Syringomyelia is a term for accumulations of fluid (syrinxes) within the spinal cord parenchyma that are thought to form as a result of obstruction to the flow of CSF. It is an inherited disease of CKCSs and has been associated with occipital and other skull bone malformations. The associated herniation of the caudal part of the cerebellum is thought to compromise normal CSF flow at the level of the foramen magnum. Syringomyelia may be associated with neuropathic pain via alteration of afferent stimulus processing in the dorsal horn of the spinal cord. This is clinically important because some dogs affected with cervical syringomyelia will develop signs of apparent pain and allodynia, which may be sufficiently severe to result in euthanasia. Treatment with diuretics, corticosteroids, or neuromodulating drugs (eg, gabapentin or amitriptyline hydrochloride) has been attempted, as has surgical management, but the response to all modes of treatment is variable and recurrence of clinical signs is common.

A major obstacle to improving treatment of syringomyelia is that assessment of treatment protocols typically relies on comparison of subjective data such as questionnaire responses from owners or veterinarians’ interpretations of patient history, which are open...
to bias. Results of electrodiagnostic tests provide objective measures of altered spinal cord function associated with cervical syringomyelia in people; findings in affected humans typically include notable attenuation of SEPs, increased spontaneous activity detected via EMG, and increased latency of TMMEPs. Somatosensory-evoked potentials are the travelling or field potentials that are recorded from the CNS following stimulation of a mixed or sensory nerve. The SEPs provide evidence of the integrity of the somatosensory pathways from the point of stimulus to the site of recording. Via EMG, the excitability of muscle is assessed, and this test method is consequently sensitive to changes in the lower motor neurons that innervate the muscle and their upper motor neuron regulation. The TMMEPs represent muscle activity generated from electromagnetic stimulation and are indicators of the integrity of the motor pathways in the central and peripheral nervous systems.

The purpose of the prospective study reported here was to determine the effects of syringomyelia on EMG findings and standard features of SEPs and TMMEPs in CKCSs with and without syringomyelia. We hypothesised that CKCSs with syringomyelia would have reduced SEP amplitudes, increased TMMEP latencies, and increased spontaneous activity in EMG recordings, compared with findings in unaffected CKCSs.

Materials and Methods

Dogs—Dogs included in the study were CKCSs that were brought to the Department of Veterinary Medicine in February through May 2009 for prebreeding MR imaging screening for syringomyelia or for investigation of clinical signs consistent with syringomyelia. All dogs underwent a full clinical examination prior to MR imaging and electrodiagnostic testing. For dogs that spontaneously vocalized or scratched on or around the shoulder or neck region, analysis of a CSF sample collected from the lumbar portion of the vertebral column was performed in addition to MR imaging and the electrodiagnostic testing. On the basis of MR imaging findings, dogs were categorized as having or not having syringomyelia; a diagnosis of clinically apparent syringomyelia was accepted when the dog had syringomyelia-associated clinical signs and the clinical examination, MR imaging, or CSF analysis did not reveal any other causes for the clinical signs. All electrodiagnostic tests were performed with standard needles and recording equipment. Owners of the dogs included in the study gave informed consent to the procedures, and the study was approved by the Departmental Ethical Review Committee.

Experimental procedures—Each dog was sedated by use of medetomidine (10 μg/kg, IM) and butorphanol (0.3 mg/kg, IM) immediately prior to MR imaging. The dog was then anesthetized with isoflurane and oxygen delivered via a face mask for EMG and SEP recordings. Once the dog could maintain sternal recumbency following withdrawal of isoflurane, TMMEPs were recorded.

MR imaging examination—Sagittal (from the cerebellum to the C5 vertebra) and transverse (from the caudal aspect of the cerebellum to the C4 vertebra) T1- and T2-weighted MR images were obtained from each dog by use of a 0.25-T open field scanner. A diagnosis of syringomyelia was made when there was a well-defined region of hypointensity (compared with the appearance of the surrounding spinal cord tissue) on T1-weighted images within the center of the spinal cord that was ≥ 2 mm in width on transverse images. Syrinxes were considered asymmetric when they were predominantly located within 1 side of the spinal cord in transverse images. Lesions that were centrally placed within the cord and < 2 mm in width were considered consistent with central canal dilatation only. The MR imaging examinations were undertaken after the electrodiagnostic tests were performed so that recordings were made by a blinded operator.

