



Torque and mechanomyogram relationships during electrically-evoked isometric quadriceps contractions in persons with spinal cord injury

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ABSTRACT

The interaction between muscle contractions and joint loading produces torques necessary for movements during activities of daily living. However, during neuromuscular electrical stimulation (NMES)-evoked contractions in persons with spinal cord injury (SCI), a simple and reliable proxy of torque at the muscle level has been minimally investigated. Thus, the purpose of this study was to investigate the relationships between muscle mechanomyographic (MMG) characteristics and NMES-evoked isometric quadriceps torques in persons with motor complete SCI. Six SCI participants with lesion levels below C4 [(mean (SD) age, 39.2 (7.9) year; stature, 1.71 (0.05) m; and body mass, 69.3 (12.9) kg)] performed randomly ordered NMES-evoked isometric leg muscle contractions at 30°, 60° and 90° knee flexion angles on an isokinetic dynamometer. MMG signals were detected by an accelerometer-based vibromyographic sensor placed over the belly of rectus femoris muscle. The relationship between MMG root mean square (MMG-RMS) and NMES-evoked torque revealed a very high association ($R^2 = 0.91$ at 30°; $R^2 = 0.98$ at 60°; and $R^2 = 0.97$ at 90° knee angles; $P < 0.001$). MMG peak-to-peak (MMG-PTP) and stimulation intensity were less well related ($R^2 = 0.63$ at 30°; $R^2 = 0.67$ at 60°; and $R^2 = 0.45$ at 90° knee angles), although were still significantly associated ($P \leq 0.006$). Test-retest interclass correlation coefficients (ICC) for the dependent variables ranged from 0.82 to 0.97 for NMES-evoked torque, between 0.65 and 0.79 for MMG-RMS, and from 0.67 to 0.73 for MMG-PTP. Their standard error of measurements (SEM) ranged between 10.1% and 31.6% (of mean values) for torque, MMG-RMS and MMG-PTP. The MMG peak frequency (MMG-PF) of 30 Hz approximated the stimulation frequency, indicating NMES-evoked motor unit firing rate. The results demonstrated knee angle differences in the MMG-RMS versus NMES-isometric torque relationship, but a similar torque related pattern for MMG-PF. These findings suggested that MMG was well associated with torque production, reliably tracking the motor unit recruitment pattern during NMES-evoked muscle contractions. The strong positive relationship between MMG signal and NMES-evoked torque production suggested that the MMG might be deployed as a direct proxy for muscle torque or fatigue measurement during leg exercise and functional movements in the SCI population.

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1. Introduction

The study of motor unit (MU) recruitment to evoke force production is of clinical interest, particularly during neuromuscular electrical stimulation (NMES)-evoked contractions of paretic or paralyzed muscles in neurological populations [1]. Incremental MU

recruitment during voluntary [2,3] and NMES-evoked contractions [4] has been used to describe muscle force modulation in healthy individuals. However, while NMES-evoked contractions have been utilized for muscle force production in individuals with spinal cord injury (SCI) [5], the mechanical and morphological changes associated with muscle contraction in this population have been poorly documented. To evaluate the effectiveness of NMES interventions, it is important to quantify stimulus-evoked muscle force. In particular, understanding motor recruitment and muscle force characteristics could provide key insights about the contractile properties of the muscle [6] and this has important implications for the use of

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