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Relationship between regional neuromuscular regulation within human rectus femoris muscle and lower extremity kinematics during gait in elderly men

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ABSTRACT

Biomechanical and neurophysiological mechanisms of age-related gait dysfunction have not been fully understood. We aimed to investigate the relationship between region-specific electromyography (EMG) response of the rectus femoris (RF) muscle and lower extremity kinematics during swing phase of gait for the elderly. For thirteen elderly men (age: mean 71.3 years, standard deviation 5.7 years), multi-channel surface EMG from the proximal to distal regions of the RF muscle and lower extremity kinematics were measured during normal gait on a treadmill. At minimum foot clearance during swing phase, relationship between central locus activation (CLA), which is indicator of spatial distribution of surface EMG along the RF muscle and lower joint kinematics were calculated. No significant correlations were found between CLA and any joint angle ($p > 0.05$). The results of our study suggested that regional neuromuscular activation of the RF muscle is not associated to lower extremity joint movements and toe clearance strategy during gait in the elderly.

1. Introduction

Swinging a leg with safety foot clearance is a key movement for a prevention of tripping, dragging, and/or falls during gait in the elderly. Theoretically, when the distance between a foot of swing leg and a walking surface, i.e., minimum foot clearance (MFC), is reduced to zero or very small, the tripping and/or falls would occur. The previous studies suggested that the potential for trip-related falls is to be greatest at the timing of MFC (Barrett et al., 2010; Winter, 1992). Therefore, effect of aging on the variables of MFC and joint kinematics and/or kinetics around MFC has been investigated (Barrett et al., 2010; Begg et al., 2007; Khandoker et al., 2008; Mills et al., 2008; Nagano et al., 2014; Winter, 1992; Winter et al., 1990). Barrett et al. (2010) reviewed that greater variability in MFC were observed in the elderly when comparing with the young (Barrett et al., 2010). Also, although relationship between variabilities in MFC and lower joint kinematics were investigated in the young and elderly, it was concluded that factors other the magnitude of joint angle variability at the timing of MFC may contribute to the variability of MFC in the elderly (Mills et al., 2008).

In the patients with upper motor neuron injures, decrease in knee flexion during swing phase were seen and it induces impairment of safety toe clearance (Reinbolt et al., 2008; Sung et al., 2003). It was suggested that one of the causes for this pathological gait pattern, i.e., stiff-knee gait, is hyperactivity of the rectus femoris (RF) muscle (Chantraine et al., 2005; Reinbolt et al., 2008; Sung et al., 2003). Our recent studies demonstrated that the proximal regions of the RF muscle is selectively activated during swing phase in gait (Watanabe et al., 2014b) and this regional neuromuscular regulation was attenuated with increases in activations at the distal regions in the elderly (Watanabe et al., 2016). Since we had already reported that the proximal and all/distal regions of the RF muscle contribute to hip flexion and knee extension joint moments, respectively (Watanabe et al., 2014a, 2012), this age-related change in regional neuromuscular regulation of the RF muscle in the elderly may produce the unexpected knee extension joint moment during the swing phase. We suspected that age-related change in regional activation pattern of the RF muscle is one of the causes for impairment of smooth leg swing movement and is a key to understanding mechanisms of pathological gait pattern in the patients with upper motor neuron injures. However, effect of age-related changes in regional neuromuscular activation in the RF muscle during the swing

Abbreviations: CLA, central locus activation; CV, coefficient of variance; EMG, electromyography; MFC, minimum foot clearance; RF, rectus femoris; SD, standard deviation