Cervical (C1 vertebra) SEP recording—The SEPs were generated by use of a previously described protocol. Briefly, 20- or 40-mm-long, 28- or 30-gauge, fluoropolymer-coated, stainless-steel needles, each with a 0.3-mm bare terminal, were used as recording electrodes; 15-mm stainless-steel needles were used as stimulus or ground electrodes. The median nerve was stimulated with the cathode placed cranial to the flexor tendons of the carpus (2 cm proximal to their insertion on the accessory carpal bone), and the anode was placed 1 cm distal to the cathode, also cranial to the flexor tendons. Repetitive, rectangular impulses of 0.2 milliseconds’ duration were delivered to the nerve at a frequency of 3.1 Hz. The intensity was adjusted to a value that was 50% greater than the value that induced a visible foot twitch (to ensure stimulation was supramaximal). The active recording electrode was inserted dorsosventrally at the cranial edge of the spinous process of C2 until it contacted the underlying dorsal lamina of C1. The reference electrode was placed subdurally over the ipsilateral acromion, and then a 26-gauge, 30-mm-long concentric EMG needle was inserted just lateral to the midline until it contacted the dorsal lamina of the underlying vertebra, after which it was retracted to measure the activity at 3 depths (approx 1 cm apart). The needle was then directed 45° laterally and the process was repeated. This examination was performed at 5 evenly spaced intervals between the C2 and T1 vertebrae to provide a total of 10 measurements from each side (ie, 20 measurements/dog). Spontaneous electrical activity was recorded.

Cervical needle EMG—For each dog, an EMG examination of the cervical epaxial musculature was performed following the MR imaging examination. A standardized EMG protocol was used for all dogs. A ground needle electrode was inserted subdermally over the ipsilateral acromion, and then a 26-gauge, 30-mm-long concentric EMG needle was inserted just lateral to the midline until it contacted the dorsal lamina of the underlying vertebra, after which it was retracted to measure the activity at 3 depths (approx 1 cm apart). The needle was then directed 45° laterally and the process was repeated. This examination was performed at 5 evenly spaced intervals between the C2 and T1 vertebrae to provide a total of 10 measurements from each side (ie, 20 measurements/dog). Spontaneous electrical activity was recorded.

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nerve, and the recorded potentials were averaged into 1 trace. To ensure a recorded trace was not the product of background noise, SEPs were only accepted when 2 consecutive recordings overlaid each other. When the amplitude of the SEP was low (< 1 µV) despite repositioning the electrodes, an additional trace was obtained after the stimulator was disconnected; the SEP was rejected when it was indistinguishable from noise. Data recorded from the SEPs of both thoracic limbs included onset latency (onset of the first negative deflection), amplitude and latency of N1, and amplitude and latency of P1 following N1 (Figure 1); additionally, the total SEP amplitude (P1 minus N1 [P1-N1]) was determined. All wave amplitudes were recorded from the maximum deviation of a waveform from baseline.

**TMMEP recording**—Magnetic stimulation was applied over the vertex in each dog by use of a 70-mm-diameter round coil capable of generating a maximum magnetic field of approximately 4 T at 70% intensity. Electromyographic responses (ie, TMMEPs) were recorded bilaterally from the extensor carpi radialis and cranial tibial muscles in each dog by use of 15-mm-long stainless-steel electrodes; the active electrode was inserted into the muscle belly, and the reference electrode was inserted subdermally at a location 3 cm distal to the active electrode. A ground electrode was inserted over 1 acromion. The recording electrodes were connected to a 4-channel amplifier with the active electrodes in the inverting channel. Time base was 100 milliseconds with a gain of 100 µV to 5 mV/division and filter settings from 20 Hz to 3 kHz. The EMG recording was automatically triggered by generation of the stimulus to allow recording of the response latency from the time of the onset of the stimulus. Stimulation was repeated until 2 adequate traces from each muscle were obtained or the dog no longer permitted examination. Traces were analyzed for onset latency as defined by the first marked positive or negative deviation of the trace.

**Data and statistical analyses**—Analyses were carried out with statistical software, and the limit of significance for all tests was set at a value of P < 0.05. The proportion of dogs with EMG activity at ≥ 1 location in the groups of dogs with and without syringomyelia were compared by use of a Fisher exact test.

For analysis of the evoked potentials (SEPs and TMMEPs), mean data from both body sides of unaffected dogs and dogs with symmetric syringomyelia were used, whereas data from the affected side only in dogs with asymmetric syringomyelia were used. This method was selected to control for the fact that highly asymmetric syringomyelia may only affect 1 side of the spinal cord, and mean values calculated from both body sides would underestimate the effect of the syrinx. Measurement on 1 body side only in dogs that were bilaterally affected would still detect changes attributable to the syrinx. The SEP wave onsets, latencies, and amplitudes and TMMEP onset values were analyzed for normal distribution by use of the Shapiro-Wilk test; normally distributed data were analyzed by use of a 2-tailed, unpaired Student t test, and nonnormally distributed data were analyzed by use of a Mann-Whitney U test.

