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Full Length Article

Region-specific modulation of tendon reflex along human rectus femoris muscle

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ABSTRACT

Introduction: We investigated regional differences in amplitude modulation of the spinal reflex along the human rectus femoris (RF) muscle to test the hypothesis that this muscle is regionally regulated at the spinal cord or a higher level.
Methods: Surface electromyography was conducted at six different sites along the RF muscle during the conditioned patellar tendon reflex in eight healthy young men.
Results: A significant difference in the reflex amplitude among the channels was observed during 20% of the maximal voluntary contraction (MVC) and there was a significant difference in normalized reflex amplitude between 10 and 20% of the MVC at most proximal channel ($p < 0.05$), but not at the other channels ($p > 0.05$), during knee flexion of the ipsilateral leg.
Discussion: From the results in the present study, we infer that the amplitude modulation of the tendon reflex within the RF muscle is regionally regulated, and that this regulation is dependent on the performed tasks.

1. Introduction

The human rectus femoris (RF) muscle consists of two semi-independent components. The proximal one-third and distal two-thirds of the muscle fibers originate from the anterior inferior iliac spine and superior acetabular ridge, respectively (Hasselman, Best, Hughes, Martinez, & Garrett, 1995; Sung, Jung, Kim, Ha, & Ko, 2003). Also, this muscle is innervated by two motor nerve branches that insert into the proximal and middle/distal regions (Yang & Morris, 1999). Based on the unique anatomical properties of the RF muscle, it has been suggested that the proximal and middle/distal regions of the muscle are separately regulated and have different functional roles (Hasselman et al., 1995).

Our recent studies demonstrated the possibility that the human RF muscle is regionally regulated during human movements and exhibits non-uniform physiological responses along the muscle. Preferential neuromuscular activation in the proximal regions was observed during isometric hip flexion (Watanabe, Kouzaki, & Moritani, 2012), the swing phase of normal gait (Watanabe, Kouzaki, & Moritani, 2014) and stair ascent (Watanabe, Kouzaki, & Moritani, 2017), and the pulling phase of cycling on an ergometer (Watanabe, Kouzaki, & Moritani, 2015). The selective myoelectric manifestation of fatigue in the proximal regions was also found during isometric contraction of knee extension and hip flexion (Watanabe, Kouzaki, & Moritani, 2013). In addition to studies at the peripheral muscle level, we also investigated the mechanisms of regional regulation along the rectus femoris at the motor nerve level (Watanabe, Kouzaki, Ando, Akima, & Moritani, 2015). The M-wave was elicited from proximal to distal regions of the RF muscle by transcutaneous electrical nerve stimulation via the femoral nerve. During low-level stimulation, M-waves were selectively observed

Abbreviations: CH, channel; EMG, electromyography; MVC, maximal voluntary contraction; RF, rectus femoris muscle; VL, vastus lateralis muscle

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in the proximal regions. This suggests that motor nerve branches that innervate into proximal and middle/distal regions are localized and/or separated upstream of the femoral nerve. From these findings, we consider that two different components along the RF muscle are independently regulated at peripheral muscle and motor nerve levels. Independent action during voluntary contraction would reflect independency of the two components of the RF muscle at the spinal level or a higher level such as the brain stem. In fact, the previous studies confirmed localization of afferent information from muscle spindle within the tibialis anterior muscle (McKeon, Gandevia, & Burke, 1984) and of stretch reflexes within the vastus medialis muscle (Gallina, Blouin, Ivanova, & Garland, 2017) in human, meaning that the neuromuscular activation within some human muscles are regionally regulated at the spinal cord level. However, it had not been experimentally confirmed the potential different neural regulations between proximal and middle/distal regions of the RF muscle at the spinal level.

