Effect of Fine Wire Electrode Insertion on Gait Patterns in Children with Hemiplegic Cerebral Palsy

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Gait & Posture, Vol. 37, No. 2 (February 2013): 251-257. DOI.

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Abstract

Background

Fine wire electromyography (EMG) is commonly used for surgical decision making in equinovarus foot deformity. However, this invasive technique may have the unwanted effect of altering the gait of children with cerebral palsy (CP). The purpose of this study was to determine if fine wire insertion into the posterior tibialis muscle affects temporal-spatial parameters and hindfoot kinematics during gait in children with equinovarus secondary to hemiplegic CP.

Methods

12 children with hemiplegic CP who presented with an equinovarus foot (mean age 12.5 yrs, four right-sided, eight left-sided) were recruited. Temporal-spatial parameters and 3-D segmental foot and ankle kinematic gait data were collected utilizing standard gait analysis and the Milwaukee Foot Model (MFM). Three representative trials with and without fine wire electrode insertion were compared to determine the effect of electrode placement in the posterior tibialis on temporal spatial-parameters and hindfoot sagittal, coronal and transverse plane kinematic peaks, timing of kinematic peaks, and excursions.

Results

No significant differences in any temporal-spatial or kinematic parameters were observed between “with wire” and “without wire” conditions. Strong correlations were observed among the gait parameters, with the exception of cadence, for the two conditions.

Discussion

Fine wire insertion into the posterior tibialis had no measurable effect on the gait of individuals with equinovarus secondary to hemiplegic CP. This suggests that the simultaneous collection of segmental foot and ankle kinematics and fine wire EMG data of the posterior tibialis is acceptable for surgical decision making in this patient population.

Keywords

Cerebral palsy, Equinovarus, Electromyography

1. Introduction

The use of electromyographic (EMG) patterns for surgical decision making in the lower extremities of children with cerebral palsy (CP) has become commonplace, and more recently it has been used to assist with understanding the pathomechanics associated with equinovarus foot [1]. A combination of surface electrodes for the more superficial musculature (anterior tibialis and gastrocnemius) and fine wire electrodes for deeper musculature (posterior tibialis) is used to determine the primary neuromuscular contributor(s) of the deformity [2]. Previously reported EMG studies have demonstrated that varus deformity in children with hemiplegic CP resulted from the anterior tibialis alone in 34% of cases, posterior tibialis alone in 33%, both muscles in 31%, and muscles other than the anterior or posterior tibialis in 2% [3]. In order to reliably use this assessment technique the question must be answered as to whether the introduction of a fine wire electrode alters the existing gait pattern, as young children can experience a combination of pain, anxiety, and discomfort

associated with the technique. This becomes problematic when EMG and kinematic data are collected simultaneously for the purpose of surgical decision making.

Fine wire electrodes have been found to result in alterations in temporal-spatial parameters in children with diplegic CP [4]. Specifically, significant reductions were identified in cadence, walking velocity, step length of the measured limb, and step length of the non-measured limb when children were instructed to walk at a self-selected velocity. Although these findings implied that caution should be taken when utilizing these data collected simultaneously with 3-D kinematics for surgical decision making, it must be noted that all of the measures were temporal-spatial parameters. Fatigue might have been another factor for the reported gait alterations since the internal electrode trials were always conducted last. Also, this study only examined children with diplegic CP. Equinovarus deformity is most common in children with hemiplegic CP who have consistently been described as having improved gait and lower extremity function compared to children with diplegia [5].

In addition to temporal-spatial parameters, 3-dimensional hindfoot kinematics can provide quantitative data regarding possible alterations in walking due to fine wire insertion into the posterior tibialis. A method for calculating hindfoot kinematics has been described by Kidder et al. and has been validated for use in children [6], [7]. The Milwaukee Foot Model (MFM) is a four-segment foot and ankle kinematic model that uses passive surface markers to quantify motion of the tibia, hindfoot, forefoot and hallux. Unique to the MFM is the use of radiographic offset measurements in anterior/posterior, lateral, and a coronal-plane hindfoot view to relate the underlying orientation of the bony anatomy to the surface markers, i.e. neutral referencing [8]. The kinematics are expressed with the tibia referenced to the global coordinate axes, and the remaining segments are represented in a distal relative to the next proximal segment relationship using an Euler System.

