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Spinal Reflex Arc Excitability Corresponding to the Vastus Medialis Obliquus and Vastus Medialis Longus Muscles

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Abstract. [Purpose] The gross morphology of the vastus medialis (VM) muscle has been thoroughly described. However, there is insufficient evidence of physiological differentiation between the VM obliquus (VMO) and VM longus (VML). To elucidate spinal reflex arc excitability in two divisions of the VM, we compared H-reflexes and T-waves in VMO and VML. [Subjects] Twenty-three healthy male volunteers participated in this study. [Methods] The H-reflex was evoked from the VMO and VML by electrical stimulation of the femoral nerve during knee extension at 10% maximal voluntary isometric contraction. Also, the patellar tendon was tapped by an examiner using an electrical tendon hammer, and a component of the compound muscle action potential (T-wave) was recorded. [Results] The configurations of the H-reflex and T-wave were sharp and slow in VMO and VML, respectively. No significant differences in the amplitudes of the H-reflexes and T-waves were observed between VMO and VML. The durations of VML H-reflexes and T-waves were significantly longer than those in VMO. [Conclusion] Spinal reflex arc excitability corresponding to VMO and VML was similar. However, the configurations and durations of the H-reflex and T-wave were differentiated with electromyography. On the basis of these findings, we suggest that VMO and VML are electrophysiologically distinct entities.

Key words: Vastus medialis, H-reflex, T-wave

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INTRODUCTION

The vastus medialis (VM) is regarded an important muscle in knee rehabilitation. However, there is limited evidence regarding its physiological function. A systematic review by Smith et al.[1)] discussed how the VM is divided by differentiation of fibre orientation, the presence of a fascial plane that separates VM, and different innervation patterns.

The fibres in the distal part of VM run approximately 50–55° medially in relation to the long axis of the femur in the frontal plane and insert as fleshy fibres into the medial patellar retinaculum and the upper half of the medial side of the patella[2–6)]. Therefore, the distal part has been termed the VM obliquus (VMO), and its contraction pulls the patella medially and rotates the tibia internally via the patella and the patellar tendon[7–9)]. In contrast, the proximal fibres of VM run approximately 15–20° medially and insert into the medial margin and anterior surface of the aforementioned aponeurosis, which merges with the aponeurosis of the vastus intermedius muscle[2–6)]. Therefore, the proximal part has been termed the VM longus (VML). Although the main action of the VML is to extend the knee, it also stabilizes the patella similar to the VMO[3, 4, 10, 11)].

There are conflicting reports of specific separate innervation[3, 5, 12, 13)], and shared innervation[4, 13, 14)] of the two structures. If the innervation were separate, the timing of contraction in each part would be independently regulated, and the differentiation of muscle activation related to VM contraction could be revealed by electromyographic (EMG) findings. Although there are some EMG studies on the subject, muscle activation patterns in the two divisions of VM have not yet been determined[10, 15–18)].

Investigating the excitability of spinal motoneuron as the final common pathway that drives the muscles may elucidate the physiological function of VM. The Hoffmann reflex (H-reflex) amplitude is useful as an indirect measure of the excitability of the spinal motoneurons activating VM[19)]. However, when electrical stimulation for evoking the H-reflex is delivered to the femoral nerve just below the inguinal ligament, it is not possible to distinguish the branches of the different components in the quadriceps femoris[20)]. Therefore, matching the stimulus intensity for evoking each H-reflex from VMO and VML is difficult. Also, the temporal summation of the M-wave and H-reflex is likely to occur in the quadriceps femoris muscle (especially the H-reflex in VML). For these reasons, we also used the compound muscle action potential (CMAP) evoked by the patellar tendon reflex (i.e. T-wave) as an index in addition to the H-reflex. The purpose of this present study was to investigate and

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compare the H-reflexes and T-waves in VMO and VML.

SUBJECTS AND METHODS

This study was approved by the institutional research ethics committee of Kansai University of Health Sciences. The study procedures, risks, and benefits were explained verbally and in writing to all the participants, who provided their written informed consent prior to their participation.

We analysed H-reflex and T-wave characteristics recorded in VMO and VML.

Experiment 1: H-reflexes in VMO and VML

Twelve healthy male volunteers (mean age: 21.3±2.3 years, mean height: 173.7±3.8 cm) participated in this study. None of the subjects had a history of orthopaedic or neurological disease.

Subjects sat on the seat of a torque machine (Biodex Medical Systems, Inc., USA) with their left hips and knees flexed at 30° and 60° (0° indicates the extended position), respectively. Knee extension torque was measured during maximal voluntary isometric contraction (MVIC). The H-reflex was recorded using a Viking Quest system ver.9 (Nicolet Biomedical, Inc., USA). The H-reflex was evoked during knee extension at 10% MVIC in order to regularise the appearance of the H-reflex in VM. The cathodal electrode (10 mm diameter) for evoking the H-reflex was positioned over the femoral nerve just below the inguinal ligament and the anodal electrode (40 × 50 mm) was placed over the greater trochanter. Stimulus conditions for evoking H-reflexes were 1.0 ms rectangular wave pulses with a frequency of 0.2 Hz. The stimulus intensity was the threshold for the appearance of M-wave. Five VMO H-reflexes were recorded, and then a short break was taken before recording five VML H-reflexes within a bandwidth of 20 Hz–3 kHz. This procedure was then repeated. Lastly, the maximal M-wave was recorded once in each muscle by supramaximal stimulation to the femoral nerve.

