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Review

The potential and limitations of quantitative electromyography in equine medicine

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ABSTRACT

This review discusses the scope of using (quantitative) electromyography (EMG) in diagnosing myopathies and neuropathies in equine patients. In human medicine, many EMG methods are available for the diagnosis, pathophysiological description and evaluation, monitoring, or rehabilitation of patients, and some of these techniques have also been applied to horses. EMG results are usually combined with other neurophysiological data, ultrasound, histochemistry, biochemistry of muscle biopsies, and clinical signs in order to provide a complete picture of the condition and its clinical course. EMG technology is commonly used in human medicine and has been subject to constant development and refinement since its introduction in 1929, but the usefulness of the technique in equine medicine is not yet widely acknowledged. The possibilities and limitations of some EMG applications for equine use are discussed.

Introduction

Since the first concentric needle electrode was constructed in 1929, electromyography (EMG) has been developed extensively and used for a variety of clinical and experimental studies. The first publications on its use in humans were on myasthenia gravis and neuropathies in 1941, followed by myopathies in 1949 (Stålberg and Falck, 1997). Professor Fritz Buchthal (1907–2003) and his colleagues played an important role in the development of quantitative EMG (QEMG); these early analyses were performed manually and examined the influence of age and muscle on motor unit action potential (MUP) parameters (Fig. 1), as well as the effect of batches of needles, temperatures, and many other technical and physiological factors. In addition to the shape of an MUP, the sound produced by MUP activity and pathological spontaneous activity was evaluated (Buchthal et al., 1954; Buchthal and Rosenfalck, 1955). This pioneering group also reported on topics such as the diagnostic significance of EMG in myopathies and neuropathies (Buchthal and Pinelli, 1952, 1953; Pinelli and Buchthal, 1953a and b; Buchthal, 1970).

In the 1970s, the effect of muscle effort on MUPs in healthy, myopathic, and neuropathic patients was studied by Professor Anders Fuglsang-Frederiksen and his group at Aarhus University (Fuglsang-Frederiksen and Mansson, 1975; Fuglsang-Frederiksen et al., 1976, 1977, 1984; Fuglsang-Frederiksen, 1981; Fuglsang-Frederiksen and Rønager, 1988). Computer technologies enabled the use of automatic analysis techniques such as peak-ratio interference pattern analysis and amplitude-turn analysis in insertional analysis (Finsterer et al., 1997; Finsterer and Fuglsang-Frederiksen, 2003). These researchers also developed the application of concentric needle EMG in healthy humans and in patients with neuromuscular disease. Fuglsang-Frederiksen is still active

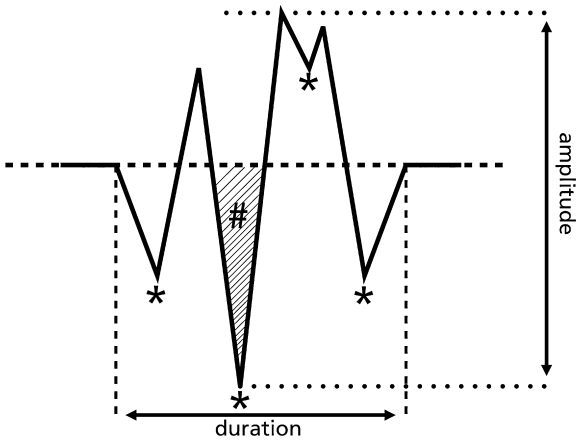

Fig. 1. # represents a phase, * represents a turn. The figure shows seven turns and five phases (for definitions see text).

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in the field, as illustrated by his recent reviews on the role of different EMG methods in evaluating myopathy (Fuglsang-Frederiksen, 2006) and on the current status of electrodiagnostic standards and guidelines in neuromuscular disorders (Fuglsang-Frederiksen and Pugdahl, 2011).

The works of Nandedkar (2008) but especially those of Professor Erik Stålberg from Uppsala University have dominated the clinical literature on applications of EMG since the 1980s and 1990s (Stålberg et al., 1996, 1999, 2000, 2013; Stålberg and Erdem, 2002; Stålberg, 2004). Stålberg developed single-fibre EMG (SFEMG) (Schwartz and Stålberg, 1975; Stålberg and Sanders, 2009; Stålberg, 2010; Tankisi et al., 2012) to study neuromuscular transmission using a needle that only records the activity of a single muscle fibre during spontaneous contraction or after electrical stimulation. In addition, SFEMG appears to be helpful in studying lower motor neuron disorders and a variety of peripheral nerve system disorders through the assessment of patterns of re-innervation (Kimura, 2001a and b).

Since the late 1970s, there have been reports from small-animal and equine medicine on topics such as EMG and nerve conduction in dogs with brachial plexus injuries (Steinberg, 1979) and neuropathies (Cooper et al., 1984). Earlier reviews have been published on EMG or nerve conduction on dogs (Farnbach, 1979, 1980) and horses (Andrews and Fenner, 1987; Wijnberg et al., 2003c; Wijnberg, 2005). Moore et al. (1988) were the first to describe EMG as a tool for evaluating laryngeal hemiplegia, which was followed by latency studies (Cook and Thalhammer, 1991; Hawe et al., 2001), but it took until 2013 for another report to appear on the use of EMG to study laryngeal musculature (Westermann and Wijnberg, 2013).