The purpose of the present study is to determine if fine wire insertion into the posterior tibialis affects the gait pattern of children with hemiplegic CP and equinovarus. We tested the hypothesis that reductions in cadence, walking velocity and step length will be similar in children with hemiplegia to those previously reported for children with diplegic CP. We also hypothesized that fine wire electrode insertion will alter hindfoot sagittal, coronal, and transverse plane kinematics during locomotion. Specifically, we expected that the presence of the inserted electrode would result in earlier onsets and reductions in peak motion, as well as, diminished overall hindfoot excursion (ROM) during the gait cycle.

2. Methods

2.1. Participants

Twelve children with hemiplegic CP (seven males, five females, average age: 12.5 yrs, range: 5–17 yrs). All participants presented with a unilateral equinovarus foot deformity and were recruited for the present study as a part of a diagnostic gait analysis with a plan for possible surgical correction. Four of the participants presented with right-sided hemiplegia, and eight presented with left-sided hemiplegia. Based on the hemiplegic gait classification system established by Winters et al., two participants had a type I pattern, four had a type II pattern, two had a type III pattern, and four had a type IV pattern [9]. All participants had no prior history of orthopedic surgery for equinovarus and had not received botulinum toxin injections within one year prior to evaluation. Children were excluded if they presented with cognitive or behavioral impairments that interfered with their ability to understand and follow basic commands necessary to participate in quantitative gait analysis and a standing weight-bearing X-ray series. All participants gave informed consent according to a University approved protocol.

2.2. Instrumentation

Subjects underwent 3-D gait analysis using a 14-MX camera motion analysis system (VICON, Oxford, UK) collected at 120 Hz. Cadence, walking velocity, and step length were calculated using Vicon Workstation (version 5.2.4) software and the PlugInGait model.

Simultaneously, the Milwaukee Foot Model was employed to measure multisegmental foot and ankle motion [6]. 12 passive 9 mm reflective markers were placed on the tibia, calcaneus, forefoot and hallux. A triad was placed on the proximal phalange to obtain hallux data. Resolution, accuracy, and reliability of the foot and ankle system has been established [10]. The kinematic data were processed and calculated using a custom program in Matlab (Matlab, Mathworks®, Natick, MA, USA).

Fine wire EMG electrode insertion into the posterior tibialis was performed with participants in a seated, reclined position and the measured lower extremity in external rotation. Needle insertion was performed as reported by Yang et al. with a posterior approach under the medial tibial shaft and directed deep along the bone where the muscle lies against the interosseous membrane [11]. A 27 Ga., 30 mm hypodermic needle with paired hook wire electrodes was used. Wire electrode placement into the posterior tibialis was confirmed using pulsed electrical stimulation and visual observation of real time raw EMG display during voluntary contraction. Surface electrode placement on the anterior tibialis was 1/3 of the distance from the lower margin of the patella to the lateral malleolus. Medial gastrocnemius surface electrode placement was 1/3 of the distance from the medial femoral condyle to the bisection of the posterior aspect of the calcaneus [12]. Surface and fine wire data were captured with Vicon Workstation software at a sampling rate of 2160 Hz.

2.3. Experimental protocol

Participants were instructed to walk "at a comfortable walking speed" over a 30 m walkway. A total of 20–30 trials were collected until six representative trials (three "with wire" and three "without wire") were obtained for analysis. The presence of fatigue effects was tested by having the first six participants (Wire 1st Group) undergo the "with wire" trials first followed by the "without wire" trials. The second six participants (Wire 2nd Group) underwent the "without wire" trials first followed by the "with wire" trials. All kinematic data was collected with surface EMG electrodes over the anterior tibialis, gastrocnemius, rectus femoris, and medial hamstrings.

