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Original Research

Magnetic Motor Evoked Potential Recording in Horses Using Intramuscular Needle Electrodes and Surface Electrodes

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ABSTRACT

To date, motor evoked potential (MEP) recording in animals is often performed using intramuscular monopolar needle electrodes. Their placement and use has several disadvantages. Adhesive surface electrodes appear to be attractive because they are painless and easy to place. Because these are not used in horses, a scouting study is performed to (1) explore the applicability of surface electrodes in horses (2) determine the repeatability of motor latency times (MLTs) and amplitude measurements, and (3) to investigate if MLTs and amplitude values of surface electrode recordings were similar to intramuscular needle electrode recordings. Transcranial MEP recordings were performed by both coated needle and surface electrodes on ten sedated warmblood horses. Mean MLTs for the thoracic limbs were 20.8 ± 1.5 ms for needle and 21.2 ± 1.4 ms for surface electrode recording and 39.4 ± 3.8 ms and 39.2 ± 3.8 ms for the pelvic limbs, respectively. Mean amplitude values were 8.3 ± 4.1 and 7.2 ± 4.7 mV for the thoracic limbs and 4.2 ± 3.1 and 3.8 ± 2.4 mV for the pelvic limbs, respectively. A good agreement and repeatability for MLTs but insufficient agreement and repeatability for amplitude between both recording types were determined by Bland-Altman plots and Passing-Bablok regression and coefficients of variation calculation. In conclusion, this preliminary study shows that surface electrode recording of MEP is possible and well tolerated in horses. Surface recordings were repeatable and look similar to the intramuscular recordings when regarding MLTs, but overshadowing effects of large test-to-test variations precluded a conclusion concerning amplitude.

1. Introduction

To date, noninvasive diagnostic testing of the motor function of the spinal cord is performed by recording of muscular motor evoked potentials (MEPs) that are elicited by transcranial magnetic stimulation (TMS) or transcranial electrical stimulation (TES). Mayhew et al. introduced the TMS technique in horses and obtained extramuscular (EM) MEPs at the surface of the skin [1]. Extramuscular MEPs are compound muscle potentials that reflect the electrical activity of many motor neurons. Subcutaneous needle electrodes measure similar EM MEPs and are also applied in horses [2]. Surface electromyography (EMG) is a noninvasive technique to measure summed muscle activity of many motor neurons on the skin overlying a muscle or group of muscles [3,4] and is widely used to record compound muscle action potentials.

Alternately, the group of Nollet et al. recorded transcranial elicited intramuscular (IM) MEPs in horses by inserting insulated needle electrodes with uncoated tips in muscles [5–9]. Intramuscular MEPs result from a few single muscle fibers. Intramuscular needle electrodes are specifically useful for diagnostics on the peripheral motor neuron function but is, when compared to subcutaneous needle or surface electrodes, very painful and therefore a reason not to apply in children unless when strictly necessary [4]. When compared to EM MEPs, IM MEPs will have variable and different amplitudes and more polyphasic waves because the characteristics of only few lower motor neurons dominate the shape of the MEPs [10,11]. This means that surface and intramuscular electrodes are interchangeable for measuring motor latency times (MLTs).

Adhesive surface electrodes have successfully been used in electrocardiography (ECG) in horses as the alternative to alligator

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clips [12]. Alligator clips have also been used for MEP measurements with TMS [1]. Adhesive surface electrodes offer features like being painless for the horse, absence of stick injuries, no risk of iatrogenic infections, and being easy to apply.

To our knowledge, adhesive surface electrodes are not applied in horses for transcranial MEP recording and may be an attractive alternative for intramuscular needle electrodes for measurement of only MLTs. For this reason, the goal of this scouting study was to investigate the characteristics and applicability of surface electrodes for recording of MEPs that are elicited by TMS by comparing with intramuscular needle electrodes.

2. Material and Methods

2.1. Sample Size Calculations and Animals

Sample size was calculated using Win Episcope 2.0. The sample size was estimated based on MLTs (in milliseconds [ms]) because it is clinically the most decisive MEP parameter. With a standard deviation (SD) of 1.8 ms in the thoracic limbs and 2.8 ms in the pelvic limbs [5,13], 95% confidence and 80% power, 10 animals were required for a two-tailed test with paired samples.