**Results**

Twenty-seven 12- to 36-month-old dogs were included in the study; 16 were female. Excessive scratching of the neck and excessive vocalization were reported for 3 dogs. All 3 dogs could be triggered to scratch on or around their neck by applying light pressure, but only 1 dog had signs of neck pain. No abnormalities were observed during examination of the other dogs.

All 27 dogs had evidence of cerebellar herniation secondary to Chiari-like malformation on sagittal T1-weighted MR images. Eleven dogs had apparently normal spinal cords, and 5 dogs had central canal dilatation...
(all of which were categorized as dogs without syringomyelia); 11 had syringomyelia (of which 3 had clinical signs). Two syrinxes were right sided, 3 were left sided, and 6 were symmetric; 2 were within the body of C3 only, 3 were within C3 and C4, and 6 extended from C2 to C7.

In the 16 dogs without syringomyelia, spontaneous EMG activity was recorded at 1 location in 4, at 2 locations in 3, and at 3 locations in 4; no spontaneous activity was recorded in 5 dogs. In the 11 dogs with syrinxes, activity was recorded at 1 location in 1, at 2 locations in 3, and at 6 locations in 1; no spontaneous activity was recorded in 6 dogs. The dogs with clinical signs of syringomyelia had abnormal activity detectable at 2 locations in 2 dogs and at 6 locations in 1 dog. The proportions of dogs that had > 1 area of abnormal activity in dogs with and without syrinxes (4/11 vs 7/16) were not significantly (P = 1.00) different.

Somatosensory-evoked potentials were recorded successfully in all but 1 dog that had syringomyelia. Data from that 1 dog were not further included in the analyses. All other data were normally distributed (P > 0.05) except for the N1 and total SEP amplitudes (P1 – N1) recorded for dogs with syringomyelia (P = 0.02 and P = 0.03, respectively).

The SEP latency measurements were similar between groups. For dogs with syringomyelia, mean N1 onset latency was 3.81 milliseconds (95% CI, 3.37 to 4.24 milliseconds), the N1 peak latency was 5.45 milliseconds (95% CI, 5.17 to 5.67 milliseconds), and the P1 peak latency was 9.08 milliseconds (95% CI, 8.67 to 9.45 milliseconds). For dogs without syringomyelia, mean N1 onset latency was 3.78 milliseconds (95% CI, 3.54 to 4.01 milliseconds), the N1 peak latency was 5.42 milliseconds (95% CI, 5.02 to 5.87 milliseconds), and the P1 peak latency was 9.06 milliseconds (95% CI, 8.45 to 9.71 milliseconds). These values were not significantly different between groups (all values of P > 0.05).

The SEP amplitudes recorded for dogs with syringomyelia were approximately 50% of those recorded for dogs without syringomyelia; the differences were significant (Figure 2). Mean N1 amplitude was −0.94 µV (95% CI, −0.54 to −1.33 µV; median N1 amplitude, −0.69 µV) in dogs with syringomyelia and −2.00 µV (95% CI, −1.62 to −2.31 µV; median N1 amplitude, −2.0 µV) in dogs without syringomyelia (P < 0.01). Mean P1 amplitude was 0.54 µV (95% CI, 0.18 to 0.89 µV; median P1 amplitude, 0.53 µV) in dogs with syringomyelia and 0.99 µV (95% CI, 0.76 to 1.23 µV; median P1 amplitude, 0.89 µV) in dogs without syringomyelia (P = 0.02). Total (P1 minus N1) amplitude was 1.47 µV (95% CI, 0.75 to 2.19 µV; median total amplitude, 1.25 µV) in dogs with syringomyelia and 3.00 µV (95% CI, 2.43 to 3.49 µV; median total amplitude, 2.70 µV) in dogs without syringomyelia (P < 0.01).

The TMMEPs could not be recorded in 9 dogs (3 with and 6 without syringomyelia) because of excessive movement artifact. The TMMEP latencies for the 8 remaining dogs with syringomyelia were very similar to those recorded for the remaining 10 dogs without syringomyelia. Mean TMMEP onset latency for the 8 dogs with syringomyelia was 12.11 milliseconds (95% CI, 10.57 to 13.65 milliseconds) in the thoracic limbs and 18.70 milliseconds (95% CI, 12.69 to 24.71 milliseconds) in the pelvic limbs; for the 10 dogs without
syringomyelia, values in the thoracic and pelvic limbs were 12.22 milliseconds (95% CI, 10.63 to 13.81 milliseconds) and 17.60 milliseconds (95% CI, 15.44 to 19.84 milliseconds), respectively. The thoracic or pelvic limb latencies did not differ significantly (P > 0.05) between groups.

