compression (C6 through C8 spinal cord segments) with clinical signs reflecting predominantly pelvic limb dysfunction; however, many had notable thoracic limb involvement (7/16 dogs [grades 4 and 5]), and yet the thoracic limb MEPs were not significantly different from those of clinically normal Doberman Pinschers.

Although transcranial magnetic stimulation has been used for many years, questions still remain regarding which structures are stimulated in quadrupeds. The stimulated structures relate to the depth of penetration of the stimulus, which is dependent on anatomic factors, coil size, coil geometry, and intensity of the applied stimulus.⁴⁹ In cats, the structures involved in MEP generation include the cerebral cortex, vestibular nuclei, reticular formation, and caudal medulla.⁵⁰⁻⁵² In the dogs of the present study, it is possible that cortical and noncortical structures were stimulated for MEP generation. Further studies controlling for the aforementioned variables are needed to elucidate the origin of MEP in dogs.

In the study reported here, the reference range for MEP latencies and amplitudes for normal Doberman Pinschers was established and revealed that the cranial tibial muscle MEP latency is the most reliable parameter for differentiating between clinically normal and CSM-affected Doberman Pinschers. Neurologically normal Doberman Pinschers can have MR image abnormalities comparable to those identified in CSM-affected dogs. Overall, the cranial tibial muscle MEP findings had a high correlation with MR image and neurologic findings. Assessment of MEPs is a fast, safe, and noninvasive test that does not require anesthesia, and results provide considerable information in the evaluation of patients with spinal cord disease. Motor evoked potential evaluation is routinely used in humans and should be considered as a diagnostic adjunct in the case management of veterinary patients with spinal disorders and in future studies of CSM treatment in dogs.

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- a. Cadwell model MES-10, serial No. MS0200364, Cadwell Laboratories Inc, Kennewick, Wash.
 - b. Cadwell model Excel, serial No. 081290175, Cadwell Laboratories Inc, Kennewick, Wash.
 - c. Cadwell Laboratories Inc, Kennewick, Wash.
 - d. Magnetom Vision. Siemens Canada, Mississauga, ON, Canada. Signa Excite II, GE Medical Systems Canada, Moncton, NB, Canada.
 - e. SAS statistical software, version 8.2, SAS Institute Inc, Cary, NC.
 - f. Poma R. *The use of transcranial magnetic stimulation in the evaluation of Doberman pinschers with cervical spondylopathy*. DVSc thesis, Department of Clinical Studies, University of Guelph, Guelph, ON, Canada 2001.
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