Assessment of impulse duration thresholds for electrical stimulation of muscles (chronaxy) in dogs

Serge G. Sawaya, DEDV, PhD; Delphine Combet, DEDV; Guillaume Chanoit, DEDV, MS; Jean-Jacques Thiebault, DEDV, PhD; David Levine, PT, PhD; Denis J. Marcellin-Little, DEDV

Objective—To determine the electrical impulse duration thresholds (chronaxy) for maximal motor contraction of various muscles without stimulation of pain fibers in dogs.

Animals—10 healthy adult Beagles.

Procedures—The dogs were used to assess the minimal intensity (rheobase) required to elicit motor contraction of 11 muscles (5 in the forelimb [supraspinatus, infraspinatus, deltoideus, lateral head of the triceps brachii, and extensor carpi radialis], 5 in the hind limb [gluteus medius, biceps femoris, semitendinosus, vastus lateralis, and tibialis cranialis], and the erector spinae). The rheobase was used to determine the chronaxy for each of the 11 muscles in the 10 dogs; chronaxy values were compared with those reported for the corresponding muscles in humans.

Results—Compared with values in humans, chronaxy values for stimulation of Aα motor fibers in the biceps femoris and semitendinosus muscles and muscles of the more distal portions of limbs were lower in dogs. For the other muscles evaluated, chronaxy values did not differ between dogs and humans.

Conclusions and Clinical Relevance—Application of the dog-specific chronaxy values when performing electrical stimulation for strengthening muscles or providing pain relief is likely to minimize the pain perceived during treatment in dogs. (Am J Vet Res 2008;69:1305–1309)

F

or dogs, NMES is used in rehabilitation programs primarily to strengthen atrophied or denervated muscles.1,2 Neuromuscular electrical stimulation increases muscle strength; improves posture, active joint stability, and range of joint motion; decreases muscle spasm; and promotes muscle nutrition in humans.3 Muscle strengthening is most often achieved through intermittent tetanic muscle contractions separated by periods of rest. The generation of these tetanic contractions in a muscle requires motor nerve depolarization followed by propagation of the action potential along the neuron, which results in depolarization of the muscle cell membrane. The electrical impulses used to depolarize the nerve have varying intensities and pulse durations. The electric current delivered to the motor nerve to generate these muscle contractions has to be greater than a threshold value to depolarize Aα (motor) nerve fibers and create muscle contractions.4,5 Theoretically, the rheobase is the intensity threshold that leads to Aα fiber depolarization when the pulse duration is infinitely long; practically, the rheobase is determined by use of pulse duration > 100 milliseconds. The chronaxy of a muscle is the pulse duration needed to obtain Aα fiber depolarization with an intensity value twice that of the rheobase. For each muscle, intensity (I), pulse duration (t), rheobase (Rh), and chronaxy (Ch) are linked as follows: I = Rh (Ch/t + 1).7 The chronaxy of each muscle is considered to be the optimal pulse duration required to depolarize Aα fibers and create muscle contraction without stimulating Aδ and C nociceptive fibers.8,9 Muscle chronaxy in humans has been reported, but to our knowledge, chronaxy has not been assessed in dogs.10,11 The purpose of the study of this report was to assess the chronaxy of sev-
eral muscles used in canine NMES protocols and to compare these values with previously reported chronaxy values in humans.

**Materials and Methods**

The ethical and scientific committees of the primary author's institution approved the experimental protocol. Ten healthy male Beagles ranging in age from 5 to 8 years were enrolled. The experiments were judged to be painless and did not require any sedation. All tests were performed with the dogs in lateral recumbency. The dogs walked for 5 minutes between forelimb and hind limb tests.

Results of preliminary tests conducted on 7 muscles of 4 dogs indicated that there were no differences in chronaxy values for left and right limbs (t test; \( P = 0.960 \) [value of \( P < 0.05 \) was considered significant]); therefore, chronaxy values were determined only for left limbs in this study. Eleven muscles were tested: 5 in the forelimb (supraspinatus, infraspinatus, deltoideus, lateral head of the triceps brachii, and extensor carpi radialis), 5 in the hind limb (gluteus medius, biceps femoris, semitendinosus, vastus lateralis, and tibialis cranialis), and the erector spinae. For each dog, hair was clipped at each test site before each testing session. The overlying skin at each site was cleaned with isopropyl alcohol and diethyl ether approximately 30 seconds before carbon electrodes were placed. Stimulating and dispersive electrodes were placed on the skin surface over the motor point and body of each muscle, respectively. The stimulating electrode (cathode) was placed at a skin location that matched the entry point of needle electrodes used in a previous study. Dispersive electrodes were placed on muscle bodies at a location at least 1 electrode width away from the stimulating electrodes. To evaluate the erector spinae musculature, the stimulating and dispersive electrodes were placed approximately midway between the spinous and transverse processes, at the junction of the spinals and longissimus muscles. The stimulating electrode was placed at the thoracolumbar junction. The dispersive electrode was placed at the junction of the fifth and sixth lumbar vertebrae. Electrodes were cleaned by use of isopropyl alcohol and diethyl ether after each muscle was tested.

