J. Vet. Med. A 39, 372–381 (1992)

ISSN 0931–184X

From the Veterinary Surgery Clinic, Faculty of Veterinary Medicine of the University of Zürich, Switzerland

Neuromuscular Transmission Studies in the Healthy Dog: EMG and Muscle Force Measurement after Repetitive Nerve Stimulation

M. K. WAXENBERGER, R. HECKMANN, TH. WIESTNER and H. P. HOGG

Address of authors: Veterinär-Chirurgische Klinik der Universität Zürich, Winterthurerstrasse 260, CH-8057 Zürich, Switzerland

With 7 figures and one table

(Received for publication December 6, 1991)

Summary

In 10 healthy anaesthetized female dogs the ulnar and the mandibular nerve were stimulated supramaximally by repetitive electric impules according to a fixed programme. To evaluate the neuromuscular transmission system the course of the evoked compound muscle action potential and the near-isometric force of forelimb and masticatory muscles were studied respectively. The presented results are comparable to values obtained from small hand muscles of conscious, healthy human subjects. The simultaneous measurement of both the electrical and the force response may improve the diagnostic accuracy of the examination in presumed neuromuscular transmission failure in the dog, as it does in humans.

Introduction

In human medicine, neurophysiological examination techniques are important as a diagnostic aid in neuromuscular transmission disorders, such as myasthenia gravis (MG), myastheniform syndromes, botulism and tick paralysis. The most common electrodiagnostic method is the stimulation electromyography (EMG), another one is the single fibre EMG (LUDIN, 1988; HECKMANN, 1989).

These examination techniques are indicated in presumed discreet transmission disorders or supplementary when the results of other auxiliary diagnostic means (injection of Tensilon, immunocytochemical and immunoserological tests) are equivocal. Furthermore, they are important in case control studies of MG patients (LUDIN, 1988).

In the stimulation EMG, a peripheral nerve is electrically stimulated by supramaximum rectangular impulses at different frequencies and the compound action potential of a related muscle (CMAP) is recorded. Repetitive nerve stimulation at various frequencies has also been applied to evaluate neuromuscular transmission disorders in dogs, but for many years, there was no information available concerning the normal CMAP-response in the healthy dog. Recently, reference values for short lasting low frequency nerve stimulation (1, 3 and 5 Hz up to 40 s) and for high frequency stimulation (10, 20, 30 and 40 Hz up to 20 s) have been established by MALIK et al. (1989) and SIMS and MCLEAN (1990).

U.S. Copyright Clearance Center Code Statement: 0931–184X/92/3905–0372$02.50/0

However, the normal response to long term low frequency stimulation and to stimulus rates above 40 per second in the dog is still unknown.

In humans suffering from a transmission failure, the diagnostic accuracy is enhanced when EMG techniques are combined with the simultaneous recording of the muscle tension under approximately isometric conditions (SLOMIC et al., 1968; LUDIN, 1988). In small animal neurology, the combined recording of EMG and muscle tension has so far not been applied for clinical use, and then only for the investigation of the effect of muscle relaxant drugs (HECKMANN et al., 1977).

The aim of our investigation was to study the course of the developed muscle force and of the amplitude of the compound muscle action potential after supramaximum nerve stimulation at different frequencies in the healthy dog. With these parameters the neuromuscular transmission system can be evaluated. The presented study may be the basis for a subtle diagnostic procedure in small animals suffering from diseases affecting the neuromuscular junction.

Material and Methods

Our examinations were carried out in 10 healthy female dogs, 1 to 4 years old and weighing 15 to 25 kg, under general anaesthesia (9 Appenzell mongrel dogs, 1 German Shepherd). As a preanaesthetic agent, 0.05 mg/kg of atropine sulphate was administered subcutaneously. Five minutes later anesthesia was induced by the intravenous injection of 0.1 mg/kg of acepromacine[1] and 0.83 mg/kg of 1-methadone[2]. Thereafter, the animals were intubated and anaesthesia was maintained with halothane as needed. Oxygen and nitrous oxide were given in a ratio of 1 : 2.

For instrumentation, EMG and force measurement equipment, refer to WIESTNER et al. (1992).

With reference to experience in human patients, we used a stimulation programme consisting of five steps (SLOMIC et al., 1968; DESMEDT, 1973; MEIENBERG and LUDIN, 1977; LUDIN, 1988). Single square-wave stimuli of 0.1 ms duration and twice the current that is needed for the maximal stimulus response were used. A 3 Hz stimulus train of 3 s was delivered before each step of the programme. The first CMAP and force response served as control values to calculate the relative course of the measured parameters.