Following gait data collection, participants received a series of weight-bearing radiographs of the foot in the anterior–posterior and lateral views along with a modified hindfoot coronal alignment view [8]. All fine wire electrode placement and specific radiographic offset measurements were obtained by the same author (JK).

2.4. Data analysis

Group averages were calculated using six representative trials from each participant (three "with wire" and three "without wire") and were compared across the gait cycle using two-way, repeated measure analyses of variance. This was performed to determine the effect the of presence of a fine wire electrode in the posterior tibialis and trial order on temporal-spatial parameters, as well as, hindfoot sagittal, coronal and transverse plane kinematic peaks, timing of kinematic peaks, and ROM. Individual change scores were also calculated for the amplitude and timing of kinematic peaks, as well as, hindfoot ROM by subtracting the value obtained from the "without wire" trials from the "with wire" trials. A negative score indicates an earlier onset of peak motion, decrease in peak motion, or decrease ROM with the presence of a wire electrode in the posterior tibialis. Conversely, a positive score indicates a delayed onset of peak motion, increase in peak motion, or increase in ROM with the presence of a wire electrode. Due to multiple comparisons a Bonferroni correction was implemented to minimize the risk of a type I error. This yielded an adjusted alpha value of 0.004.

Once non-significant differences were identified among the variables, Pearson correlation coefficients (*r*) were then calculated to further analyze the association between the gait parameters of the “with wire” trials and the “without wire” trials, as well as, provide an effect size estimate [13]. In accordance with Cohen's Classification, a strong association was defined as an *r* value of greater than 0.70, a moderate to substantial association was defined as an *r* value between 0.30 and 0.70, and a weak association was defined as an *r* value of less than 0.30 [14].

3. Results

3.1. Temporal-spatial parameters

Table 1 shows the temporal-spatial parameters of the measured and non-measured side averaged (with standard error) over all trials for the “with wire” and “without wire electrode” trials. The *p*-values indicate a non-significant effect of the presence of a fine wire electrode on walking speed, cadence, and step length of the measured and non-measured side. Correlation analysis demonstrated strong associations between “with wire” and “without wire” conditions for walking speed ($r = 0.81$, $p = 0.001$), step length of the measured leg ($r = 0.96$, $p \leq 0.0001$), and step length of the non-measured leg ($r = 0.91$, $p \leq 0.0001$). Correlation of cadence between conditions was not significant.

Table 1. Group averages and standard errors (SE) of temporal-spatial parameters with and without a fine wire electrode in the posterior tibialis.

Temporal-spatial gait parameters: group averages			
Variable	**With wire trials average (SE)**	**Without wire trials average (SE)**	***p* value**
Walking speed (m/s)	0.94 (0.05)	0.95 (0.07)	n.s.
Cadence (steps/min)	116.98 (4.32)	118.70 (4.26)	n.s.
Step length: measured leg (m)	0.47 (0.03)	0.46 (0.04)	n.s.
Step length: non-measured leg (m)	0.49 (0.02)	0.50 (0.02)	n.s.

3.2. Hindfoot kinematics

Plots of individual sagittal kinematics with and without the presence of a fine wire electrode are presented in Fig. 1. The first plot shows the Wire 1st group and second plot shows the Wire 2nd group. The “with wire” and “without wire” trials are plotted on top of one another and demonstrate minimal deviation. Fig. 2, Fig. 3 display averages and standard errors of hindfoot kinematic peaks timing of peaks, and ROM in the sagittal, coronal, and transverse planes. Fig. 4, Fig. 5 display the change score of the Wire 1st and Wire 2nd groups for hindfoot peaks, timing of kinematic peaks, and, excursions in the sagittal, coronal and transverse planes. No significant main effect of fine wire insertion, nor interactions of fine wire insertion and trial order, were found for hindfoot peaks, timing of those peaks, and ROM. Correlation analysis of hindfoot kinematics demonstrated strong associations between the conditions for all gait parameters: peak maximum and timing of peak maximum (range: $r = 0.78–1.00$, $p \leq 0.0025$), peak minimum and timing of peak minimum (range: $r \leq 0.89–1.00$, $p \leq 0.0001$), and ROM (range: 0.89–0.99, $p \leq 0.0001$).