Clearly, the research and development of EMG has been very limited in equine medicine compared with human medicine. The understanding of human neuromuscular disorders has improved greatly thanks to the contribution of several EMG techniques. The marked difference in progress between the two species will be discussed in this review, focusing on quantitative needle EMG, its applications in man, and its possibilities and limitations for use in the horse (for earlier reviews, see Wijnberg et al., 2003c; Wijnberg, 2005, 2012).

The motor unit

The focus of interest in EMG is the motor unit (MU) and its individual constituents, such as the alpha motor neuron, its axon, the motor endplates, and concomitant muscle fibres. The summated MUPs of individual muscle fibre action potentials (APs) within the pickup area of the needle electrode contribute to the overall MUP. The size of the MU varies within muscles. In general, the smaller MUs are recruited at low force and larger MUs at higher force, meaning that smaller MUs containing slow twitch fibre types (I) are recruited before the larger MU containing fast twitch (II) fibre types, according to the so-called size principle.

Muscle fibres vary in diameter depending on the muscle involved, training status, age and gender (Stålberg and Daube, 2003). All fibres within an MU are activated synchronously, and in humans APs are propagated with a velocity of 1.5–6.5 m/s. The velocity is influenced by temperature, fatigue, and fibre diameter. In horses no data exist on the number of MUs in different muscles or on the number of muscle fibres per muscle. The variation in humans is from nine fibres per MU in the extrinsic eye muscles to 2000 in the gastrocnemius muscle (Stålberg and Falck, 1997). In neuromuscular disease, the random scattering of the MUs in a certain area is altered, leading to alterations in the EMG signals, since MU structure and electrophysiological events are closely related (Stålberg and Falck, 1997).

The shape of an MUP in mammals is characterised by amplitude, duration, number of turns, and number of phases (Fig. 1, Appendix: Supplementary Table S1) (Cuddon, 2002; Wijnberg et al., 2002c; Stålberg, 2003; Daube and Rubin, 2009). Amplitude is determined by muscle fibre diameter, whereas duration, turns, and phases are related to the conduction time differences (temporal dispersion) between individual APs of the MU and, therefore, to muscle fibre AP velocity. Other parameters are MUP area and size index. MUP area is calculated automatically as is size index using EMG software and the formula $2 \times \log(\text{amplitude}) + \text{area}/\text{amplitude}$. A satellite potential is a late component of the MUP and can be recorded in both normal and pathological muscles (Kimura, 2001b).

Needle EMG can be used to study the MU and has the advantage over more classical methods (based on histochemical and biomechanical characteristics) to study muscle fibres in that it can assess multiple muscles and areas of the muscle in a relatively non-invasive manner. Alterations in microphysiology, muscle fibre composition, and interstitial tissue in both nerve and muscle disorders result in changes in the electrical signals generated by the MU. This allows assessment of the type of structural alterations of the MU in individual muscles and the distribution of the abnormalities (e.g., localised, multifocal, or generalised). In addition to identifying a lesion and its location, EMG has proved to be useful in following the progression and/or healing of neuromuscular disease (Stålberg et al., 1996, 2000; Stålberg and Falck, 1997; Cuddon, 2002; Stålberg and Daube, 2003; Fuglsang-Frederiksen, 2006; Lacombe and Andrews, 2008).

EMG electrodes

MU activity is generated by the alpha motor neuron, its axon, the motor endplates, and the muscle fibres that are innervated by the MU. This functional unit can be examined using different EMG methods (Stålberg and Falck, 1997). The uptake area of the electrical activity generated by the MU largely depends on the electrode type and size (pickup area). Single-fibre recordings use a specialised very small recording surface, permitting the measurement of electrical activity of one muscle fibre. Surface EMG records activity from a large part of a muscle or neighbouring muscle and is therefore used more often in anatomical studies or rehabilitation programmes than in the diagnosis of neuromuscular diseases (Franssen, 1995a, 1995b, 1995c; Stålberg and Falck, 1997; Daube and Rubin, 2009) and will therefore not be discussed in this review.

Selecting the type of electrode used in EMG depends on the indication. In needle EMG, the concentric needle is used most commonly because it records with minimum interference from surrounding muscles, has a fixed-size recording surface with the cannula serving as the reference electrode (Stålberg and Falck, 1997), and data are available as reference values, which are extensive for humans (Daube and Rubin, 2009) but limited for horses. Concentric needles are routinely used in both humans and horses for the diagnosis of neuromuscular disease. Needle size varies and with it the pickup area of the recording surface, which potentially influences reference values (Stålberg et al., 1996; Wijnberg et al., 2003c). The concentric needle electrode measures about 30–50 muscle fibres of an MU (Wijnberg et al., 2003c) and the pickup area of needles used in equine studies is 0.068 mm^2 (Wijnberg et al., 2002b and d). The MUP is the sum of potentials of individual muscle fibres innervated by a single lower motor neuron that are near the recording electrode.

Monopolar needles have a conical recording surface of 0.25-mm diameter, and two are needed for a recording. The pickup area is larger, and the variability in the distance between the two recording electrodes makes it less convenient. In equine medicine, monopolar needle use has been limited although they have been used to apply *Clostridium botulinum* toxin in several studies on stringhalt (Wijnberg et al., 2009b), in pilot studies on botulinum toxin used