Breaks between low frequency stimulation steps were not shorter than 2 minutes and between high frequency stimulation sequences not shorter than 5 minutes.

1) *3/s test:* Stimulation at 3 Hz during 3 s (10 stimuli).
2) *Long-lasting stimulation* during 2 minutes at 1 and 2 Hz and at 3 Hz for 130 s.
3) *High frequency stimulation* at 10, 25, 50, 100 and 200 Hz for two seconds.
4) *Post-tetanic control studies:* 3/s stimulus trains 15, 30, 60, 120, 180, 240 and 300 seconds after tetanic stimulation, each train lasting for 3 seconds.
5) *Tensilon^R administration[3] test:* Intravenous Tensilon^R administration with subsequent recording of EMG and muscle force.

At the *3/s test* the 1st, 2nd and 5th response of the integral of the rectified CMAP (IU), the negative (U_{Neg}) and positive (U_{pos}) peak of the CMAP amplitude (U), the maximum muscle force of single twitches under near-isometric conditions (F) and the corresponding force integral (IF) were analysed. For each parameter, the second and the fifth value were divided by the first (2/1, 5/1) to characterize the relative course of the 3 Hz stimulus response.

The staircase phenomenon ("Treppe") was studied with *long-lasting stimulation* at low frequencies. A positive staircase phenomenon describes a regressive increase of the twitch tension during the stimulation period.

At *high frequency stimulation* the subtetanic and tetanic force development and the course of the CMAP amplitude and integral of the rectified CMAP respectively was examined.

In *post-tetanic control studies* the recovery of the muscle twitch height and the amplitude of the CMAP after a brief tetanic stimulus burst were measured. Therefore the quotients of the first response of the actual post-tetanic 3 Hz stimulus train (U1n, F1n) to the first pre-tetanic value (U1 control, F1 control) were calculated.

---

[1] Vétranquil^R 1 %, Lathévet, Paris, France.

[2] 1-Polamivet^R, Hoechst AG, Frankfurt/Main, West Germany.

[3] Edrophonium chloride 1 %, Roche Products Limited, Welwyn Garden City, England.

Finally, *in the Tensilon test* the course of muscle force and of the CMAP amplitude were examined 90 s after i. v. administration of Tensilon (1 mg / 10 kg body weight) at 200 Hz stimulation and at post-tetanic control studies as listed in 4). In the forelimb the ulnar nerve was stimulated near the elbow and the CMAP of the interossei muscles was recorded in the endplate region. Simultaneously, the muscle tension of the flexor muscles of the paw was measured. Since the diagnostic yield of force measurement improves in human myasthenia gravis patients, when both proximal and distal muscles are tested, the EMG and the twitch tension of head muscles were also recorded (LUDIN, 1988). For this purpose the mandibular nerve was stimulated at the foramen ovale and the CMAP of the temporalis or masseter muscle was measured in the endplate region. In addition, the force development of the masticatory muscles was recorded.

Results

In the *3/s test* the F5/F1 ratio in the flexor muscles decreased not more than 10 % with a mean value of about 5 % (Table 1). The second twitch showed a smaller amplitude and a shortened relaxation time with regard to the first one. This phenomenon disappeared at stimulus intervals longer than 1 s and it was not seen in the masticatory muscles. The F5/F1 value for the masticatory tension amounted to 112–114 % (Fig. 1). The U5/U1 ratio remained constant within a range of ± 6 % (Table 1). This holds true for values of the masticatory muscles as well as of the limb muscles, where the CMAP of the interossei muscles and the force of the flexors were measured.

With *long lasting stimulation* at frequencies of 1, 2 and 3 Hz, a positive staircase phenomenon for Fn/F1 between 107 and 130 % was always observed when the stimulation period was shorter than 100 s. The higher values were measured in the masticatory

Table 1. Results of the 3/s test, measured at the forelimb. Mean values ($\bar{x}$) and standard deviations (sd) from 7 recordings (7 dogs). *Absolute values:* 1st, 2nd and 5th response for the following parameters: maximum muscle force F (N = Newton) and related integral IF (Ns = Newton × second), contraction time t_c (ms = millisecond), relaxation time t_r (ms), total time of muscle twitch t_t (ms), CMAP amplitude U (mV = millivolt), negative peak of CMAP amplitude U_{neg} (mV) and CMAP integral IU (mVms = millivolt × millisecond). *Relative values:* Quotients 2/1 and 5/1 of each of the parameters mentioned above