Ten healthy horses (five mares and five geldings; seven warmbloods, one trotter, one Friesian, and one Andalusian), aged between 3 and 17 years, (mean ± SD 11 ± 5 years) were used. Their height ranged from 153 to 169 cm (mean ± SD 160 ± 5 cm) and their weight from 460 to 660 kg (mean ± SD 535 ± 67 kg). Only horses without abnormalities on neurological examination (normal behavior and mental status, head position and head movements, normal gait, posture, and coordination) were included in this study.

2.2. Magnetic Stimulation and MEP Recording

Each horse was sedated with a combination of detomidine (Domidine [Eurovet Animal Health, Bladel, The Netherlands], 10 μg/kg body weight) and butorphanol (Dolorex [MSD Animal Health, Boxmeer, The Netherlands], 10 μg/kg body weight). For each horse, magnetic motor evoked potential (mMEP) recording for IM needle and surface electrodes was done in one single sedation period. The test protocol started in five horses with IM needle electrodes and in the remaining five horses with surface electrodes.

A magnetic stimulator (Magstim 200) (The Magstim Company Ltd, Whitland, United Kingdom) and a round 70 mm coil were used to generate a maximal magnetic field of 4 Tesla at the coil surface. The coil was centered over the forehead and maximal stimulus intensity (100%) was applied [7]. A standard electromyograph (Medelec Sapphire) (Medelec Ltd, Surrey, United Kingdom.) recorded the muscle responses. For mMEP recording with needle electrodes, the procedure as described by Nollet et al. [7] was followed. The active electrode (25 mm monopolar, disposable, insulated, stainless steel needle) (TECA Corporation, Pleasantville, New York, USA.) was inserted at the middle of the tibialis cranialis (TC) muscle in the pelvic limbs and of the extensor carpi radialis (ECR) muscle in the thoracic limbs. The reference electrode was placed subcutaneously at the lateral side of the lateral malleolus of the tibia for the pelvic limb and at the lateral side of the radial tuberosity for the thoracic limb. Following the recommendation of Verheyen et al. [12] for recording of ECG on horses, Skintact FS50 (Skintact, Innsbruck, Austria.) adhesive surface electrodes were attached to the unclipped skin. The first electrode was placed, analogous to the needle electrode, at the middle of the TC muscle in the pelvic limbs and the ECR muscle in the thoracic limbs. The second electrode was placed at the central part of the distal tendon of the corresponding muscle (Fig. 1). For both recording types, the ground electrode was attached in the groin region while testing the pelvic limbs and in the elbow region while testing the thoracic limbs. For every limb, four sequential muscle responses were recorded starting with the left pelvic and the right pelvic limb followed by the left thoracic and finally the right thoracic limb. Thereafter, the test was immediately repeated with the other electrode type, resulting in 32 recordings per horse.

Of each elicited MEP, MLTs and amplitude were acquired as characterizing parameters. The MLT is defined as the time interval between the onsets of the TMS pulse and MEP wave and measured in millisecond (ms) units. The amplitude was measured as the difference between the largest peaks of opposite polarity and measured in millivolt (mV) units. After completion of the 32 MEP measurements per horse, the MEP parameters were analyzed from MEP curves on the screen. All curves were archived as printed screen copies. All measurements and MEP analysis were performed by one nonblinded operator.

2.3. Statistical Analysis

All responses were included for statistical analysis. Means, SD, minimum, maximum, mean difference, minimum difference, maximum difference, and 95% confidence intervals (CIs) of MLT and amplitude recording with both methods were calculated. To determine repeatability for both methods, the four responses per limb were superposed on the EMG screen and coefficients of variation (CV [%] = [SD]/mean × 100) were calculated on limb and estimated CVs (estimated CV = [1 + {4 * number of observation}$^{-1}$] × CV) on horse level. CV on limb level is the mean of the thoracic and pelvic limb CVs for each horse. CV on horse level was calculated using the minimum values for MLT and the maximum values for amplitude. The tests with the lowest CVs have the best repeatability.