For each muscle, chronaxy was determined by use of a stimulator that delivered a constant monopolar symmetric rectangular current, from which a graph of \( I = Rh \) (Ch/t + 1) was created. Square electrodes (2 × 2 cm) were used for the deltoideus, extensor carpi radialis, and tibialis cranialis muscles, and round (3-cm-diameter) electrodes were used for other muscles. The electrodes were cut from a carbon electrode ribbon. To optimize electrode placement, we induced slight muscle contractions, displaced the stimulating electrode slightly, and assessed changes in the strength of muscle contractions. The location of the stimulating electrode that resulted in the strongest contractions was selected. As described, the rheobase for each muscle was determined as the lowest intensity required to detect the slightest contraction with the monopolar rectangular current, with a preprogrammed pulse duration of 500 milliseconds. To maximize the detection of these slight contractions, the skin surface was observed with tangential line of sight and simultaneously palpated with fingertips. The chronaxy was determined as the minimal pulse duration value required to obtain the same slight muscular contraction with an intensity twice as large as the rheobase. For each muscle, the accuracy of these measured chronaxy values was confirmed via 2 methods. First, the measured chronaxy values were plotted on the \( I = Rh \) (Ch/t + 1) curve determined by use of the stimulator, and the corresponding rheobase values were calculated on these curves. The measured and calculated rheobase values were compared and had to be within 10% of each other to validate the accuracy of the measured chronaxy values. Second, the smoothness of muscle contractions and absence of apparent discomfort among dogs during NMES sessions (3 to 5 minutes’ duration), in which the muscle chronaxy was used as pulse duration and current frequencies of 60 Hz were applied, were assessed. Specifically, 4 or 5 smooth tetanic muscle contractions (2-second ramp up, 6-second on phase, 1-second ramp down, and 12-second off

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Chronaxy value (( \mu )s)</th>
<th>Range of recommended pulse durations for use in dogs* (( \mu )s)</th>
<th>Reported human chronaxy range (( \mu )s)</th>
<th>Range of recommended pulse durations for use in humans (( \mu )s)</th>
</tr>
</thead>
</table>

*These recommended pulse durations are intervals centered over the mean values calculated in this study with an approximate range of ± 10% or ± 20 µs. This range facilitates the selection of a single chronaxy value when stimulating several muscles in 1 region.

**Table 1**—Mean ± SD (95% confidence interval) chronaxy of 11 muscles in 10 dogs and clinical recommendations for pulse duration for electrical stimulation of canine muscles. The range of chronaxy values for the corresponding muscles in humans and clinical recommendations for pulse duration for electrical stimulation of human muscles are provided for comparison.
phase) were observed at each of 2 or 3 intensity levels for each muscle. Intensity levels were slightly increased to ensure that the contractions were maximal and did not lead to a pain response.

The mean ± SD chronaxy values and 95% confidence interval of the mean were calculated. Outlying values, defined as pulse durations < 100 or > 300 microseconds, were included in all calculations. The recommended pulse durations for NMES of the forelimb, hind limb, and erector spinae of 3 commercially available machines were collected and compared with the values calculated in this study.14-16

Results

None of the dogs appeared anxious during the assessments. Skin irritation secondary to clipping or cleaning was not evident. Mean ± SD values and 95% confidence intervals for chronaxy of the 5 forelimb, 5 hind limb, and erector spinae muscles in the study dogs were calculated and compared with muscle chronaxy values in humans and recommended pulse duration values for the 3 NMES machines designed for human use (Table 1). Muscle chronaxy ranged from 100 to 300 microseconds (mean values, 155 to 270 microseconds). Outlying values were rare.

Discussion

In the study of this report, the pulse duration thresholds for contraction of 11 muscles in 10 healthy dogs were determined. Knowledge of the optimal pulse durations enables clinicians to effectively recruit muscle fibers during electrostimulation sessions while lowering the likelihood of stimulating pain fibers.

Chronaxy values did not appear to differ between muscles of left and right limbs of the dogs used in our study. This is in agreement with a report1 of human muscle chronaxy. The chronaxy values for the biceps femoris and semitendinosus muscles and muscles of the more distal portions of limbs (extensor carpi radialis and tibialis cranialis muscles) in dogs were lower than reported values for those muscles in humans. Application of chronaxy values extrapolated from human data when strengthening these muscles in dogs would increase the likelihood of depolarization of Aδ and C nerve fibers that are responsible for nociception. The differences between chronaxy values in humans and dogs are likely linked to the differing proportions of slow- (type I) and fast-twitch (type II) fibers in hind limb muscles and in the more distal portion of the forelimb. Slow-twitch fibers are predominantly present in muscles responsible for stance and high-endurance activities. Fast-twitch fibers are predominantly present in muscles responsible for locomotion.17 The hind limbs of quadrupeds in general and of dogs in particular have a high proportion of fast-twitch fibers, compared with the legs of humans.18-21 Fast-twitch fibers are activated by motor nerves that have action potentials with higher conduction velocity and higher motor neuron discharge frequency than the action potentials of motor nerves that activate slow-twitch fibers.22 These fast-twitch fibers have shorter chronaxy values than slow-twitch fibers.

