Mechanomyography and Torque during FES-Evoked Muscle Contractions to Fatigue in Individuals with Spinal Cord Injury

Nor Zainah Mohamad 1, Nur Azah Hamzaid 1,* , Glen M. Davis 1,2, Ahmad Khairi Abdul Wahab 1 and Nazirah Hasnan 3

1 Department of Biomedical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia; jenazainah@siswa.um.edu.my (N.Z.M.); glen.davis@sydney.edu.au (G.M.D.); khairi@um.edu.my (A.K.A.W.)

2 Clinical Exercise and Rehabilitation Unit, Discipline of Exercise and Sports Sciences, Faculty of Health Sciences, University of Sydney, Lidcombe, NSW 2141, Australia

3 Department of Rehabilitation Medicine, Faculty of Medicine, University of Malaya, Kuala Lumpur 50603, Malaysia; nazirah@ummc.edu.my

* Correspondence: azah.hamzaid@um.edu.my; Tel.: +60-3-7967-4487; Fax: +60-3-7967-4579

Academic Editor: Panicos Kyriacou

Received: 5 January 2017; Accepted: 12 April 2017; Published: 14 July 2017

Abstract: A mechanomyography muscle contraction (MC) sensor, affixed to the skin surface, was used to quantify muscle tension during repetitive functional electrical stimulation (FES)-evoked isometric rectus femoris contractions to fatigue in individuals with spinal cord injury (SCI). Nine persons with motor complete SCI were seated on a commercial muscle dynamometer that quantified peak torque and average torque outputs, while measurements from the MC sensor were simultaneously recorded. MC-sensor-predicted measures of dynamometer torques, including the signal peak (SP) and signal average (SA), were highly associated with isometric knee extension peak torque (SP: $r = 0.91$, $p < 0.0001$), and average torque (SA: $r = 0.89$, $p < 0.0001$), respectively. Bland-Altman (BA) analyses with Lin’s concordance ($\rho_C$) revealed good association between MC-sensor-predicted peak muscle torques (SP; $\rho_C = 0.91$) and average muscle torques (SA; $\rho_C = 0.89$) with the equivalent dynamometer measures, over a range of FES current amplitudes. The relationship of dynamometer torques and predicted MC torques during repetitive FES-evoked muscle contraction to fatigue were moderately associated (SP: $r = 0.80$, $p < 0.0001$; SA: $r = 0.77$, $p < 0.0001$), with BA associations between the two devices fair-moderate (SP; $\rho_C = 0.70$: SA; $\rho_C = 0.30$). These findings demonstrated that a skin-surface muscle mechanomyography sensor was an accurate proxy for electrically-evoked muscle contraction torques when directly measured during isometric dynamometry in individuals with SCI. The novel application of the MC sensor during FES-evoked muscle contractions suggested its possible application for real-world tasks (e.g., prolonged sit-to-stand, stepping,) where muscle forces during fatiguing activities cannot be directly measured.

Keywords: MC sensor; spinal cord injury (SCI); muscle fatigue; functional electrical stimulation (FES)

1. Introduction

Muscle contractions, evoked by skin-surface functional electrical stimulation (FES) [1], result in rapid muscle fatigue, particularly during prolonged FES exercise performed by individuals with spinal cord injury (SCI), who lack voluntary muscle recruitment [2,3]. A limiting factor to any potential benefits of FES-evoked daily-living tasks has been rapid muscle fatigue [4], which leads to low adoption rates of FES-evoked activities by these individuals. Due to impaired proprioceptive