Parameter		Absolute values			Relative values	
Number of response		1	2	5	2/1	5/1
F	$\bar{x}$	5,53	5,27	5,27	0,95	0,95
(N)	sd	0,38	0,37	0,42	0,01	0,02
IF	$\bar{x}$	0,77	0,63	0,61	0,81	0,79
(Ns)	sd	0,12	0,10	0,11	0,02	0,03
t_c	$\bar{x}$	59,7	57,1	57,0	0,96	0,96
(ms)	sd	9,3	9,0	8,8	0,02	0,03
t_r	$\bar{x}$	216,2	188,5	184,0	0,87	0,85
(ms)	sd	29,5	26,9	25,9	0,04	0,05
t_t	$\bar{x}$	275,8	245,6	241,0	0,89	0,87
(ms)	sd	35,9	34,3	33,2	0,03	0,04
U	$\bar{x}$	13,29	13,07	13,06	0,98	0,98
(mV)	sd	2,05	2,00	2,04	0,01	0,01
U_{neg}	$\bar{x}$	9,15	8,90	8,84	0,97	0,97
(mV)	sd	1,22	1,23	1,23	0,01	0,01
IU	$\bar{x}$	13,34	13,38	13,53	1,00	1,01
(mVms)	sd	2,28	2,20	2,29	0,02	0,03

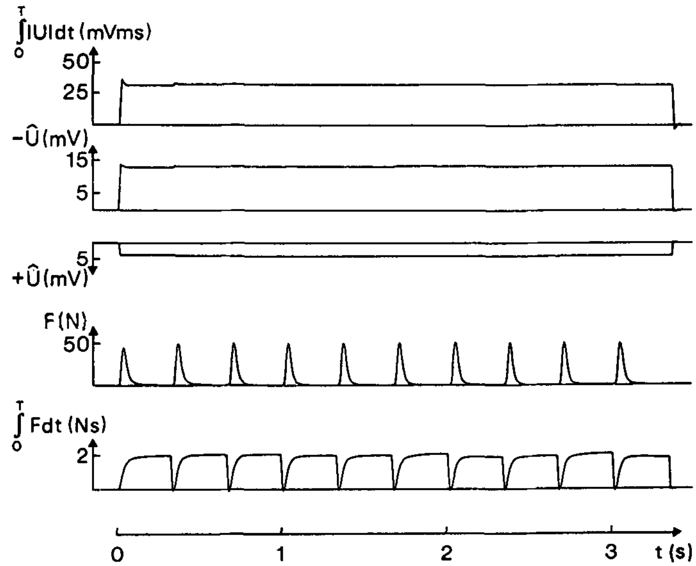

Fig. 1. Example of the course of the compound muscle action potential (CMAP) and myogram parameters at a stimulus rate of 3 per second for 3 s. Stimulation: Mandibular nerve at the foramen ovale. Recording: M. masseter (CMAP) and the force developed by the masticatory muscles respectively. From above to below: Integral of the rectified CMAP (millivolt × millisecond), maximum negative deflection of the CMAP (millivolt), maximum positive deflection of the CMAP (millivolt), tension curves of single twitches (Newton), integral of the twitch curve (Newton × second), reset at each stimulus

muscles. At stimulation periods longer than 100 s the muscle force sometimes showed a slight subsequent decline (Fig. 2). The higher the stimulus rate the more pronounced was the staircase phenomenon.

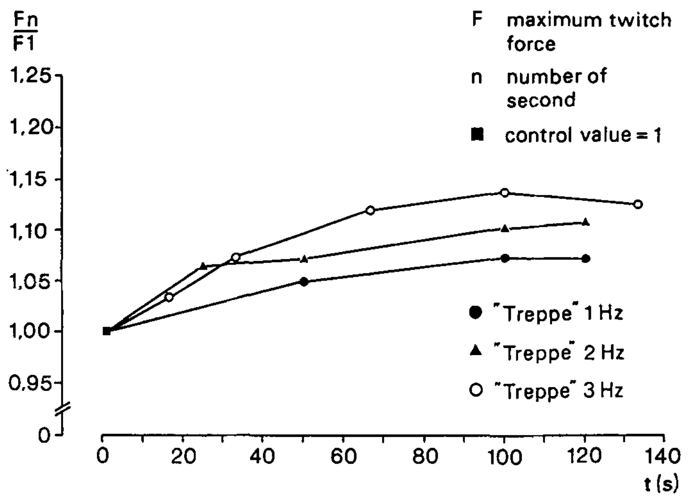

Fig. 2. Positive staircase phenomenon of the muscle force during long lasting stimulation of 1, 2 and 3 Hz. Stimulation: Ulnar nerve at the elbow. Recording: Isometric tension of the flexor muscles of the paw. Mean values of 7 recordings (7 dogs)