The present study had several limitations. The impact of electrode resistivity and tissue impedance on muscle chronaxy in dogs or humans is not known. Skin surface temperature was not monitored during the study. A change in skin surface from 32°C to 22°C does not impact chronaxy in humans.23 The impact of breed, aging, sex, training, or neurogenic injuries on these differences on muscle chronaxy in dogs is not known. However, in studies of histochemical and morphometric features of muscles, differences between Beagles and hound-type dogs or mixed-breed dogs were not identified. In humans < 60 years old, the chronaxy of sensory nerves does not seem to be influenced by age.30 Nevertheless, muscle composition changes over time and as a result of some chronic diseases; a muscle-specific increase in proportion of slow-twitch fibers occurs with aging, particularly for the vastus lateralis muscle in humans.31,32 Age-related differences in muscle composition were not identified in a study involving 28 dogs. Muscle fiber distribution appears to differ between men and women,34 but histochemical differences in muscles of male and female dogs have not been identified.33,35 Training appears to influence muscle composition in rats and horses,36,37 but little is known about the impact of training on fiber types in dogs. In 1 study,38 no histochemical changes were detected in the gastrocnemius, triceps brachii, and semitendinosus muscles of Foxhounds after a 12-week-long endurance training program. A decrease in the proportion of slow-twitch fibers in skeletal muscles of dogs with chronic heart failure has been reported.29 To our knowledge, few data regarding the impact of denervation and other musculoskeletal diseases on chronaxy in dogs have been published. Results of a study indicated that the chronaxy of denervated muscles in dogs sharply increased (5- to 100-fold), compared with chronaxy values in clinically normal dogs. Chronaxy also increased in 2 American Foxhounds with type C botulism, compared with chronaxy values in clinically normal dogs.40

Muscle chronaxy is primarily influenced by abnormalities of peripheral nerves and neuromuscular junctions.41 During temporary denervation, muscle chronaxy increases within a few days of denervation and returns to predenervation values over a period of weeks to months.42-44 Change in chronaxy, combined with assessment of nerve accommodation index, is 100% sensitive for detection of denervations that are complete or have a sudden onset.42 Our clinical experience suggests that chronaxy also increases in dogs with neurologic diseases involving the brachial and lumbo-sacral plexi. Clinically, however, muscle denervation in companion animals is universally confirmed via needle electromyography.

Although the assessment of the chronaxy of individual anterobrachial extensor muscles was not possible because of the small size of these muscles in relation to the size of the surface electrodes used in our study, our focus was to assess muscles of the more distal portion of the limbs that have maximal clinical relevance. These included the tibialis cranialis muscle, which is strengthened in patients with sciatic or peroneal nerve palsy and with instability or weakness of the medial aspect of the tarsus, and the extensor carpi radialis, which...
is strengthened in patients with radial nerve palsy. The elbow flexors (brachialis and biceps brachii muscles) were not included because, in our experience, their stimulation is a lower priority than stimulation of the extensor muscles of the carpus and digits and the triceps brachii muscle when treating neurologic injuries of the forelimb. Also, we considered the fact that the biceps brachii muscle was covered in large part by the brachiocephalicus and superficial pectoral muscles, which would make the detection of slight muscle contractions challenging.

Intensity values were not reported because these values vary with electrode size and material, conduction from the electrode to the skin surface, and skin and subcutaneous tissue impedance. When performing NMES in dogs for clinical purposes, we used the pulse durations determined in the present study and selected the lowest intensities that lead to effective tibial contractions. A small number of dogs with severe neuromuscular disease (eg, polyradiculoneuritis) do not appear to tolerate NMES performed under these conditions. These patients have been reported to be hyperesthetic to sensory stimuli and typically have rapid muscle atrophy and muscle fibrosis. Electrical stimulation at brief pulse durations (5 to 15 microseconds) may be used in these dogs, particularly on the postural muscles. At these brief pulse durations, there is no excitation, and muscle contractions may be achieved at high current intensities. However, these contractions do not lead to muscle strengthening, but rather are used to maintain muscle excitability over time and to promote muscle nutrition. Unfortunately, few electrical stimulation machines are programmed to operate with such brief pulse durations.

The findings of the present study may be used as guidelines for the electrical stimulation of sensory nerve fibers such as the AB fiber stimulation achieved by use of TENS. On the basis of reported differences in electrical threshold of motor and sensory fibers, we anticipate that the optimal pulse duration for TENS use in dogs would be no higher than the muscle chronaxy determined for motor fibers in our study. We conclude that the optimal pulse durations required for stimulation of Aβ motor fibers (chronaxy) in the biceps femoris and semitendinosus muscles and muscles of the more distal portions of limbs are lower in dogs, compared with the durations in humans. Results of our study indicated that pulse durations of NMES protocols for use with commercially available machines in humans are not optimized for NMES use in dogs. The use of dog-specific chronaxy values during strengthening procedures in these muscles and the provision of pain relief by use of NMES or TENS are likely to minimize the pain perceived during treatment.

References