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Comparison of the duration and power spectral changes of monopolar and bipolar M waves caused by alterations in muscle fibre conduction velocity

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The muscle compound action potential (M wave) recorded under monopolar configuration reflects both the propagation of the action potentials along the muscle fibres and their extinction at the tendon. M waves recorded under a bipolar configuration contain less cross talk and noise than monopolar M waves, but they do not contain the entire informative content of the propagating potential. The objective of this study was to compare the effect of changes in muscle fibre conduction velocity (MFCV) on monopolar and bipolar M waves and how this effect depends on the distance between the recording electrodes and tendon. The study was based on a simulation approach and on an experimental investigation of the characteristics of surface M waves evoked in the vastus lateralis during 4-s step-wise isometric contractions in knee extension at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% MVC. The peak-to-peak duration (Durpp) and median frequency (Fmedian) of the M waves were calculated. For monopolar M waves, changes in Durpp and Fmedian produced by MFCV depended on the distance from the electrode to the tendon, whereas, for bipolar M waves, changes in Durpp and Fmedian were largely independent of the electrode-to-tendon distance. When the distance between the detection point and tendon lay between approximately 15 and 40 mm, changes in Durpp of bipolar M waves were more pronounced than those of distal monopolar M waves but less marked than those of proximal monopolar M waves, and the opposite occurred for Fmedian. Since, for bipolar M waves, changes in duration and power spectral features produced by alterations in MFCV are not influenced by the electrode-to-tendon distance, the bipolar electrode configuration is a preferable choice over monopolar arrangements to estimate changes in conduction velocity.

1. Introduction

The muscle compound action potential (M wave) has been widely used as an indirect measure of sarcolemmal excitability (Sejersted and Sjøgaard, 2000; Nielsen and Clausen, 2000) and also to estimate muscle fibre conduction velocity (MFCV) (Cupido et al., 1996). In the overwhelming majority of cases, the M wave is recorded using the classical bipolar configuration, which means that it is obtained by subtracting the monopolar contributions of the proximal and distal electrodes (from now on referred to as proximal monopolar M wave and distal monopolar M wave, respectively, see Fig. 1). The monopolar configuration is rarely used in physiology experiments due to its sensitivity to common mode signal (Merletti and Hermens, 2004). However, the signal-to-noise ratio of monopolar M waves has been demonstrated to be acceptable if the indifferent electrode is adequately placed in a non-conduction portion of the body (Tucker and Türker, 2005). The major advantage of monopolar signals is that they contain the entire information available from the detected signal. This means that the monopolar M wave is the "genuine" representation of the electrical potential generated by the muscle.

Estimation of conduction velocity of muscle fibres is highly valuable in the context of clinical neurophysiology. Algorithms for calculation of MFCV, however, are not normally incorporated in commercial EMG equipment and their use is normally restricted to research purposes. M waves provide an alternative, yet approximate, method to estimate changes in MFCV which is based on the dependence of the M-wave time course on the velocity of propagation of action potentials along the fibres (Cupido et al.,

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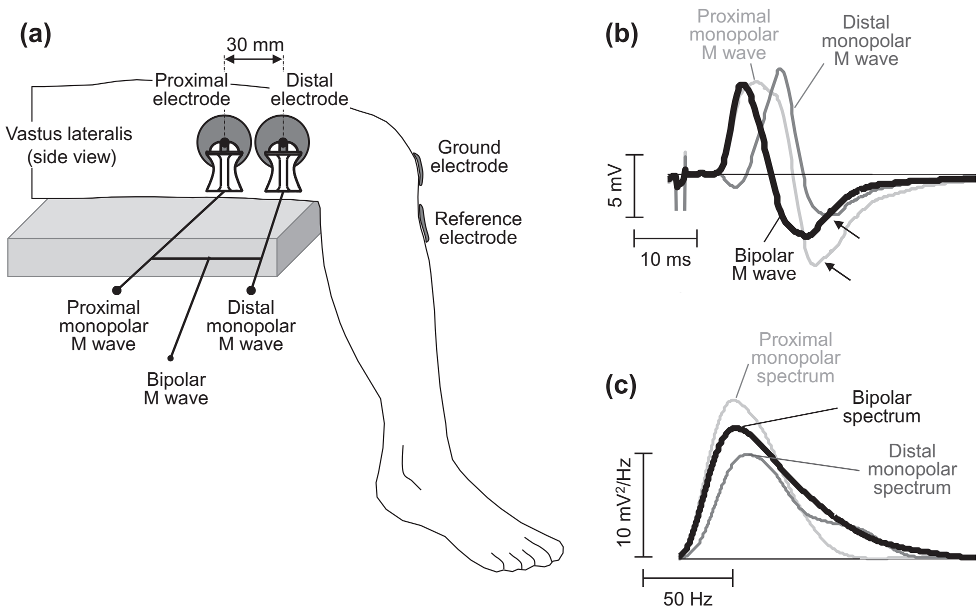