An exploring electrode (Ag/AgCl, 10 mm diameter) for recording the H-reflex and maximal M-wave was positioned over the VMO motor point. The exploring electrode for VML was positioned on the muscle belly slightly distal to the motor point to avoid sartorius muscle activation because the location of the motor point was close to the sartorius muscle. Both motor points were defined as the point where muscle fibre recruitment was obtained with the least amount of current. To locate the motor points, the two divisions of VM were investigated by moving a pentype cathodal probe over the muscle belly as distally or proximally as possible using a Recording Chronaxie Meter CX-3 (OG Giken, Co., Ltd., Japan). The anode was placed over the proximal aspect of the belly of the rectus femoris. The current was a 1.0 ms monophasic square wave that was percutaneously delivered to the muscle at a frequency of 1.0 Hz. Reference (Ag/AgCl, 10 mm diameter) and ground electrodes were positioned over the patella and the centre of the thigh, respectively. Before electrode placement, the skin surface at each site was rubbed with an abrasive gel and cleansed with alcohol to remove dead skin cells and oils that might have affected the signal integrity.

The amplitudes of the H-reflex and maximal M-wave were measured from the baseline to the negative peak. Ten H-reflex amplitudes were averaged and normalised to the maximal M-wave amplitude in each muscle. H-reflex duration was measured as the time of the negative phase, and the 10 H-reflex durations were averaged. The normalised amplitude and duration of the H-reflex in VMO were compared with those in VML using Student's t test. Statistical analysis was performed using IBM SPSS Statistics version 19 and a significance level of 5%.

Experiment 2: T-waves in VMO and VML

Eleven healthy male volunteers (mean age: 21.4±1.2 years, mean height: 171.9±6.2 cm) with sensitive patellar tendon reflexes participated in this study. None of the subjects had a history of orthopaedic or neurological disease.

Subjects relaxed on a reclining seat with their left hips and knees flexed at 45° and 60°, respectively. The examiner tapped the patellar tendon using an electrical tendon hammer with an EMG unit attached (Viking Quest system ver.9, Nicolet Biomedical, Inc., USA). Consequent T-waves were simultaneously recorded from the VMO and VML within a bandwidth of 20 Hz–3 kHz. Exploring electrodes (Ag/AgCl, 10 mm diameter) for recording the T-waves were positioned on the motor points of the VMO and VML. The reference and ground electrodes were positioned as described for the H-reflex. The motor points were identified as in Experiment 1.

The same examiner evoked the T-waves in all subjects and tried to elicit T-waves as large and as stably as possible. Four T-waves in each of VMO and VML were recorded for analysis. Lastly, the maximal M-wave was recorded once in each muscle by supramaximal electrical stimulation of the femoral nerve. The manner of nerve stimulation was the same as in Experiment 1.

The amplitudes of the T-wave and maximal M-wave were measured from the baseline to the negative peak. Four T-wave amplitudes were averaged and normalised to the maximal M-wave amplitude. T-wave duration was measured as the time of the negative phase, and four T-wave durations were averaged. The normalised amplitude and duration in VMO were compared with those in VML as described for Experiment 1.

RESULTS

Experiment 1: H-reflexes in VMO and VML

In three subjects, the accurate measurement of amplitude and duration of H-reflexes in VML was difficult because the baseline immediately before H-reflex appearance was unstable due to the M-wave. Consequently, these subjects' data were excluded from the analysis.

The levels of the exploring electrodes for VMO and VML were 3.1±0.6 cm and 12.4±0.9 cm, respectively, from the superior border of the patella along the longitudinal axis of the thigh.

Figure 1 shows typical H-reflexes. The negative phase of the H-reflex in VMO was sharp, while that in VML was

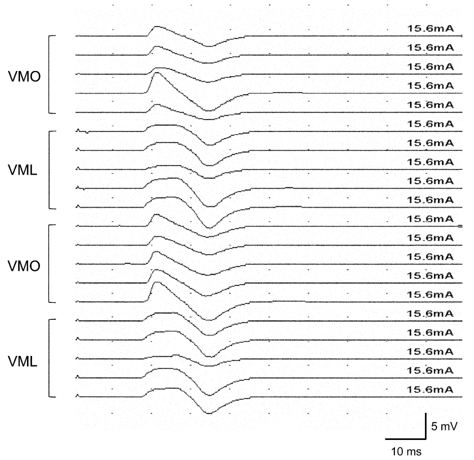

Fig. 1. Typical H-reflexes recorded in VMO and VML. The H-reflexes were evoked by a stimulus intensity of 15.6 mA