Subsequently, Passing-Bablok regression was used to compare mMEP recording with both electrode types. This nonparametric test determines a regression equation ($Y = a + bX$) between recordings of the same subject with two recording methods, with Y being mMEP recording with surface electrodes and X recording with needle electrodes. No systematic differences are present if the 95% CI of the intercept (1) contained 0; no proportional differences are present if the 95% CI of the slope and (2) contained 1. Confirmation of a linear relationship between both methods was assessed with a cumulative sum control (CUSUM) test. All analyses were performed in Microsoft Excel 2016.

3. Results

In 10 horses, a total of 320 stimuli in the thoracic and pelvic limbs were done. All stimulations led to measurable responses. The needles were in general more difficult to place than the surface electrodes and lost their position occasionally (2-3 times per 16 stimuli) because of mild reactions (muscle trembling, moving of the limbs…) of the horses. During a test run with a series of four subsequent TMS stimuli, the change in electrode position was recognized by varying MEP wave forms starting with a typical intramuscular polyphasic morphology that sometimes transited into extramuscular MEP wave patterns resembling those of surface electrodes with a decreased number of phases. Fig. 2 shows a typical polyphasic intramuscular MEP (left) and a typical MEP of surface electrodes with a reduced number of phases (right). Surface electrodes did not dislodge during the four runs, and their superimposed MEPs showed good reproducible wave shapes when compared to the four runs superimposed IM MEPs, often showing large varying wave patterns.

Means, SD, minimum, maximum, 95% CI, and CV of MLT and MEP amplitude for both electrode types are shown in Table 1. For

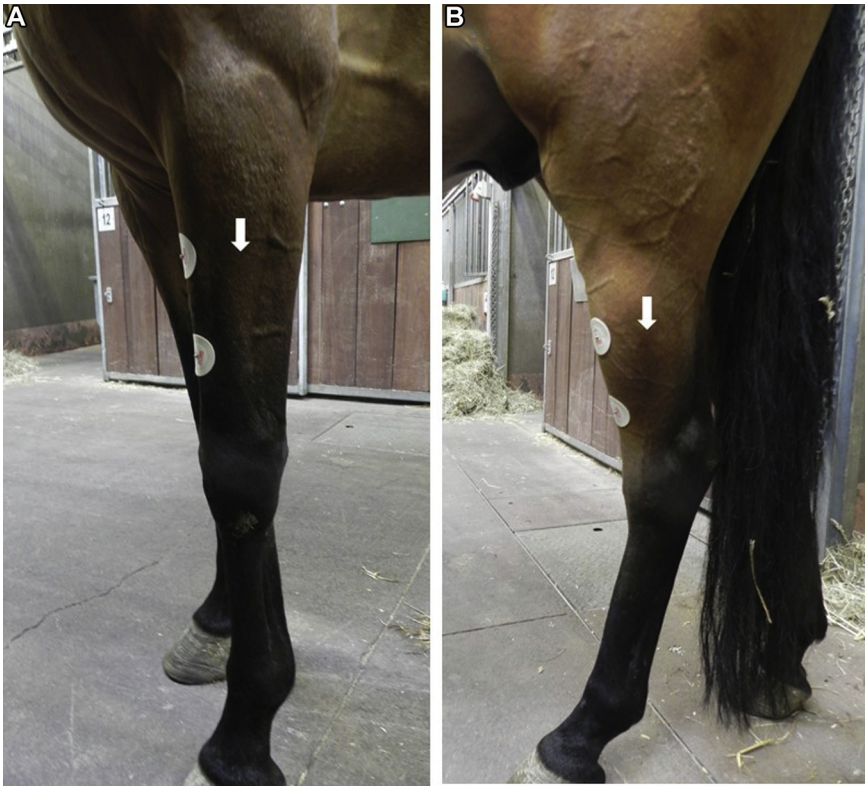

Fig. 1. Positioning of the surface electrodes in thoracic (A) and pelvic (B) limbs. The first needle electrode was placed at the level of the proximal surface electrode; the arrow indicates the position of the second needle electrode.

MLT, the mean difference between needle and surface electrode recordings was −0.4 ms (minimum −2.6 ms, maximum 2.7 ms) in the thoracic limbs and 0.1 ms (minimum −9.5 ms, maximum 6.5 ms) in the pelvic limbs. For MEP amplitude, these values were, respectively, 1.1 mV (minimum −11.6, maximum 14.7 mV) and 0.4 mV (minimum −9.1 mV, maximum 13.4 mV).