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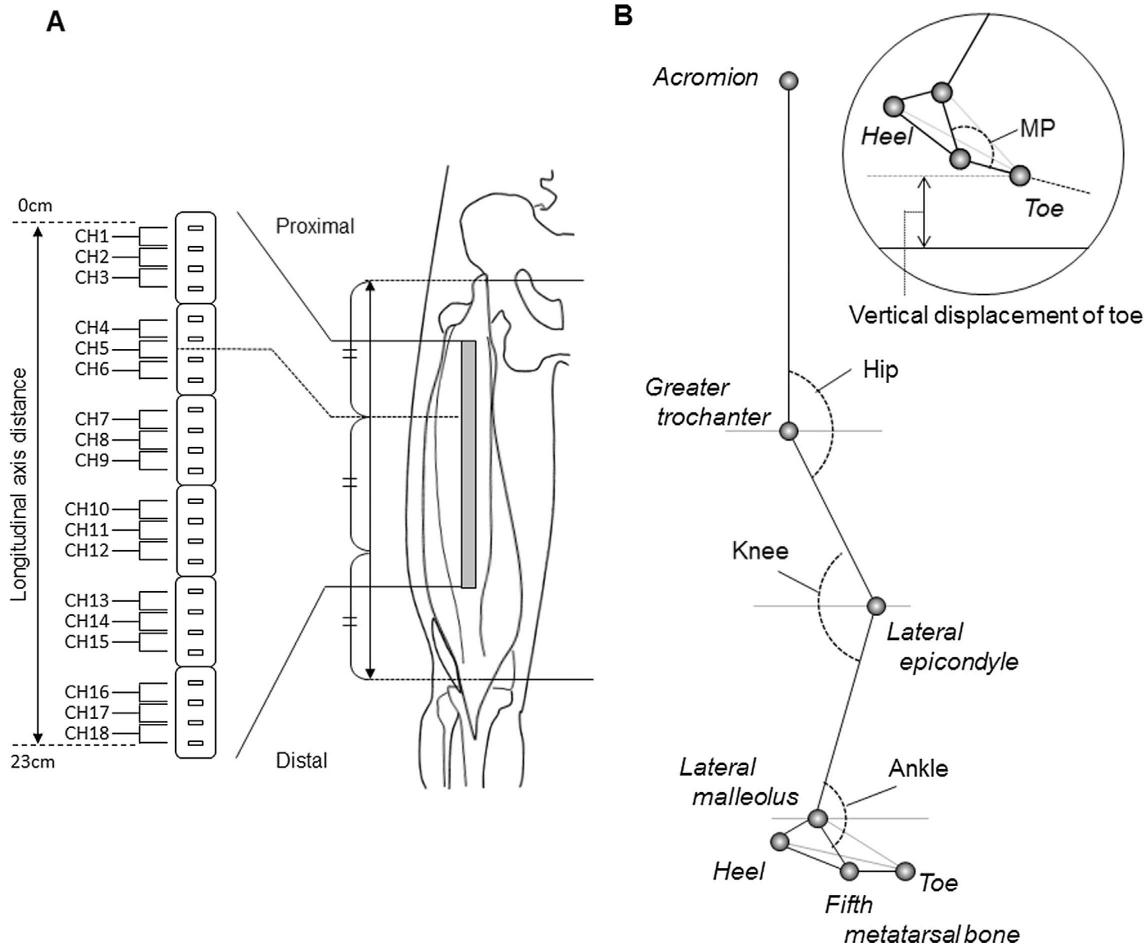

Fig. 1. Electrode positions and definitions of channel numbers for the rectus femoris muscle (A) and definitions of lower extremity joint and locations of reflective markers (B).

phase on lower extremity joint kinematics has not been investigated.

The aim of this study was to investigate the relationships between the lower extremity joint kinematics around timing of MFC and regional neuromuscular activation along the RF muscle during gait in the elderly. We hypothesized that based on region-specific functional role of the RF muscle (Watanabe et al., 2014a, b, 2016, 2012) the attenuated selective activation of the proximal region and/or additional activation at the distal regions of the RF muscle induces a decrease in hip and knee flexions at the timing of MFC in the elderly. Also, we inferred that regional neuromuscular activation of the RF muscle relates with variables of MFC since functional role of the RF muscle such as hip flexion and knee extension, directly contribute to the vertical position of toe.

2. Methods

2.1. Subjects

Thirteen elderly men (age: 71.3 (SD:5.7) years, height: 167.3 (SD:5.1) cm, body mass: 62.6 (SD: 7.1) kg) volunteered for the present study. The subjects gave written 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 study procedures were in accordance with the Declaration of Helsinki and research code of ethics of Chukyo University and were approved by the Committee for Human Experimentation of the Chukyo University.

2.2. Experimental design

All subjects came to the laboratory 6–16 days before the experimental day to familiarize themselves with the walking on treadmill and to determine preferred gait speed. Average gait speed was calculated from three trials of 10 m of normal gait on the flat floor on the familiarization day and was used as preferred gait speed. On the experimental day, the subjects walked on a treadmill (MEDTRACK ST65, Quinton Instrument Co., WA, USA) in the preferred gait speed for 20 min. During walking on the treadmill, multi-channel surface electromyography (EMG) was recorded from the RF muscle and coordinates on sagittal plane of reflective markers on lower extremity were measured simultaneously.

2.3. Multi-channel surface EMG recording

Surface EMG signals were recorded from the RF muscle of the right thigh with 24 electrodes which consists of 6 of 4 electrode array (1 × 5 mm detection area, 10-mm inter-electrode distance) (ELSH004, OT Bioelectronica, Torino, Italy) (Fig. 1A). The method used for selecting electrode location and recording surface EMG from the RF muscle were as previously described (Watanabe et al., 2015, 2014a, 2013, 2016, 2012). A reference electrode was placed at the iliac crest. Detected EMG signals with monopolar recording were amplified by a factor of 1000, sampled at 2048 Hz with an 8th order Bessel band pass filter at 10–750 Hz (anti-aliasing filter), and converted to digital form by a 12-bit analog-to-digital converter (EMG-USB, OT Bioelectronica, Torino, Italy). In off-line analysis (MATLAB R2008a, MathWorks, MA,