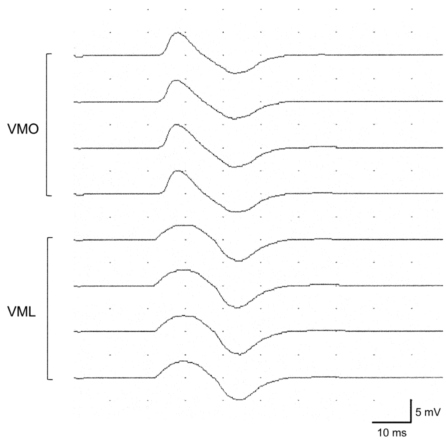

Fig. 2. Typical T-waves recorded in VMO and VML. The VMO and VML traces correspond, e.g. the first traces in VMO and VML were simultaneously recorded following a patellar tendon tap

slow. The normalised amplitude and duration of H-reflexes in VMO and VML are presented in Table 1. No significant difference in normalised H-reflex amplitudes was observed between VMO and VML but H-reflex duration was significantly longer in VML ($p<0.001$).

Experiment 2: T-waves in VMO and VML

The levels of the exploring electrodes for VMO and VML were 2.8±0.6 cm and 14.4±1.3 cm, respectively, from the superior border of the patella along the longitudinal axis of the thigh.

Figure 2 displays typical T-waves. The negative phase of the T-wave in VMO was sharp, while that in VML was slow. The normalised amplitudes and durations of T-waves in VMO and VML are presented in Table 1. No significant difference was observed in the normalised T-wave amplitude between VMO and VML. T-wave duration was significantly longer in VML than in VMO ($p<0.001$).

Finally, each maximal M-wave configuration recorded from VMO and VML was similar to those observed for the H-reflex and T-wave.

Table 1. Mean and SD of H-reflex and T-wave amplitudes and durations

		Normalised amplitudes (%)	Durations (ms)
H-reflex	VMO	10.8±6.0	8.6±0.8
	VML	9.4±5.3	10.3±1.0 *
T-wave	VMO	32.5±10.3	11.7±1.2
	VML	36.6±11.8	14.9±2.4 *

*$p<0.001$; VMO: Vastus medialis obliquus; VML: Vastus medialis longus

DISCUSSION

Amplitude alteration of the H-reflex and T-wave can be explained by variations in motoneuron excitability and the amount of neurotransmitter released by the afferent terminals[21, 22]. Therefore, it is considered that the alteration of their amplitudes reflects spinal reflex arc excitability.

Although we could not confirm the innervation modes that drive VMO and VML in this study, we were careful to ensure that each exploring electrode location matched the VMO and VML areas in which the femoral nerve branches are specifically illustrated by Lieb and Perry[3], and were photographed by Ono et al[12].

EMG studies have not previously shown functional differentiation between the two VM divisions[10, 17, 18]. Rainoldi et al.[15] and Botter et al.[16] investigated EMG differentiation of the VMO, VML, and vastus lateralis (VL) during a fatiguing condition using linear array of electrodes. In both reports, the differences were greater between VL and the two VM divisions than between VMO and VML.

The lack of significant differences for H-reflex and T-wave amplitudes between VMO and VML described in our present study may support previous EMG research[10, 15–18]. However, the configurations of the H-reflex and T-wave in VMO and VML are clearly different, and the durations of both parameters were significantly longer in VML than in VMO. Moreover, the maximal M-wave configurations in VMO and VML were also clearly different. The H-reflex and T-wave are components of the late-response CMAP. CMAPs are the summation of nearly synchronous muscle fibre action potentials recorded from a muscle, and are commonly produced by stimulating the nerve supplying the muscle either directly or indirectly. CMAP configuration is affected by muscle fibre properties. The impulses of slow-conducting fibres lag behind those of the fast-conducting fibres[23]. When the difference in conduction velocity between the fastest and slowest is high, the summation of muscle fibre action potentials is asynchronously recorded.

Consequently, CMAP configuration and duration become slower and longer. Travnik et al.[24] investigated the histochemical and morphometric characteristics of VML and VMO, and reported that the proportions of type I and IIb fibres were significantly higher and lower, respectively, also, the diameters of type I and IIa fibres were significantly smaller in VML than in VMO. The analysed portions of VMO and VML were near the superomedial border of the patella and approximately 15.0 cm proximal to the base of patella, which generally matches the regions investigated in our study. Based on the above data, we consider that the different configurations of the H-reflex and T-wave were related to muscle fibre composition in the two VM divisions examined in our study. Although the H-reflex and T-wave are known to be composed of slow motor units that are recruited first[25], we consider that there is a difference of muscle fibre properties in the slow units. Also, the earliest components of the H-reflex and T-wave are predominantly comprised of monosynaptic Ia effects, and the later portions probably include contributions from the oligosynaptic Ia pathway[22]. This synaptic factor may relate to H-reflex and T-wave configurations.

In conclusion, although the excitability of spinal reflex arcs corresponding to VMO and VML were similar, the differentiation of configurations and durations of the H-reflex and T-wave were detectable on EMG. On the basis of the present findings, VMO and VML training may be addressed differently during knee rehabilitation because they are two electrophysiologically distinct parts.

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