Fig. 3 and Table 2 show Passing-Bablok regression graphs and equations for MLT and MEP amplitude in the thoracic and pelvic limbs. No systematic or proportional differences between needle and surface electrode recording for MLT were present in the thoracic or pelvic limbs. For MEP amplitude, no systematic or proportional differences were present in the pelvic limbs, but there were systematic differences recorded in the thoracic limbs. For all recordings, except MEP amplitude in the pelvic limbs, CUSUM test confirmed linearity.

4. Discussion

Adhesive surface electrodes have successfully been used in ECG [12]. Their features invited us to introduce these in horses and use them for assessment of the motor function of spinal cord function using TMS. Currently, most TMS-MEP tests are performed in horses with intramuscular needle electrodes and used to diagnose impaired motor functions of the spinal cord in horses with clinical signs of impaired motor function, such as ataxia, muscle weakness, spasticity, dystonia, abnormal reflexes, and myopathy, resulting

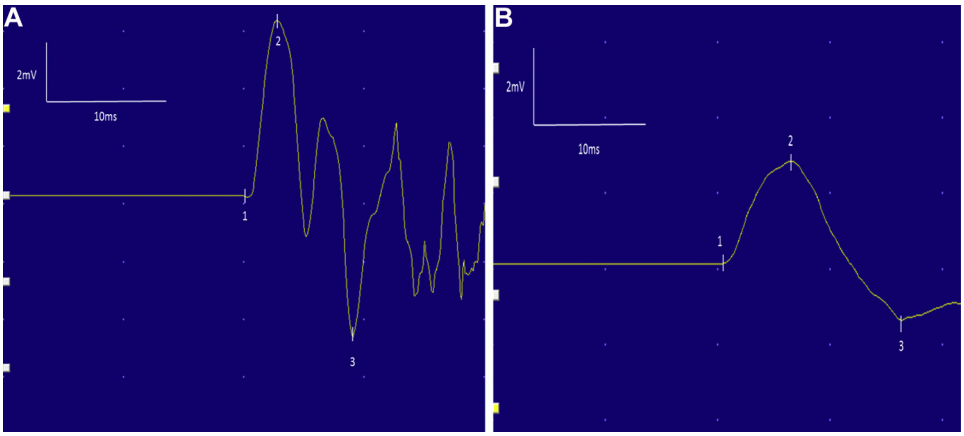

Fig. 2. Example of a mMEP recorded in the thoracic limb with needle electrodes (A) and surface electrodes (B). The time between Y-axis and number 1 reflects MLT; the amplitude is measured between numbers 2 and 3. MLT, motor latency time; mMEPs, magnetic motor evoked potentials.

Table 1
Comparison of MLT and MEP amplitude measurements with needle (MLT N and AMPL N) and surface (MLT S and AMPL S) electrodes.

Limb	MLT N (ms)		MLT S (ms)		AMPL N (mV)		AMPL S (mV)	
	Thoracic	Pelvic	Thoracic	Pelvic	Thoracic	Pelvic	Thoracic	Pelvic
Mean	20.8	39.4	21.2	39.2	8.3	4.2	7.2	3.8
SD	1.5	3.8	1.4	3.8	4.1	3.1	4.7	2.4
Minimum	17.4	33.8	17.3	34.3	0.4	0.2	1.1	0.8
Maximum	24.0	51.5	24.0	54	18.6	15.6	17.7	9.7
95% CI	20.5–21.1	38.5–40.2	20.9–21.5	38.4–40.1	7.4–9.2	3.5–4.9	6.1–8.3	3.3–4.4
Mean CV limb	3.0%	3.5%	3.2%	3.3%	35.0%	59.6%	32.6%	39.5%
SD of mean CV limb level	1.73%	1.68%	1.25%	2.59%	6.96%	12.65%	22.40%	12.71%
Estimated CV horse level	8.4%	9.0%	7.5%	7.9%	22.8%	23.8%	27.5%	28.5%

Abbreviations: AMPL N, amplitude recorded with needle electrodes; AMPL S, amplitude recorded with surface electrodes; MEP, motor evoked potential; CI, confidence interval; CV, coefficient of variation; MLT, motor latency time; MLT N, MLT recorded with needle electrodes; MLT S, MLT recorded with surface electrodes; SD, standard deviation.

from lesions in the spinal cord, brain stem, and brain [5,7–9]. The goal of this pilot study is to explore the features of the use of adhesive surface electrodes and to compare these with intramuscular electrodes.