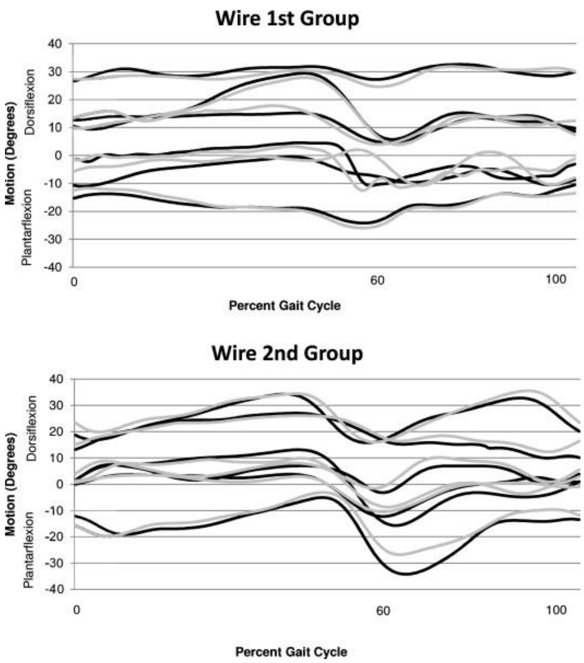


Fig. 1. Individual sagittal plane hindfoot kinematic plots of the twelve participants with (black) and without (gray) a wire electrode in the posterior tibialis. Participants were separated into a "Wire 1st" group or a "Wire 2nd" group depending on when during testing the participants had the wire electrode inserted.

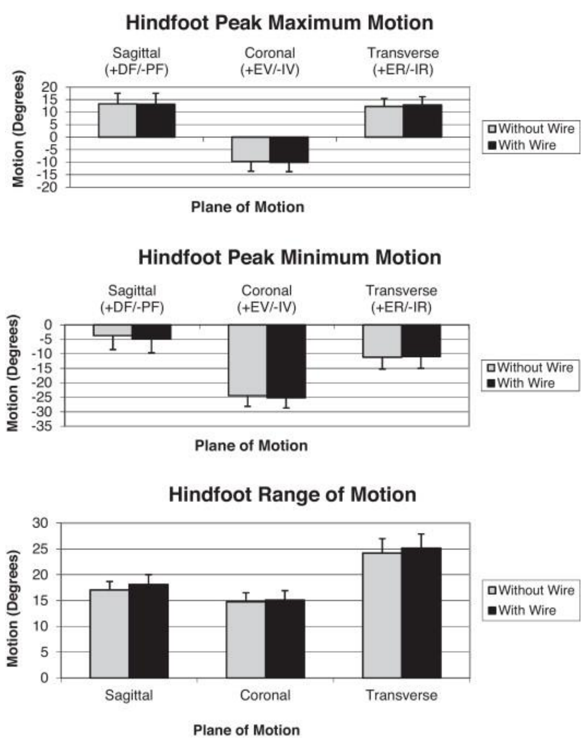


Fig. 2. Group averages and standard error bars of hindfoot kinematic peaks and range of motion during gait in the sagittal, coronal, and transverse planes with (black) and without (gray) a wire electrode in the posterior tibialis.

