Neuromuscular electrical stimulation and volitional strength training on in children with cerebral palsy: a preliminary study

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Abstract

Ten children with spastic diplegic cerebral palsy underwent a 12-week strengthening program and were assigned to either a group that used neuromuscular electrical stimulation (NMES) or voluntary effort (VE) to strengthen the quadriceps femoris (QF) and the triceps surae (TS). Both groups had muscle strength testing, assessment of voluntary muscle activation, MRI of the right lower extremity to determine muscle cross-sectional area (CSA), a test of gross motor function (GMFM), and gait analysis were performed at weeks 0 and 12. Significant gains in QF and TS strength and QF CSA were found in the NMES group. Changes in voluntary muscle activation explained approximately 65% and 35% of the change in MVIC force for the NMES and VE groups, respectively. Additionally clinically relevant improvements in walking velocity were found for the NMES group.

1 Introduction

Children with cerebral palsy are able to attain gains in strength and these gains can improve walking velocity [1]. Walking velocity is correlated with function in children with cerebral palsy [2]. Studies examining the relationship between muscle strength and ambulatory status further support the link between strength and function [6]. The purpose of this investigation was to examine whether strength-training programs using either high-force, low-repetition neuromuscular electrical stimulation (NMES) or voluntary effort (VE) could improve strength, gross motor function, and gait in children with spastic diplegic cerebral palsy (SDCP). As strengthening programs become recognized as a therapeutic option for children with cerebral palsy, investigating which type of strengthening regime can most improve function is paramount.

2 Methods

Ten children with SDCP (7-13 y/o) were placed in either the NMES (N=5) or VE (N=5) strength training groups. Percutaneous electrodes were implanted near the femoral nerve to activate the quadriceps femoris (QF) and near the motor point for either the medial (1 electrode, N=3) or for both the medial and lateral gastrocnemius (2 electrodes, N=2) portions of the triceps surae (TS) muscles. Both NMES and VE subjects trained by performing 15, 15-sec duration, isometric contractions of each muscle group 3X/week for 12 weeks. NMES group muscle contractions were elicited using a current amplitude of 20mA and frequency of 50pps. The force was dosed to achieve maximum tolerated isometric contraction by adjusting the pulse duration between 5-200μs (mean dose at 12 weeks QF = 130% maximum voluntary isometric contraction (MVIC); TS = 61% MVIC). The VE group exercised analogously using MVICs. At weeks 0 and 12, isometric strength, voluntary muscle activation, and fat-free muscle cross-sectional area were assessed. Isometric strength was tested using a dynamometer (KinCom, Chattecx, Chattanooga, TN). Voluntary muscle activation was assessed using a superimposed electrical stimulation technique during strength testing [3]. Fat-free muscle cross-sectional area (CSA) was assessed using MRI (GE Medical Systems, Waukesha, WI). Gross Motor Functional Measure (GMFM) testing and instrumented gait analyses were performed at weeks 0 and 12 of training. Gait data were collected using a 7-camera motion analysis system and processed using Vicon Clinical Manager (Vicon, Oxford Metrics, Lake Forest, CA). A “normalcy index”, which is a composite score of gait function, was calculated for each session to quantify the amount that specific combinations of gait parameters deviated from gait parameters of typically developing children [7]. One-tailed paired *t*-tests were used to test improvements in strength, voluntary muscle activation, muscle CSA, walking velocity, and normalcy index following 12 weeks of training. Simple linear regressions were performed to examine if changes in voluntary muscle activation or CSA were related to changes in MVIC force.

3 Results

In figure 1, the increase in QF and TS forces after training were significant for the NMES group (t = -4.90; p = 0.004), but not for the VE group (t = -0.93; p = 0.20).

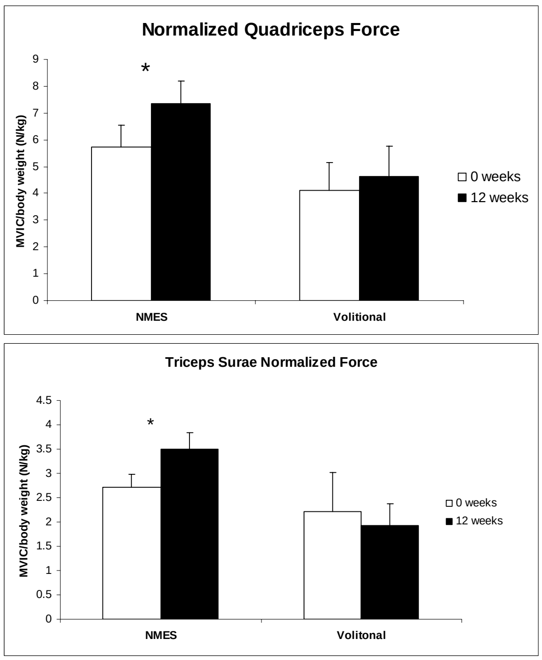

Figure 1: *QF (top) and TS (bottom) force production normalized to bodyweight (N/kg) before and after either a NMES or VE strength-training program. (* $p < 0.05$)*

Voluntary muscle activation only improved significantly for the QF of the VE group (t = -2.48; p = 0.034); however, a trend appeared for the NMES group (t = -1.678; p = 0.084). When voluntary muscle activation data was collapsed across muscle groups, changes in activation could explain approximately 65% (p = 0.005; Figure 2) and 35% (p = 0.061) of the changes observed in the MVIC force in the NMES and VE groups, respectively. The only significant increase in fat-free CSA occurred in the QF of the NMES group (t = -4.459; p = 0.01; Figure 3), and changes in CSA did not relate to changes in voluntary force production (r^2 = 0.001; F = 0.007; p = 0.933).