Measurement of the tendon reflex has been used to estimate the stretch reflex activity and excitability of the spinal cord (Koceja & Kamen, 1988; Tucker, Tuncer, & Turker, 2005). It is also well-known that the amplitude of the reflex is modulated by the excitation of antagonistic and/or ipsi- and contralateral limb motoneurons (Katz, Penicaud, & Rossi, 1991; Mrachacz-Kersting, Geertsen, Stevenson, & Nielsen, 2017; Sherrington, 1892). For example, the stretch reflex is depressed by ipsilateral antagonist muscle contraction (Katz et al., 1991) and facilitated by the contralateral homologous muscle contraction (Hortobagyi, Taylor, Petersen, Russell, & Gandevia, 2003). Therefore, it can be estimated that the ipsilateral knee flexion and contralateral knee extension should induce an inhabitation and facilitation of reflex amplitudes of knee extensor muscles including the RF muscle. Based on our previous studies (Watanabe, Kouzaki, Ando, et al., 2015; Watanabe et al., 2012, 2014), we expect that proximal and middle/distal regions behave as hip flexors and knee extensors even during reflex. Comparison of reflex amplitude modulation would help to understand whether neural regulations are different between proximal and middle/distal regions of the RF muscle at the spinal level. The present study aimed to investigate the regional amplitude modulation of the tendon reflex along the RF muscle during excitations of contralateral and ipsilateral limb muscles. We hypothesized that i) proximal and middle/distal regions show different amplitude modulation under conditioned tendon reflexes and ii) the reflex amplitudes decreases and increases during ipsilateral knee flexion and contralateral knee extension at middle/distal regions, respectively, and iii) these amplitude modulations are not found or subtle at the proximal regions.

2. Methods

2.1. Subjects

Eight healthy men (age: 20.1 ± 1.1 years, height: 171.4 ± 5.0 cm, body mass: 62.1 ± 5.9 kg) volunteered for this study. They gave informed consent for the study after receiving a detailed explanation of the purposes, potential benefits, and risks associated with participation. All subjects were healthy, with no history of any musculoskeletal or neurological disorders. All procedures were conducted in accordance with the Declaration of Helsinki and approved by the Committee for Human Experimentation at Chukyo University (No. 2015-001).

2.2. Experimental design

The subjects sat in a dynamometer with mounted torque and force transducers to separately measure knee extension/flexion joint torque of the left and right legs (Fig. 1). Hip and knee joint angles of subjects were fixed at 170° and 90° (inner angles), respectively. The right leg was used to detect the patellar tendon reflex, and the knee of the right leg was tightly fixed to the dynamometer with a sponge and strap. A hand-made rubber-tipped hammer was used to tap the patellar tendon of the right leg. An equal amount of force was loaded on the patellar tendon by the motion of a pendulum from the same height (1.025 J:kg·m/s). During testing of the reflex, the subject's visual field was restricted by semi-blinding goggles and the subjects could only confirm the visual feedback on the monitor in front of their face. Also, soothing music was played through headphones during testing of the reflex to restrict auditory information.

Before tendon reflex trials, the subjects performed two maximum voluntary contractions (MVC) of isometric contraction for three different tasks: knee extension and knee flexion of the right leg and knee extension of the left leg, respectively. The highest force of two trials was used as the MVC force of each task.

After reflex trials under a resting condition, conditioned reflex trials were conducted under four different conditions in random order. Numbers of trials were 10, 10, 5, 10, and 5 for the resting condition, during 10 and 20% of the MVC for knee extension of the contralateral (left) leg, and during 10 and 20% of MVC for knee flexion of the ipsilateral (right) leg. Intervals between trials were 4–7 s and those between conditions were > 5 min. During the conditioned reflex trials, the subject was instructed to maintain the target force, and the performed and target forces were shown on a monitor as visual feedback with task instruction.

2.3. Surface electromyography

Surface electromyogram signals were recorded at the six different sites along the longitudinal axis of the RF muscle and midpoint of the vastus lateralis (VL) muscle (Fig. 2). Electrode locations on the RF muscle were defined as CH1 to CH6 from the proximal site, as shown in left panel of Fig. 2. For the RF muscle, the edge of the superficial region was identified by ultrasonography (FAZONE CB, FUJIFILM, Tokyo, Japan). Six electrode pairs were equally placed between proximal and distal edges of superficial regions of the RF muscle on a line between the anterior superior iliac spine and superior edge of the patella. Also, the midpoint between CH3 and CH4