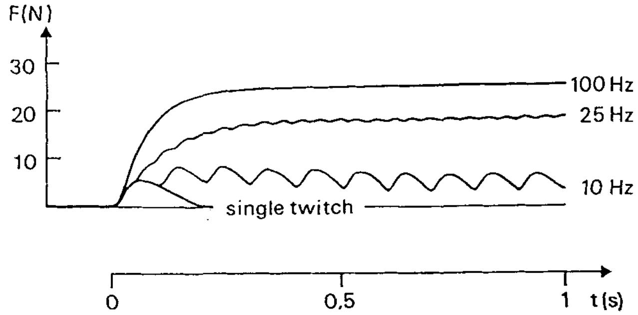

Fig. 3. Force development at stimulus rates of 1 per second (single twitch) and at 10, 25 and 100 Hz. Original recordings have been projected one upon another. Stimulation: Ulnar nerve at the elbow. Recording: Flexor muscles of the paw

With *increasing stimulus frequency* the subsequent single twitches started to fuse (Fig. 3). In limb muscles the contraction was subtetanic at stimulus frequencies of 10 and 25 Hz, at frequencies of 50, 100 and 200 Hz a smooth tetanic contraction was achieved. The tetanic muscle tension was maintained for two seconds except at 200 Hz stimulation, where a slight decline of the force plateau (about 5 %) was always present (Fig. 7). This stimulation response pattern was identical in the forelimb flexor as well as in the masticatory muscles, with the exception of the 10 Hz stimulus response of the jaw-closer muscles. At this frequency no distinct twitch fusion occurred.

In the flexor muscles of the forelimb a decline of the CMAP amplitude and integral was observed, which became more pronounced with increasing stimulus rates (Fig. 4). At

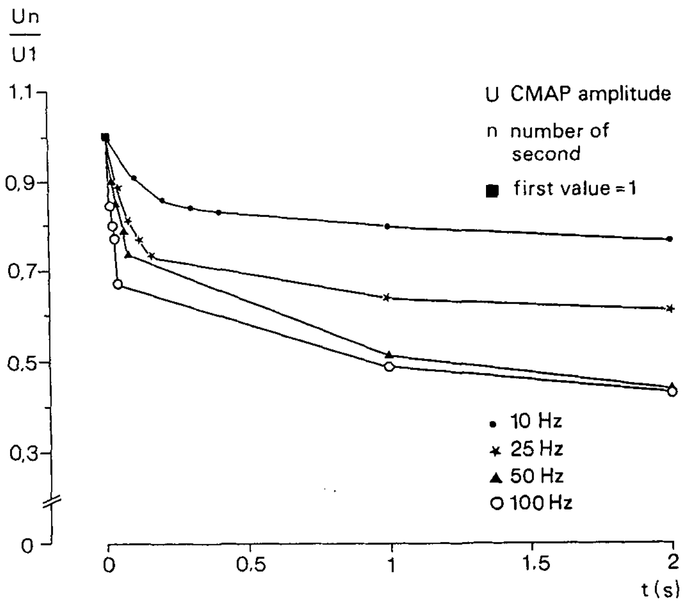

Fig. 4. Relative course of the CMAP amplitudes at high frequency stimulation of 10, 25, 50 and 100 Hz. Stimulation: Ulnar nerve at the elbow. Recording: Interossei muscles. Mean values of 7 recordings, 7 dogs