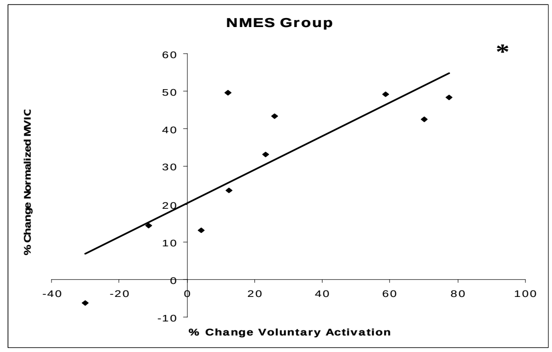

Figure 2: *The relationship between the percent change in voluntary muscle activation and the percent change in MVIC force in the NMES group. (* $p < 0.05$)*

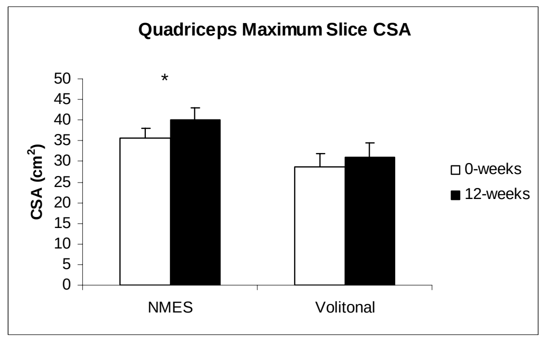

Figure 3: *Maximum fat-free CSA of the QF before and after a NMES and VE strength-training program. (* $p < 0.05$)*

Neither group had significant changes in GMFM dimensions 4 and 5. The normalcy index tended to improve for the VE group (t = 2.00; p = 0.058); however, the NMES group demonstrated an improvement in walking velocity after 12 weeks of training (t = -3.25; p = 0.011; Figure 4).

4 Discussion and Conclusions

This study provides evidence that high-force, low-repetition contractions elicited by a percutaneously implanted NMES system can be used to make gains in force production in the QF and TS of children with SDCP. Previous studies (5,9) have unsuccessfully attempted to use NMES to produce force gains in children with SDCP; however, these studies failed to employ principles of NMES that have been shown to improve force generation after training in adult populations [4][8].

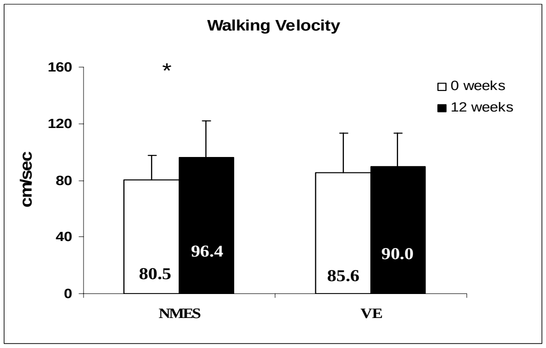

Figure 4. *Walking velocity across weeks 0 and 12 of strength training. (* p < 0.05)*

We examined two mechanisms that could contribute to gains in force production (voluntary muscle activation and fat-free CSA) after strength training. The gains in force production for both the NMES and VE group were best explained by changes in the voluntary activation. Although, were did observe a significant increase in QF CSA, there was no relationship to the amount of increased force output.

Functional gains were made in walking velocity for the NMES group, and these gains are approximately twice the magnitude observed by studies with greater numbers of subjects [1].

Although changes in GMFM scores in the NMES group were of similar magnitude as studies with greater subject numbers [1], the changes were not significant. Interestingly, despite no significant changes in QF and TS strength and walking velocity, the VE group demonstrated trends for improvement in the normalcy index score for gait. This perplexing finding may be related to the already low normalcy index demonstrated by the NMES group and/or to the choice of variables included in the normalcy index.

Therapeutic treatment for children with SDCP typically involves multiple strategies aimed at improving both strength and motor control. This study, however, focused on determining the effects of strengthening with NMES or VE in isolation. Previous research has established that improvements in gait kinematic parameters and function can be achieved with isometric NMES strength training in adults without central nervous system dysfunction [4][8]. Although the results of this study are preliminary, we provide proof of concept that isometric strengthening with NMES in children with SDCP can produce force augmentation in the QF and TS. Additional subjects, however, will be required to determine the relative effectiveness of training using NMES *versus* VE on strength, function and gait parameters. Future investigations could include optimizing the parameters included in the normalcy index, investigating additional types of NMES and VE exercise, and investigating the effects of strength training on joint kinetics.

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