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Non-Uniform Changes in Muscle Fiber Conduction Velocity during Sustained Isometric Contraction of the Vastus Medialis Muscle

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Abstract

Muscle fiber conduction velocity (MFCV) decreases during sustained fatiguing contraction due to metabolic accumulation. Differences in morphological and architectural characteristics of muscle fibers within the vastus medialis muscle may result in non-uniform metabolites accumulation and as consequence non-uniform changes in fiber conduction velocity. The aim of this study was to assess muscle fiber conduction velocity at the level of single motor unit in different locations of the vastus medialis muscle during sustained contraction. Surface and intramuscular EMG signals were recorded from two locations of the right vastus medialis muscle of ten healthy men during 70s isometric contraction at 20% of the maximal force. The distal location of the vastus medialis muscle resulted in a larger value of conduction velocity ($p < 0.05$) and greater conduction velocity rate of reduction ($p < 0.05$) during sustained contraction compared with the proximal region. These results indicated a non-uniform change in electrophysiological membrane properties at different locations of the vastus medialis muscle during sustained contraction.

Keywords: conduction velocity, fatigue, muscle locations

Introduction

Muscle fiber conduction velocity (MFCV) decreases during sustained fatiguing contraction due to metabolic accumulation [1, 2, 3]. The resting membrane potential of skeletal muscle fiber is largely potassium [K^+]-dependent potential [4]. During sustained fatiguing contractions, an increase in metabolic accumulation reduces pH of the extra-cellular environment and increases K^+ permeability in the muscle fiber membrane as a consequence of stimulation of the ATP-dependent and/or Ca^{2+}-dependent K^+ channels [1]. Increased extra-cellular K^+ results in sarcolemma and T tubular depolarization, which in turn increases the excitation threshold and reduces the action potential amplitude and conduction velocity [2, 3].

The extent of muscle fatigue during a sustained muscle contraction is depended on the morphological characteristics of muscle fiber within the skeletal muscle [5]. Vastus medialis muscle as medial component of the quadriceps is characterized by varying fiber pennation angles and fiber-type composition, in the distal relative to the proximal regions [6, 7]. Thus different locations of the vastus medialis muscle may experience a non-uniform muscle activity and, as a consequence, non- uniform metabolic by-production during a sustained contraction. A non-uniform production of the metabolites within the vastus medialis muscle would be expected to result in non-uniform alterations in fiber membrane properties and thus conduction velocity during sustained contraction. This information could be helpful to understand further aspects of the muscle fiber adaptation to exercise within the skeletal gross muscle. However, analyzing muscle fiber membrane properties at different locations of the skeletal gross muscle has received little attention. Therefore, the purpose of this study was to assess single motor unit conduction velocity at different locations of the vastus medialis muscle.

Methods

Participants

Ten healthy men (age, mean ± SD, 24 ± 6.4 yr, body mass 71.4 ± 4.6 kg, height 1.78 ± 0.04 m) participated in the study. All the participants were right leg dominant, without history of knee injury. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee. Participants provided informed

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written consent before participation in the study.

Procedure

MVC was measured using the KinCom dynamometer (Chattanooga, TN, USA).

Volunteers were asked to sat comfortably on chair fixed with a belt at the hip with the right knee 90_deg flexed. A strap connected to attachment arm, was attached to the ankle to measure knee extension isometric force. An oscilloscope positioned in front of subject to provide visual force feedback. The subject performed three MVC separated by 2-min rest. During each MVC contraction, verbal encouragement was provided. The highest force was considered as reference for calculating submaximal force. Volunteers were asked to maintain a constant force at 20% MVC for 70 seconds. The force signal was sampled at 2048 Hz concurrently with the surface and intramuscular EMG signals.

EMG recordings

Surface and intramuscular EMG signals were recorded from two locations of the right vastus medialis muscle during sustained isometric contractions (Figure 1). The length from the anterior superior iliac spine (ASIS) to the medial border of the patella was measured as an anatomical reference for positioning the electrodes [8]. Two adhesive arrays of eight equi-spaced electrodes (ELSCH008, SPES Medica, Salerno, Italy; interelectrode distance 5 mm, electrodes 5 mm × 1 mm) were placed at a distance from the patella of 10% and 30% of the measured anatomical length, distant from innervation zones.. The muscle innervation zones were identified during test contractions with a dry array of 16 electrodes (silver bars, 5 mm long, 1 mm diameter, 5 mm interelectrode distance), as previously described [9]. Prior to placement of the adhesive electrode arrays, the skin was shaved, lightly abraded and cleaned with water. The surface EMG signals were amplified (EMG16, LISiN – Ottino Bioelettronica, Torino, Italy; bandwidth 10–500 Hz), sampled at 2,048 Hz, and stored after 12-bit A/D conversion.

Pairs of wire electrodes made of Teflon-coated stainless steel (A-M Systems, Carlsborg, WA) were used to record intramuscular EMG signals at each location. The wires were cut to expose only the cross-section and were inserted with 25-gauge needles, 10–20 mm proximal to each array of surface electrodes. The needles were removed with the wire electrodes left inside the muscle. Intramuscular EMG signals were amplified (Counterpoint EMG, DANTEC Medical, Skovlunde, Denmark), band-pass filtered (500 Hz – 4 kHz), sampled at 10,240 Hz, and stored after 12-bit A/D conversion.