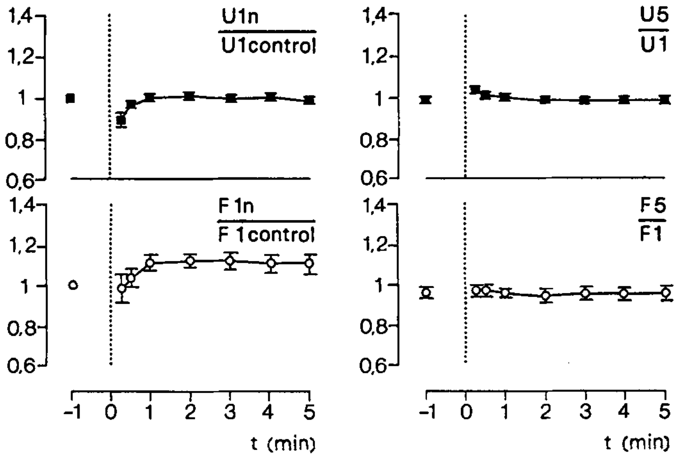

Fig. 5. Post-tetanic control studies of the relative course of the amplitudes of the CMAP and muscle force after 200 Hz stimulation (dotted line). 60 seconds before and 15, 30, 60, 120, 180, 240 and 300 seconds after high frequency stimulation, 3 Hz stimulus trains of 3 s duration were applied. Stimulation: Ulnar nerve at the elbow. Recording: Interossei muscles (CMAP), flexor muscles of the paw (muscle force). Mean values and standard deviations (error bars) of the maximum CMAP voltage (U) and of the maximum force (F) of 7 recordings (7 dogs). *Left:* Quotients of the first response of the actual post-tetanic 3 Hz stimulus train (U1 n, F1 n) to the first pre-tetanic value (U1 control, F1 control). *Right:* Quotients of the fifth to the first response within the actual pre- and post-tetanic 3 Hz stimulus train

50 and at 100 Hz stimulation the amplitude was depressed by about 50 % and at 200 Hz stimulation by >70 %. In every case the course of the CMAP amplitude and area was similar. In one record of the masticatory muscles an increase of the CMAP amplitude of

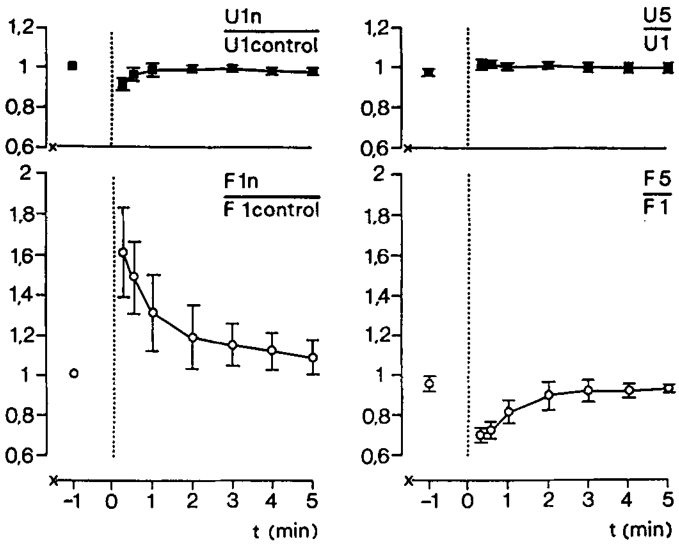

Fig. 6. Effect of Tensilon on the course of the amplitudes of the CMAP and muscle force after 200 Hz stimulation for 2 s (dotted line). Recording conditions and illustration see Fig. 5. 90 seconds before tetanic stimulation 1 mg of Tensilon per 10 kg body weight was injected intravenously (× on the time axis)

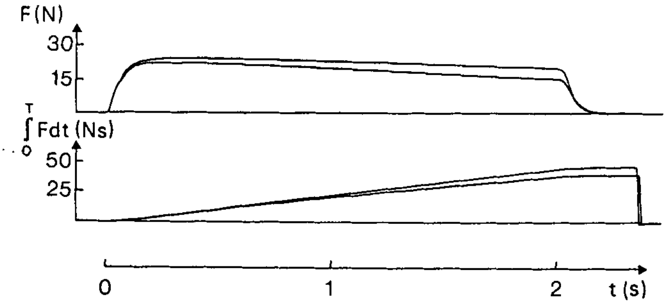

Fig. 7. Tetanic muscle tension and related integral at a stimulus rate of 200 per second for 2 seconds before (higher amplitudes) and 90 s after (lower amplitudes) Tensilon administration. Original recordings, projected one upon another. Stimulation: Ulnar nerve at the elbow. Recording: Flexor muscles of the paw

about 15 % was found at stimulus frequencies of 10 and 25 Hz, accompanied by a slightly lesser increase in CMAP area.