The practical features of self-adhesive surface electrodes in ECG recordings in horses apply also to TMS. Self-adhesive electrodes are well tolerated, while clipping of the hair coat is generally not necessary or even discouraged [12]. The electrodes are painless, noninvasive, and easy to mount. All TMS stimuli resulted in detectable MEPs in all recorded muscle groups and did not dislodge. In contrast, the IM needle electrodes were in general more difficult to place and migrated from their location about 2–3 times per 16 stimuli due to elicited or spontaneous muscle movements and trembling of the horses. This could be explained by unequal displacements of the muscle and overlaying skin during contractions. Because IM needle electrodes are mechanically connected

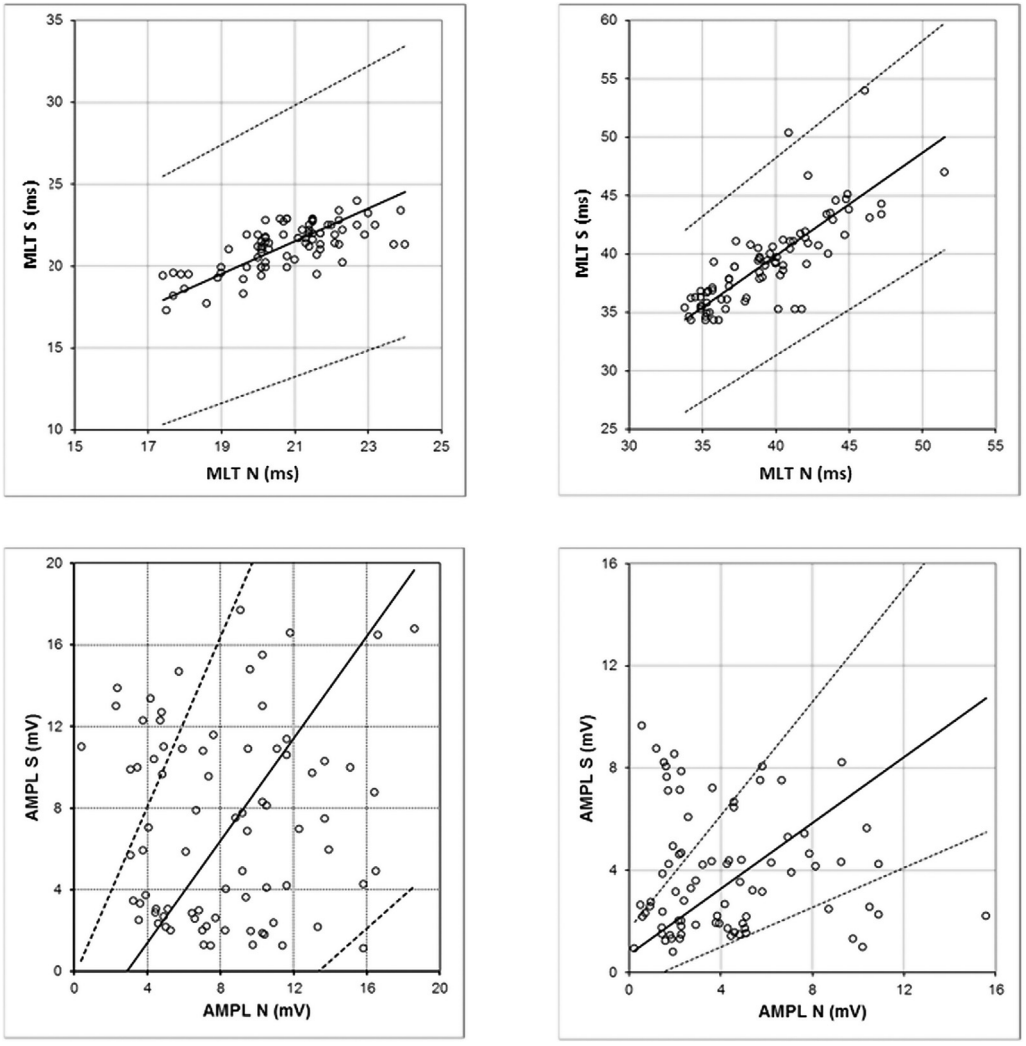

Fig. 3. Passing-Bablok plot with regression line (full line) and 95% confidence intervals (dotted lines) of MLT and amplitude recorded with surface electrodes (MLT S and AMPL S) and needle electrodes (MLT N and AMPL N) for thoracic limbs (left) and pelvic limbs (right). AMPL S, amplitude recorded with surface electrodes; MLT, motor latency time.