Signal analysis

The intramuscular EMG signals were decomposed with an algorithm which has been previously validated [10]. The discharge times of the motor unit action potentials were used as a trigger for averaging the multi-channel surface EMG signals (20 triggers in each case). Muscle fiber conduction velocity was estimated from each averaged surface potential by a multi-channel technique previously described [11]. Surface EMG signals were divided into epochs of duration 10% of the contraction time. For each epoch, mean power spectral frequency (MPF) was estimated from the central

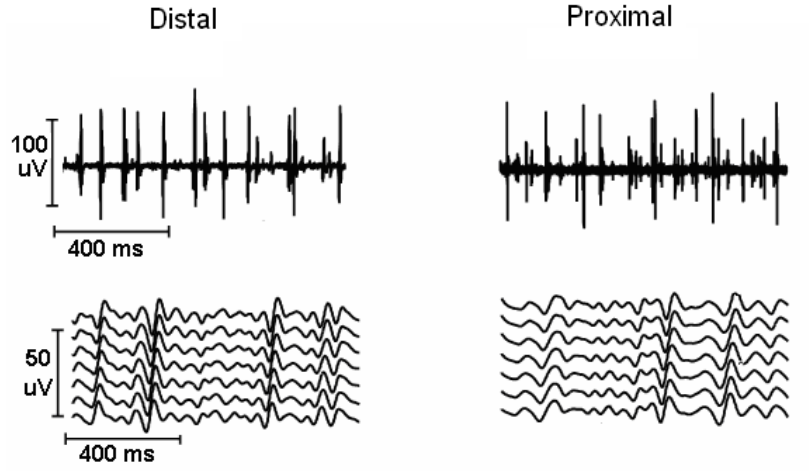

Figure 1: Example of 400 ms long epochs of intramuscular EMG signals and related surface action potentials detected from the distal and proximal portion of the right vastus medialis muscle of one subject during 20% MVC isometric contraction.

single differential channel of the array. The percent change in MFCV and MPF over time, were calculated by subtracting the final value from the initial value dividing by the initial value.

Statistical Analysis

One way analysis of variance (ANOVA) was applied to assess the initial value of MFCV and MPF at beginning of the sustained contraction with electrode locations (proximal, distal) as dependent factors. One-way ANOVA was also applied to the percent change in MFCV and MPF over sustained contraction, with factor electrode locations. Pair-wise comparisons were performed with the Student-Newman-Keuls post-hoc test when ANOVA was significant. The significance level was set to $P< 0.05$

Results

Initial value of MFCV and MPF at the distal location of the VM muscle were significantly larger than the proximal region ($P < 0.05$) (Figure 2).

Muscle fiber conduction velocity and mean power spectral frequency decreased during sustained isometric contraction ($P < 0.0001$). The percent reduction in MFCV and MPF at the distal location of the VM muscle were greater than the proximal location ($P < 0.05$) (Figure 3).

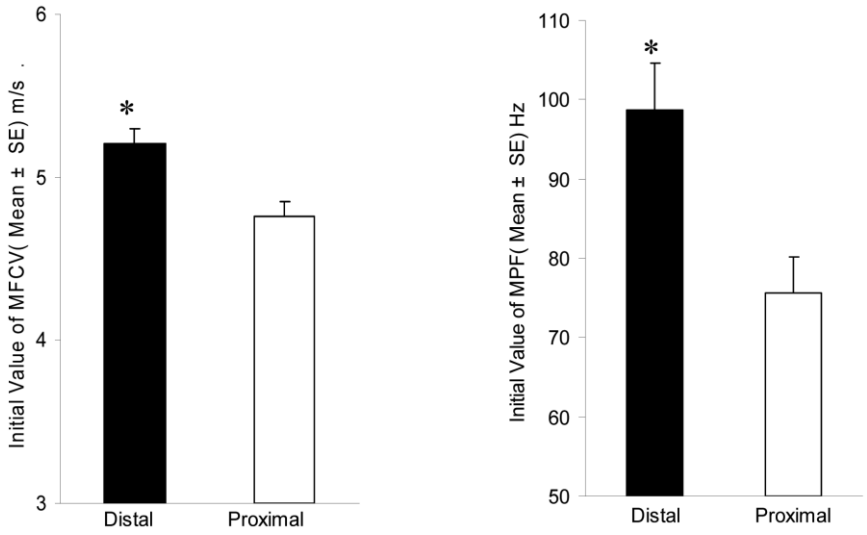

Figure 2: Initial value of muscle fiber conduction velocity (MFCV) and mean power frequency (MPF) assessed at the beginning of sustained isometric contraction: Contraction level 20% MVC

