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Editorial

Fatigue in Functional Electrical Stimulation in Spinal Cord Injury

Loss of control and sensation of the body's extremities is a common consequence of spinal cord injury (SCI). In many SCI cases, the nervous system emanating from the spinal cord below the lesion, as well as the muscles innervated by these nerves, remains intact. As such, when the paralysed muscles are electrically stimulated, they can be used as actuators to restore motor activation and control of the limbs. Furthermore, if a microprocessor-controlled muscular excitation can be suitably coordinated, locomotor function can be generated. Two major issues are associated with functional electrical stimulation (FES) of a muscle: the mechanism of force generation by the recruitment of the muscle's motor units, and the muscle force's decay with time as a result of muscle fatigue. Muscle fatigue in complete paralysis is essentially peripheral and thus presents a significant problem, because the muscles' sensory feedback that indicates fatigue development and prevents failure is missing.

This special issue comprises a multidisciplinary treatise on muscle fatigue during FES in SCI subjects. Although as of yet little work has been published on this subject, it has been recognized that the feedback approach alone is not sufficient to control muscle force without incorporating what is known about muscle dynamics. The papers in this issue thus deal with dynamic aspects of muscle fatigue in FES from different, yet complementary angles. Basic and clinical perspectives are discussed to gain a better understanding of both force production mechanisms in the muscle and force loss due to fatigue.

The principal issues discussed can be categorized according to the following topics:

(a) Fatigue characteristics of the muscle force as affected by stimulation protocols and fatigue-recovery interactions;
(b) Fatigue as expressed by myoelectric (EMG) and metabolic quantities; and
(c) Interactions between peripheral (below the lesion) and global (above the lesion) fatigue.

When studying the dynamics of the limb activated by the stimulated muscle, the first item is essential to the design of optimal stimulation and to the ability to predict the muscle force's history-dependency. The second item deals with the relations between muscle force, EMG and muscle metabolism. These relations are especially relevant in peripheral fatigue and can be of particular interest when verifying conditions under which surface EMG can be used as a non-invasive predictor of muscle fatigue. The third aspect applies to paraplegic subjects activated by FES, where standing and walking necessitate support of the upper limbs and result in upper trunk muscle involvement.

Several difficulties in studying muscle fatigue during FES in SCI subjects confront us, one of which is the heterogeneity of this population, which limits the ability to generalize the findings obtained. Furthermore, the availability of

patients who can take part in a long-term study is often very small, and decreases the statistical significance of these findings. A technical issue that further discourages the participation of SCI subjects is the use of intramuscular electrodes. Although such electrodes are minimally invasive, most subjects oppose their application, limiting the research to surface stimulation and recordings, with their own inherent limitations.

Stimulus artifact suppression is another issue that needs improvement in the future, as the high stimulus pulse duration necessary for surface stimulation often obliterates part of the manifested M-waves, and thus causes information loss.

These difficulties can be compensated for somewhat if the results obtained can be supported by physiological-biomechanical modelling aimed at explaining the relations between FES, fatigue, and individual pathology. Such modelling attempts are demonstrated in this issue.

It is hoped that the research reported in this special issue will advance our knowledge of muscle fatigue in FES and act as a contemporary baseline for future work addressing the existing problems. Learning the dynamics of muscle fatigue should eventually enable us to improve the stimulating techniques and to design strategies for efficient FES activation of the muscle. Furthermore, such knowledge may aid in the reduction of muscle fatigue and, consequently, improve rehabilitation modalities and devices for dealing with the physical limitations of spinal cord injury.

Joseph Mizrahi
Guest Editor
Department of Biomedical Engineering
Technion–Israel Institute of Technology
Haifa, Israel