Table 2
Passing-Bablok regression equation with 95% confidence interval for intercept and slope and *P*-values for CUSUM test for MLT and amplitude in thoracic and pelvic limbs.

Parameter	Thoracic/Pelvic limbs	Regression	95% CI Intercept	95% CI Slope	*P*-value, CUSUM
MLT	Thoracic	MLT S = 0.6 + 1.0 MLT N	−3.7; 4.6	0.8; 1.2	.80
	Pelvic	MLT S = 4.5 + 0.9 MLT N	−0.1; 8.2	0.8; 1.0	.80
Amplitude	Thoracic	AMPL S = −3.6 + 1.3 AMPL N	−10.7; −0.2	0.8; 2.1	.80
	Pelvic	AMPL S = 0.7 + 0.6 AMPL N	−0.5; 1.7	0.4; 1.1	.20

Abbreviations: AMPL N, amplitude recorded with needle electrodes; AMPL S, amplitude recorded with surface electrodes; CI, confidence interval; CUSUM, cumulative sum control; MLT, motor latency time; MLT N, MLT recorded with needle electrodes; MLT S, MLT recorded with surface electrodes.

with both tissues, large muscle excursions may cause gradual electrode dislocations. When not sedated, inserting IM electrodes in muscles can be very painful [4]. The mechanical disturbance from inserting the electrode in the muscle may also affect the mechanical receptors in afferents of extrafusal fibers initiating spinal reflexes and may cause muscle trembling. Based on the fact that the horses reacted less on the placement of the surface electrodes when compared to IM needle electrode placement, it can be stated that the first are better tolerated.

In this study, the characteristics of IM MEPs are compared with MEPs from surface electrodes. This implies an important limitation on the setup of the present study. Surface electrodes and intramuscular needle electrodes belong to different classes of, respectively, EM end intramuscular EMG recording. The EM class embraces electrode locations outside muscles: on the skin and subcutaneous. Comprised are electrode types on the skin such as surface and alligator clip electrodes and subcutaneous electrodes at the subcutaneous level. Insulated needle electrodes with uncoated tips belong to the IM class. IM needle electrodes are sensitive for the electrical activity of muscle fibers of only a few motor neurons [10]. These are predominantly used to evaluate the lower motor unit function. This means that in transcranial stimulation, IM MEPs only sense a relative small fraction of all activated motor neurons. A typical polyphasic MEP wave from TMS as recorded by a coated IM electrode is shown in Fig. 2A. EMG electrodes of the EM class are sensitive to the electrical activity of many muscle fibers of a whole muscle, sometimes extending to neighbor muscles [3,14]. In the bipolar arrangement, EM electrodes measure the sum of action potentials representing the whole muscle activity and even of neighbor muscles [11]. The specific motor unit potentials subside due to phase cancelation of action potentials of individual muscle fibers. Intramuscular recordings have a higher number of turns and higher frequencies than surface electrode recordings [15]. A typical EM MEP wave form as obtained from the surface electrode is shown in Fig. 2B. The number of phases is clearly reduced compared to Fig. 2A.

One shortcoming in the setup of this study is that a comparison between MEPs from surface and intramuscular electrodes not specific looks at different characteristics of electrode types only. Characteristics from both electrode classes are also included. This complicates a comparison. The electrode location predicts differences in MEP wave shape and amplitude, while MLTs are expected to be about the equal to each other. The EM-IM bias between classes would be eliminated when electrodes in the same class are compared. A comparison of surface electrodes with subcutaneous needle electrodes, both belonging to the EM class, would be more appropriate. Their EMGs of spontaneous activity and wave shapes of MEPs are highly coherent, which is not the case with IM coated needle electrode EMGs [16].