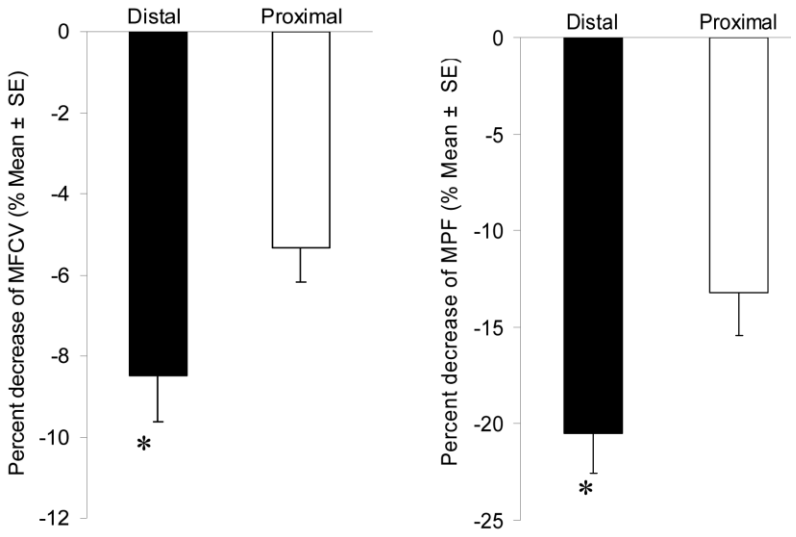

Figure 3: Muscle fiber conduction velocity (MFCV) and mean power frequency (MPF) rat of reduction over time during sustained isometric contraction: Contraction level 20% MVC.

Discussion

The aim of this study was to assess muscle fiber conduction velocity at different locations of the vastus medialis muscle. This study demonstrated non-uniform changes in muscle fiber conduction velocity at different locations of the vastus medialis muscle during sustained contraction.

In the present study, the initial value of conduction velocity and mean power frequency at the distal location of the VM muscle was significantly larger than the proximal area, most likely due to higher percentage of fast twitch muscle fibers at the distal region [7, 12]. Additionally, both distal and proximal regions of the VM muscle showed a significant reduction in fiber conduction velocity over time during sustained isometric contraction. These results are consistent with previous findings on muscle fiber conduction velocity over sustained isometric contractions [13]. However, the most distal location of the VM muscle reflected a greater rate of reduction in conduction velocity during sustained contraction as compared with the proximal portion. Moreover, mean power frequency rate of decrease in the distal location of the VM muscle was significantly larger than the proximal region during sustained contraction. This may partly explain the previous observation on relation between MFCV and MPF during fatiguing contraction [14].

The greatest reduction in conduction velocity and MPF observed in the distal location of the VM muscle may indicate a higher metabolic accumulation [1,2,3] most likely due to greater activity of this region [15] to stabilize the patella during sustained knee extension. Lieb and Perry (1987) reported a greater number of action potentials in the distal portion of the VM muscle compared to the proximal region during isometric contraction [16]. A larger number of action potentials are associated with the greater K^+ efflux during sustained contraction [17], which, in turn, further contributes to the muscle fiber membrane depolarization and reducing conduction velocity [2,3]. In addition, the elevated K^+ in inter-fiber space may also expose nonworking muscle fibers to a reduced membrane excitability and grater conduction velocity rate of reduction during sustained task [17].

A non-uniform reduction of MFCV and MPF at different locations of the VM muscle could also be explained by differences in both morphological and architectural characteristics of muscle fibers. Anatomical studies have revealed that muscle fibers at the distal part of the VM muscle are attached at larger angle to the bone with respect to the proximal regions [6]. A greater fascicle angle result in region with large physiological cross-sectional areas, and thus would be expected to generate high relative peak tension and metabolites accumulation during sustained contraction, leading to more reduction in conduction velocity [2, 3]. A greater MFCV and MPF rate of reduction in the distal location of the vastus medialis muscle may also be attributable to the higher percentage of fast twitch muscle fiber at this region in comparison with the proximal region [7]. Fast twitch fibers contains a high glycolytic, but poor oxidative capacity [17]. It is well documented that fast twitch fibers fatigue more rapidly and to a greater extent than slow twitch fibers [19]. After both dynamic and static contractions to exhaustion in humans, the fast twitch fibers produced higher lactate (25-27 mM) than the slow twitch fibers (15.8 mM) [20] and a high correlation was also observed between fatigability and percent fast twitch fibers content [5]. In skeletal muscles stimulated in vitro, the fast twitch fibers also fatigued faster and showed higher lactates and lower pH than the slow twitch fibers [21], factors known to increases K^+ conductance and decreases conduction velocity [1, 2, 3, 22]. To summarize, the results of this study showed a non-uniform changes in electrophysiological membrane properties at different locations of the VM muscle during sustained isometric contraction, probably due to differences in morphological and architectural characteristics of muscle fibers.

Conclusion

In this study, MFCV and MPF rate of reduction at the distal location of the VM muscle were significantly greater than proximal region during sustained isometric contraction. The results may suggest a non uniform metabolites accumulation within the VM muscle, most likely due to different morphological and architectural characteristics of muscle fibers at distal relative to proximal region.

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