With stimulus rates up to 100 Hz *post-tetanic changes* in the EMG and the myogram during the recovery period were not detected. Following a 200 Hz stimulus train the amplitude of the CMAP was slightly depressed (about 10 %) and returned to normal within about 30 s. In limb as well as in masticatory muscles an increase of the muscle force to about 110 % occurred, lasting for at least 5 minutes (Fig. 5).

At high frequency stimulation a marked decrease of the tetanic force plateau occurred after *Tensilon administration* (Fig. 7) and also a decrement of the CMAP amplitude. The post-tetanic maximum muscle force showed a marked pronounced (F1n/F1 control) and the F5/F1 ratio was highly depressed immediately after the tetanus (Fig. 6). An almost complete recovery occurred within 5 minutes. Tensilon effects could be registered not earlier than 60 s after the intravenous injection, hence the pretetanic reference value was not influenced (Fig. 6).

Discussion

Diagnoses of neuromuscular transmission disorders in the dog have been supported by nerve stimulation tests (LENNON et al., 1981), but simultaneous recording of the muscle tension has not been performed so far. If possible, electrical and mechanical stimulus responses should be recorded from the same muscle group (LUDIN, 1988). In contrast to the CMAPs of the flexor muscles, the CMAPs of the interossei muscles were well reproducible in their shape, duration and amplitudes and barely affected with a stimulus artifact. Therefore CMAP and tension were derived from different muscle groups. This is not a disadvantage because EMG and muscle tension represent two distinct parameters to assess neuromuscular function and they are not simply correlated. Furthermore, the individual muscles contribute different portions to the CMAP according to size and position of the recording electrode (KIMURA, 1983). Three Hz nerve stimulation *(3/s test)* is considered to be the most effective stimulus frequency in detecting neuromuscular transmission block. This stimulus rate is fast enough to cause considerable depletion of the immediately available acetylcholine store, but slow enough to avoid superimposed facilitation from neurosecretory mechanisms (KIMURA, 1983; OH, 1988).

As expected, the CMAP amplitude remained constant from the first to the fifth value. The results show that the course of the total CMAP amplitude, the negative and the positive peak of the CMAP and the integral of the CMAP are equivalent.

The slight depression of the twitch ratio F5/F1 of less than 10 % in the examined limb muscles (Table 1) is comparable to results obtained from human small hand muscles, where a decrement of 15 % is considered to be normal (LUDIN, 1988). The decrease in force integral (IF) from the first to the second value results from both a decrease in peak force and a shortening of the time course of the twitch. This depression in twitch tension and related force integral may reflect a phenomenon described as "negative staircase", which occasionally precedes the "treppe" increase with continuing nerve stimulation (SLOMIC et al., 1968). The 12 % – 14 % increase of the F5/F1 ratio measured in two experiments in the masticatory muscles (Fig. 1) is possibly an expression of the staircase phenomenon, appearing earlier in limb than in masticatory muscles. A possible explanation for the different course of the twitch response in limb and jaw muscles is their different content of fibre types. While the flexor muscles innervated by the ulnar nerve contain a high proportion of slow-twitch fibres (type I) (ARMSTRONG et al., 1982), the jaw-closer muscles are mainly composed of particular fast contracting fibres (type II M), which are exclusively found in carnivores and certain species of primates but not in man (ROWLERSON et al., 1983). It is well known that force development of fast muscle fibres is potentiated by preceeding activity, whereas the twitch tension of slow muscle fibres becomes depressed (LEWIS and RIDGE, 1981).

The cause of the *staircase phenomenon* (Fig. 2) is not known. According to BOWMAN (1980) "treppe" increase is probably a pure myogenic feature "arising from an effect on the contractile mechanism through which more Ca^{++} becomes available for cross-bridge formation between actin and myosin". In the present study values in the same range as reported from human small hand muscles were found (SLOMIC et al., 1968; MEIENBERG and LUDIN, 1977). It is likely that contractile properties of fast-twitch jaw muscle fibres are responsible for the distinct and rapid staircase increase measured in these muscles. The slight and delayed "treppe" increase in the limb flexor muscles is possibly attributed to the twitch characteristics of slow- and fast-twitch muscle fibres. The observed decline of the staircase values at stimulus periods longer than 100 s seems to represent a muscular fatigue effect since the CMAP amplitude showed no decrease during the stimulus period.