4.1. Comparison of MLTs

It was hypothesized that when nerve action potentials arrive synchronous at neuromuscular zones, EM and IM MLTs are statistically equal to each other. According to Table 1, this study shows an agreement between MLTs with coated IM needle and surface electrodes in horses when looking to overall means. Table 1 shows largely overlapping MLTs for surface and IM needle electrodes for the ECR: 20.8 ± 1.5 ms and 21.2 ± 1.4 ms and for TC: 39.4 ± 3.8 ms and 39.2 ± 3.8 ms. The mean values of both electrode types show no statistical differences. The overall differences of 0.2 and 0.4 ms support the hypothesis that MLTs from surface and the IM needle electrodes are equal to each other. The low CVs indicated good and acceptable intraindividual (within horses) and interindividual (between horses) reproducibility of repeated MEP measurements for each electrode type on the thoracic and pelvic limb muscles. Furthermore, no systematic or proportional differences between needle and surface electrode recording were found using Passing-Bablok regression.

The literature provides normal data for MLTs for EM and intramuscular MEPs that support our data. Mayhew et al started at first in 1996 with EM EMG recording on the skin surface using alligator clips [1] and assessed 10 healthy ponies with TMS. Mean MLTs and SD were for the ECR: 19.0 ± 2.3 ms and for the TC: 30.2 ± 3.4 ms. MLTs of subdermal needle electrodes in 12 healthy horses using TES were for left and right ECR: 20.8 ± 1.85 ms and 19.7 ± 1.69 ms and TC: 34.6 ± 2.01 and 34.9 ± 1.69 ms [2]. The group of Nollet et al. measured TMS-MEPs with IM needle electrodes. One article reveals in 12 healthy horses MLTs for the left and right ECR: 20.81 ± 1.85 ms and 20.59 ± 1.83 and for TC: 35.94 ± 3.43 and 36.33 ± 3.53 [5]. Another study of this group on 84 horses reveals MLTs for the ECR: 19.32 ± 2.5 ms and for the TC: 30.54 ± 5.28 ms [7]. This last mean MLT value is 4–6 ms lower than in their other study and also in the other two EM MEP studies [1,2]. However, the mean MLT values for the pelvic muscles in our study are even 4–9 ms higher than IM MLTs of the group of Nollet. This cannot be explained by differences in height of included horse groups [7]. The higher means are explained by about 15% of the points in the upper right scatter plot of the pelvic limb, which exceed the range of normal values of all referred articles. These values comply with data of two horses with bilateral hind limb ataxia showing only slightly prolonged MLTs near the 95% CI of normal values [9]. Because no myelograms are available, a subclinical myelopathy cannot be excluded in a few horses in this study.

Individual differences of MLTs between the two electrode types are visualized in the scatter diagrams of the MLTs of the thoracic and pelvic limbs. The width of the point clouds around the Passing-Bablok regression lines (parameters are listed in Table 2) indicates the variation between MLTs of the two electrode types. The variation in the upper left plot of the thoracic muscles is about ± 3 ms and in the upper right plot of the pelvic muscles is, except for 2 outliers, about ± 5 ms. When including all points, the range of differences for the pelvic muscle group is 2.6–9.9 ms. These are high values and essentially different from literature data where simultaneous measured MEPs of both electrodes are assessed. MLT differences between intramuscular and surface electrodes are one magnitude lower in a submillisecond range [17]. The variations of our study mainly reflect test-to-test variations of MLTs due to spontaneous varying spinal facilitation that modulate motor neuron membrane potentials. When increasing the facilitation, the

MLT of TMS-MEPs of striated muscles of both surface and IM electrode types, the MLTs decrease by 2–3 ms [18,19]. Repositioning of the magnetic coil may also contribute to test-to-test variations [18,20]. It is concluded that the setup of this study is insufficient to assess MLT differences of transcranial elicited MEPs between intramuscular and surface electrodes individually due to the overshadowing by relative large test-to-test variations.

