Simulated Generic and Personalized Functional Electrical Stimulation have Different Effects on Hip Contact Forces During Semi-Recumbent Cycling

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Summary

Functional electrical stimulation (FES) of semi-recumbent cycling is often used in rehabilitation after spinal cord injury. However, FES patterns are not personalized to the individual and might result in mechanical loads ill-suited for bone formation, limiting therapeutic efficacy. This study showed that personalized FES generates hip contact force magnitude and direction different to that by manufacturers' generic FES.

Introduction

FES cycling is a common rehabilitation therapy after spinal cord injury (SCI). FES non-invasively stimulates muscle via surface electrodes to elicit coordinated muscle contractions and movement. Although FES semi-recumbent cycling is well-established and has several health benefits in individuals with SCI, increasing their bone mineral density has remained elusive for over 40 years [1]. Mechanical loading drives bone remodeling, with too little or too higher loads not promoting bone formation [2]. FES's inconsistent effects on bone mineral density in people with SCI may be in using manufacturer's recommended FES patterns (e.g., start/stop angles, amplitude) that are generic and not personalized to the individual.

We studied the effect of personalized and generic simulated FES patterns on estimated hip contact force magnitude and direction during semi-recumbent cycling, in comparison to those generated during voluntary semi-recumbent cycling.

Methods

Eleven uninjured participants performed voluntary semi-recumbent cycling at 15 W at 40 revolutions/minute (rpm) while electromyograms (EMG), crank reaction forces, and body and pedal motions were recorded. For voluntary cycling, a validated biomechanical modelling pipeline using OpenSim and an EMG-assisted neuromusculoskeletal model [3] estimated the magnitude (N) and direction (deg) of the hip contact force vector. Hip contact forces were also generated using two simulated FES patterns: (i) personalized, and (ii) manufacturer's generic for ERGYS [4]. The personalized FES was calculated by static optimisation that minimized muscle activations while tracking experimental joint moments. The three models' data were resampled to 360 points/cycle per person and paired SPM1D t-tests between the voluntary and each of the simulated FES's data performed.

Results and Discussion

The personalized FES and generic stimulation had hip contact force had magnitudes equal to or less than those in voluntary cycling (Figure 1). Personalized and generic FES led to hip contact force directions closer to the acetabular rim than those during voluntary cycling.

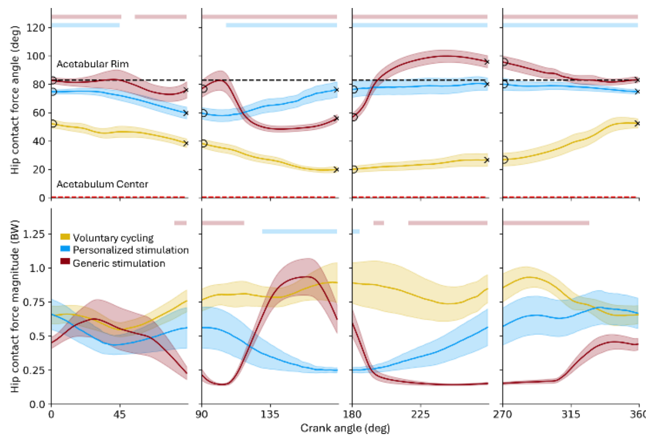

Figure 1: Hip contact force magnitude (bottom) and direction (top). Top dead center: 0 deg. Solid line: mean; shaded areas: +/- standard error of the mean. Horizontal bars: significant differences between simulated FES's and voluntary cycling.

We compared the effects of different simulated FES on hip loading to those in voluntary cycling. Generic FES produced hip contact forces significantly lower than voluntary cycling. Generic contact forces were directed towards or outside the acetabular rim for 40% of the total crank cycle, which might generate detrimental bending moments to the femoral neck. In contrast, personalized FES resulted in hip contact loads closer to those seen in voluntary cycling and always directed within the acetabulum, suggesting a safer approach for promoting favorable bone adaptations.

Conclusions

Personalized FES patterns were simulated through static optimization and could potentially be used in FES therapy for SCI, as they provided more favorable hip loading compared to generic patterns. Future research should investigate bone stress/strain using the finite element method.

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