The frequency dependent decline of the CMAP amplitude (Fig. 4) and its integral as well in the *high frequency stimulation test* is a poorly understood phenomenon. It cannot, or not exclusively, be explained by a presynaptic intermittent blocking of nerve conduction with subsequent failure of muscle fibres described to occur at stimulus frequencies ≥ 50 Hz in the rat (KRNJEVIC and MILEDI, 1959). The authors never observed a decrease of the tetanic force plateau up to 100 Hz stimulus frequencies (Fig. 3). The 5 % decline of the tetanic force at 200 Hz stimulation (Fig. 7) may partly be due to such presynaptic blocking. But there exists a discrepancy between this slight force decrease and the marked depression of the CMAP amplitude and its integral to values less than 30 %. It must be caused by a reduction of the single fibre action potentials, whereby the amplitude of most of them remains supraliminal.

The absence of twitch fusion in the jaw-closer muscles at 10 Hz stimulation is probably due to their high proportion of fast-contracting twitch fibres, which need a faster stimulation frequency to produce a fused tetanus than slow-twitch fibres (LEWIS and RIDGE, 1981).

The *post-tetanic* depression of the CMAP amplitude after 200 Hz stimulation must be due to membrane effects of the muscle fibre and not to pre- or post-synaptic blocking, since the twitch height immediatly after the tetanus is equal to the pretetanic value (Fig. 5). Therefore, the subsequent increase of the twitch force can be explained neither by a reversal of neuromuscular transmission block nor by facilitation of transmitter release; it rather seems to be a myogenic effect similar to "treppe" increase, described as "post-tetanic potentiation" of a maximal twitch (ZAIMIS and HEAD, 1976).

The decline of the tetanic force plateau (Fig. 7) and the decrement of the CMAP amplitude at 200 Hz stimulation in the *Tensilon test* is a consequence of both a rapid depletion of the available acetylocholine store (BOWMAN, 1980) and postsynaptic depolarization block with subsequent intermittent failure of muscle fibre potentials. The pronounced increase of the post-tetanic twitch magnitude (Fig. 6) is probably attributed to repetitive discharges of the muscle fibre membrane (ZAIMIS and HEAD, 1976).

The normal response to nerve stimulation depends on the muscle being examined. One explanation for this fact is that muscles of the same individual differ in histochemical composition (ROWLERSON et al., 1983). In addition, the predominant fibre type in a given muscle depends on the breed of dog. Since the contractile response to a nerve impulse differs between fast- and slow-twitch fibres, quantitative or even qualitative differences are to be expected when using nerve stimulation tests routinely in the dog. Therefore, it seems to be important to establish reference values for different breeds of dog. In the present study, a muscle group which is predominated by fast-twitch fibres and muscles containing a high proportion of slow-twitch fibres have been investigated. In every case a staircase increase at 2 Hz stimulation for 2 minutes, a smooth tetanic contraction at 50 and 100 Hz stimulation for two seconds and, after Tensilon® administration, a marked decline of the tetanic force plateau at 200 Hz stimulation for two seconds could be observed. For this reason, these parameters seem to represent a helpful aid to evaluate neuromuscular transmission in the dog.

Our investigations yielded the following conclusions:

- Recordings of the electromyogram and mechanogram at the forelimb and masticatory muscles after repetitive nerve stimulation in the anaesthetized dog lead — with regard to the course of the CMAP amplitude and of the muscle tension — to results comparable to those obtained from small hand muscles of conscious human subjects.
- The normal CMAP-response to nerve stimulation at 1, 3, and 10 Hz for a few seconds, measured in this study, corresponds well to the reference values found in anaesthetized dogs by MALIK et al. (1989) and SIMS and MCLEAN (1990).
- Simultaneous records of both the CMAP amplitude and the twitch force probably enhances the diagnostic value in presumed neuromuscular transmission disorders.
- The following examination procedure can be proposed:
  - 3/s test during 2 s; it is recommendable to calculate the quotient of the fifth to the first response; 3 minute pause
  - 2 Hz and/or 3 Hz stimulation during two minutes; 5 minute pause
  - Tetanic stimulation at 100 and 200 Hz for 2 s.
  - 3 Hz stimulus trains (duration 2 s) 1 min before and 15 s, 30 s, 1 min, 2 min, 3 min, 4 min and 5 min after the tetanus; 10 minute pause
  - Intravenous Tensilon administration (1 mg/10 kg body weight) 90 s before 200 Hz stimulation for 2 s and post-tetanic control studies.
- Overall CMAP amplitude and negative peak of CMAP are equivalent parameters. Recordings of the CMAP amplitude and the twitch height are sufficient; measurement of the integral of the CMAP and of the muscle force provides no further information.