Fig. 1. (a) Schematic representation of the electrode configuration adopted to record the monopolar and bipolar M waves and to estimate muscle fibre conduction velocity in the vastus lateralis muscle. Proximal and distal electrodes were aligned with the muscle fibre direction. Note that the components in the diagram are not to scale. (b) Representative example of the bipolar M wave obtained by subtracting the distal monopolar M wave from the proximal monopolar M wave in one subject. The arrows mark the extinction of the action potential at the tendon. (c) Typical examples of the power spectra corresponding to the proximal monopolar M wave, distal monopolar M wave, and bipolar M wave.

1996; Linnamo et al., 2001). Estimation of changes in MFCV on the basis of the duration of the M wave is rather straightforward because it can be done easily by visual inspection of the M-wave shape (Linnamo et al., 2001). However, the physiological meaning of the duration parameter is completely different for M waves recorded under monopolar and bipolar configurations, as explained next. Therefore, it is of interest to ascertain whether, when a change in conduction velocity occurs, the associated changes in the duration of bipolar M waves are comparable to those observed in monopolar M waves.

In monopolar M waves, the first (negative) phase reflects the propagation of the muscle fibres' action potentials below the recording electrode, whereas the final (positive) phase corresponds to the extinction of these action potentials at the tendon (see Fig. 1b). Thus, for a monopolar M wave, the time interval between the negative and final peaks (from now on referred to as Durpp) provides an estimation of the average time of propagation from the electrode to the tendon. For bipolar M waves, there is a widespread assumption that the first and final phases are generated by the passing of the action potentials below the proximal and distal electrodes, respectively. However, this general belief is not correct (Rodriguez-Falces and Place, 2014), which means that, for bipolar M waves, Durpp does not correspond to the average time of propagation from the proximal to the distal electrodes (see Fig. 1b). Changes in conduction velocity are easily recognised in the M-wave time course as they result in distinct alterations of Durpp (Linnamo et al., 2001). However, in view of the different formation of monopolar and bipolar M waves, a question arises as to how a given change in MFCV is reflected in the Durpp of bipolar M waves as compared to that of monopolar M waves. In other words, when MFCV is altered, are the associated changes in bipolar M-wave Durpp overestimated or underestimated as compared to those of monopolar M-wave Durpp?

Differences in the way monopolar and bipolar M waves are affected by changes in MFCV are not only manifested in the temporal domain, but they are also reflected on their power spectrum features. It is well known that monopolar signals contain non-propagating components that arise from the extinction of the action potentials at the tendon ending (Gydikov and Kosarov, 1972; Gydikov and Trayanova, 1986). These end-of-fibre signals contain higher frequency components than the propagating components (Gydikov and Trayanova, 1986). In bipolar EMG recordings, the non-propagating components are partially or completely eliminated [for details, see Falces et al. (2005) and Rodriguez-Falces and Place (2014)]. However, the system formed by the single differential detection system acts as a raised-cosine filter (with a "hump-like" frequency response) which can enhance the power of the high-frequency range of the spectrum (Zipp, 1978). Consequently, it is difficult to predict how the spectral indicators of bipolar M waves would be in relation to those of monopolar M waves (Fig. 1c). It is well established that muscle conduction velocity has a scaling effect on the EMG power spectrum (Lindström and Magnusson, 1977; Stulen and DeLuca, 1981). However, in a scenario where MFCV varies, it is not clear whether the associated power spectral changes would be comparable for monopolar and bipolar M waves. Therefore, it seems necessary to compare the sensitivity of monopolar and bipolar M-wave spectral characteristics to changes in MFCV.

The objectives of the present study were: (1) to examine possible differences in how monopolar and bipolar M waves are affected by changes in MFCV, (2) to investigate how the effect of MFCV on monopolar and bipolar M waves depends on the distance between the recording electrodes and the tendon, and (3) to determine how the peaks of the bipolar M wave are formed as a function of the proximal monopolar and distal monopolar M waves. The comparison between the responses of monopolar and bipolar M waves to changes in MFCV was performed using both simulation and experimental procedures. As mentioned above, monopolar M-waves contain the entire informative content of the propagating potential and so it is expected that changes in MFCV will result in distinct alterations in the time-course of these M waves. The rationale of this study is to determine whether the changes in bipolar M waves consequent upon alterations in MFCV are similar to those predicted in monopolar M waves.