**Discussion**

In the present study, SEPs recorded at the C1 vertebra in CKCSs with syringomyelia were significantly smaller than those recorded in CKCSs without syringomyelia, although there was no difference in SEP latency, latencies of the thoracic or pelvic limb TMMEPs, or EMG activity in the cervical paraspinal muscles between the 2 groups. These results suggest that the C1 SEP provides an objective measure of the deficits in spinal cord function associated with syringomyelia and may therefore have potential for evaluating the pathogenesis and treatment of the disease in dogs.

With regard to the comparatively reduced SEP amplitude in CKCSs with syringomyelia, there are 2 possible explanations: the syrinx could affect generation or propagation of the SEP in the spinal cord, or factors that predispose dogs to syrinx formation (overcrowding of the caudal cranial fossa1) could also impede SEP generation (eg, through direct compression of the generators of the SEP in the brainstem).

A consistent finding in the cervical SEP of humans with syringomyelia is the attenuation of a major negative wave that occurs at 13 milliseconds after stimulation of the median nerve (termed the N13 potential).13,15–18,20,28 The N13 potential is most commonly recorded at the C5 vertebra, but is also detectable at C2. There is substantial evidence that the N13 potential is primarily a stationary field potential rather than a travelling wave and that it is generated by a separate pool of neurons at each location: the dorsal horn of the spinal cord at C5 and the brainstem nuclei (predominantly the cuneate nucleus) at C2.26–33

Although the N13 potential at the C2 vertebra is preserved in humans with cervical syringomyelia, the N13 potential at C5 is attenuated because the syrinx affects the dorsal horn in that area.26 However, compressive lesions between C2 and C4 can also attenuate the N13 potential at C2,26–34 implying that functional dorsal columns are required for a normal C2 SEP.

In dogs, the SEP recorded at the C1 vertebra has also been called the cisterna cerebellomedullaris potential,15–32 with a suggested origin in the cuneate nucleus following thoracic limb stimulation.24,27,37,38 This would indicate that it is analogous to the N13 potential recorded at C2 in people and should therefore be unaffected by a syrinx. This was not the case in the dogs of the present study, which appears to support the theory that the SEP at C1 was attenuated because of a lesion that affected the cuneate nucleus, such as overcrowding of the caudal cranial fossa. Spinal cord lesions reduce the amplitude of the cranial cervical SEP in dogs26 and humans,26,34 presumably because of disruption to the dorsal columns in which the SEP is largely propagated; thus, it is still possible that the SEP recorded at C1 in the study dogs was attenuated by syrinxes. More detailed investigation of the effect of syringomyelia on the cervical SEP at various locations along the cervical portion of the spinal cord in dogs would be required to resolve this issue.

Reduced C1 SEP amplitude is not completely sensitive or specific for syringomyelia. In the present study, 1 dog with a large syrinx that extended from C2 through C5 had an apparently normal SEP amplitude, whereas 2 dogs without syrinxes had reduced SEP amplitude (Figure 2). The low SEP amplitudes in dogs without syrinxes may be a result of natural variation; alternatively, they may be indications that the SEP generator at C1 can be affected without development of a syrinx (consistent with the ubiquitous finding in CKCSs of overcrowding of the caudal cranial fossa) or that the SEP is affected by pathological changes in the spinal cord that develop before syrinx formation (as has been shown in people35). Both dogs without syrinxes that had low SEP amplitudes were 12 to 16 months old; no follow-up information was available, but an intriguing possibility is that the abnormal SEP activity may be a prelude to future development of syringomyelia in these dogs.

Spontaneous EMG activity has been detected with surface electrodes in the limb muscles of conscious humans with syringomyelia. It is thought to occur primarily as a consequence of denervation of the muscles (fibrillation and positive sharp waves) but may also occur as a consequence of damage to the spinal interneurons (resulting in continuous motor unit activity, synchronous motor unit activity, and respiratory synkinesia36). We did not find any evidence of increased spontaneous activity in CKCSs with syringomyelia in the present study. This finding suggests that neurons in the cervical ventral horn were not severely affected; furthermore, it can be concluded that isolated patches of spontaneous activity in the cervical muscles cannot be used as evidence of syringomyelia in dogs.

Similarly, TMMEP latencies in humans are thought to be increased in association with syringomyelia.17,40 However, that relationship has been debated,33 which is not surprising given that assessment of the TMMEP tests the integrity of the motor tracts and that syringomyelia secondary to Chiari malformation is predisposed to develop in the dorsal horn. The fact that TMMEP latency was similar in the 2 groups of dogs in the present study suggests that it is not a sensitive measure of the effects of syringomyelia.

Results of the present study indicated that syringomyelia is associated with a reduction in the amplitude of the SEP recorded at the C1 vertebra in CKCSs. Recording of the C1 SEP amplitude may be useful as a means of objective assessment of spinal cord function and could be used to investigate the efficacy of putative treatments for syringomyelia; findings of such an evaluation may even be a useful predictor of syrinx development in dogs, although further study of this issue is required.

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