Acknowledgement

The authors are grateful to Professor H. P. LUDIN, Neurological Clinic, Kantonsspital, St. Gallen, Switzerland, for his valuable comments on this paper.

References

ARMSTRONG, R. B., C. W. SAUBERT IV, H. J. SEEHERMAN, and C. R. TAYLOR, 1982: Distribution of fiber types in locomotory muscles of dogs. Am. J. Anat. **163**, 87—98.

BOWMAN, W. C., 1980: Pharmacology of neuromuscular function. John Wright & Sons Ltd., Bristol, pp. 71—121.

DESMEDT, J. E., 1973: The neuromuscular disorder in myasthenia gravis. I. Electrical and mechanical response to nerve stimulation in hand muscles. In: J. E. DESMEDT (Ed.), New Developments in Electromyography and Clinical Neurophysiology. Karger Verlag, Basel — München — Paris — London — New York — Sydney, Vol. I, pp. 241—303.

HECKMANN, R., 1989: Grundlagen und Methodik zu klinisch-neurophysiologischen Untersuchungen beim Hund. Enke Verlag, Stuttgart, pp. 215—237.

HECKMANN, R., R. S. JONES, and W. WUERSCH, 1977: A method for recording evoked electrical and mechanical activity of muscle in the intact dog. Res. Vet. Sci. **23**, 1—6.

KIMURA, J., 1983: Electrodiagnosis in diseases of nerve and muscle: Principles and practice. F. A. Davis, Philadelphia, pp. 189–206.

KRNJEVIC, K., and R. MILEDI, 1959: Presynaptic failure of neuromuscular propagation in rats. J. Physiol. (London) **149**, 1–22.

LENNON, V. A., E. H. LAMBERT, A. C. PALMER, J. G. CUNNINGHAM, and T. R. CHRISTIE, 1981: Acquired and congenital myasthenia gravis in dogs — a study of 20 cases. In: E. SATOYOSHI (Ed.), Myasthenia Gravis; Pathogenesis and Treatment. University of Tokyo Press, Tokyo, pp. 41–54.

LEWIS, D. M., and R. M. A. P. RIDGE, 1981: The anatomy and physiology of the motor unit. In: Sir J. WALTON (Ed.), Disorders of Voluntary Muscle. Churchill Livingstone, Edinburgh — London — New York, pp. 1–49.

LUDIN, H. P., 1988: Praktische Elektromyographie, 3. Ed. Enke Verlag, Stuttgart, pp. 46–47, 127–133, 170.

MALIK, R., S. HO, and D. B. CHURCH, 1989: A new method for recording and analysing evoked motor potentials from dogs. J. Small Anim. Pract. 30, 13–19.

MEIENBERG, O., und H. P. LUDIN, 1977: Das Treppenphänomen bei der Myasthenie und bei anderen neuromuskulären Erkrankungen. Z. EEG-EMG **8**, 192–194.

OH, S. J., 1988: Electromyography: Neuromuscular Transmission Studies. Williams & Wilkins, Baltimore — Hong Kong — London — Sydney, pp. 1–109.

ROWLERSON, A., F. MASCARELLO, A. VEGETTI, and E. CARPENE, 1983: The fibre-type composition of the first branchial arch muscles in carnivora and primates. J. Muscle Res. Cell Mot. **4**, 443–472.

SIMS, M. H., and R. A. MCLEAN, 1990: Use of repetitive nerve stimulation to assess neuromuscular function in dogs. Progr. Vet. Neurol. **1**, 311–319.

SLOMIC, A., A. ROSENFALCK, and F. BUCHTHAL, 1968: Electrical and mechanical responses of normal and myasthenic muscle. Brain Res. **10**, 1–78.

WIESTNER, TH., H. P. HOGG, R. HECKMANN, and M. K. WAXENBERGER, 1992: Instrumentation for simultaneous recording of compound muscle action potentials and related force in the dog. J. Vet. Med. A, in press.

ZAIMIS, E., and S. HEAD, 1976: Depolarizing neuromuscular blocking drugs. In: E. ZAIMIS (Ed.), Neuromuscular Junction. Springer-Verlag, Berlin — Heidelberg — New York, pp. 365–419.