4.2. Comparison of MEP Amplitudes

Table 1 shows a large overlap of the 95% CI of the MEP amplitudes of IM needle and surface electrodes for the thoracic limb muscles of, respectively, 7.4–9.2 and 6.1–8.3 mV and for the pelvic limb muscles 3.5–4.9 and 3.3–4.4 mV. The maximum differences ranged from −9.1 to 14.7 mV. The mean amplitudes of both electrode types are statistically not different. The high CVs and high SD values express high intraindividual test-to-test variations of muscle MEP amplitudes and interindividual differences between horses. High test-to-test variations are also reported in transcranial MEP studies in horses [2,5,6,9,13]. Individual differences of MEP amplitudes between the two electrode types are visualized in the scatter diagrams of the thoracic and pelvic limbs in Fig. 3. The widespread point clouds of the plots at the bottom in around the Passing-Bablok regression lines (parameters are listed in Table 2) indicate the large variation between MLTs of the two electrode types. The variation is dominated by the test-to-test amplitude variations. These are responsible for the wide scatter in the plots of the MEP amplitudes of the surface and IM needle electrodes. A linear relationship is ruled out in the CUMSUM test. However, the dominating high test-to-test variations mask any possible relationship between amplitudes of alternate recorded MEPs from IM needle and surface electrodes. Also here, it is concluded that the setup of this study, that is based on sequential comparison, precludes assessment amplitude differences of transcranial MEPs between IM and surface electrodes due to the overshadowing by relative large test-to-test variations. It is therefore impossible to check the hypothesis that MLT differences of both electrode types are equal to each other and that MEP amplitudes probably are unrelated. Test-to-test influences can be ruled out in a study setup that is based on pairwise comparison on simultaneous recorded MEPs of both electrode types.

In human, the impedance of surface electrodes is usually higher than needle electrodes. High impedances may increase the background noise which may mask small sMEPs (mMEPs recorded with surface electrodes) in deteriorated spinal cord functions. Interposed unclipped hair could possibly augment the impedance of surface electrodes. The range of sMEP amplitudes of normal horses is in a range of 1 to over 10 mV. This is large enough which means that surface electrode impedances are not of a concern. A remaining unanswered question is how critical the impedance is for detectability of small sMEPs in elevated background noise at spinal cord lesions.

4.3. Recapitulation

This pilot study indicates that surface and intramuscular insulated IM electrodes both are useful to assess the motor function of the spinal cord by assuming the MLT as a most important diagnostic parameter. The very small differences between the mean values of MLTs of both electrode types support the hypothesis that both electrode types deliver equal latency times. However, sensitivity to the test-to-test variations of the used study method precludes the possibility to precisely quantify the difference between MLTs of pairwise recorded transcranial MEPs at each test. This should be elaborated in a subsequent study with simultaneous MEP recording by the two electrode types placed on the same locations on the skin and intramuscular. When the differences per stimulus are indeed within a submilliseconds size, then IM needle electrodes and surface electrodes can be interchanged while normative data of MLTs can be shared by both electrode types. Besides practical features of easy, noninvasive and painless placement, surface electrodes sense larger portions of activated motor neurons while the sensitivity for individual motor units that harbor lower motor neuron system functions, for which IM electrodes are designed, is suppressed [16]. This is in favor for the selectivity and sensitivity for spinal motor function.

4.4. Limitations of the Study

1. Test-to-test variations of MLT and MEP amplitudes mask true within single test differences of MLT and MEP amplitudes between electrode types due to sequential comparison. These variations could be excluded by pairwise comparison of simultaneous recorded MEPs of both electrode types.
2. Specific characteristics of electrode types are intermingled with the recording properties from EM and intramuscular locations. Comparison with subdermal needle electrodes would more specifically expose the qualities of adhesive surface electrodes.
3. Lack of knowledge of noise levels from unknown impedances of surface electrodes leaves an open question on detectability of small MEPs in impaired motor functions of the spinal cord in comparison with concurrent needle electrodes.
4. Nonblinded data assessment by one observer.

5. Conclusion

This preliminary study indicates that the adhesive surface electrodes add a value in equine neurology studies. Besides practical features as easy placement, painless and noninvasive, they do not dislodge during muscle movements and are sensitive for a large portion of activated motor neurons. The study shows that mean values of MLTs from surface and IM coated needle electrodes are equal to each other while thoracic limb MLTs comply with normal data of MEPs from EM and IM MEPs in the literature. A supplementary study based on simultaneous recording sMEPs and IM MEPs and pairwise comparison is necessary for appropriate validation of MLT and amplitude differences within individual tests.

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