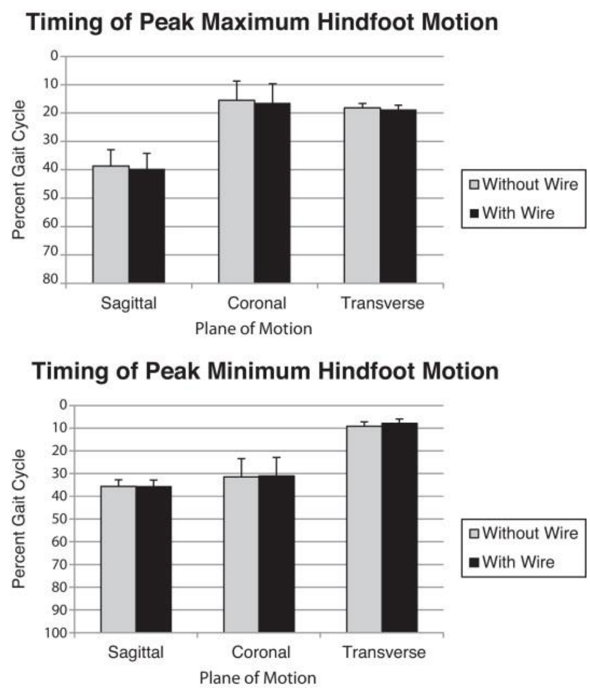


Fig. 3. Group averages and standard error bars of timing of hindfoot kinematic peaks during gait in the sagittal, coronal, and transverse planes with (black) and without (gray) a wire electrode in the posterior tibialis.

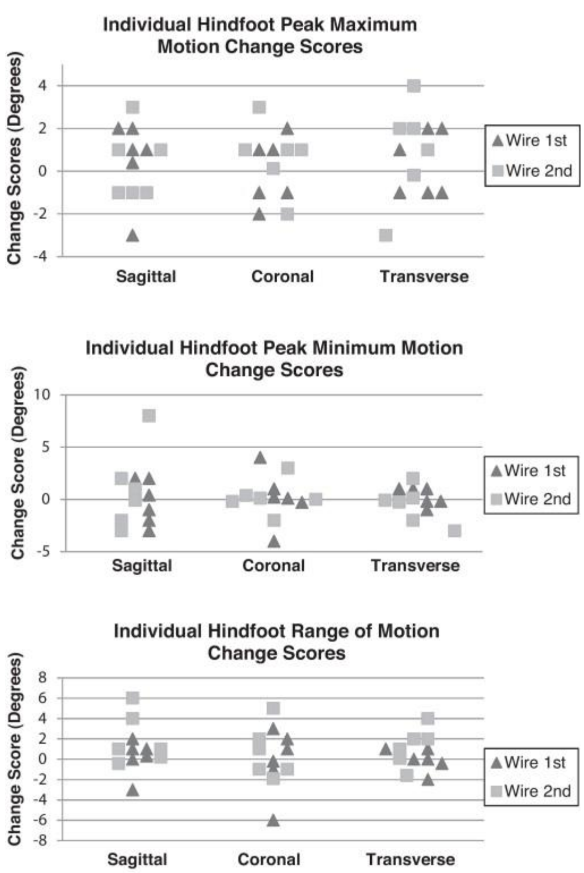
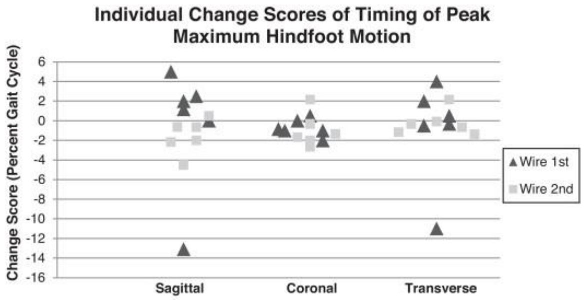


Fig. 4. Individual change scores (CS) in kinematic peaks and range of motion in the sagittal, coronal, and transverse planes stratified by trial order. Black triangles indicate the "Wire 1st" group and the gray squares indicate the "Wire 2nd" group.



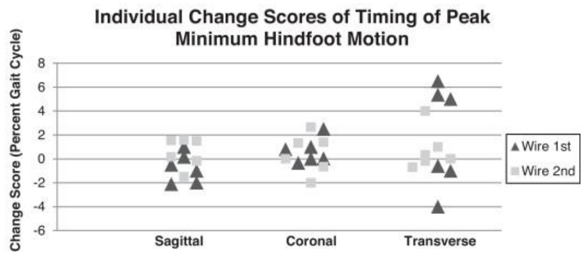


Fig. 5. Individual change scores (CS) in timing of kinematic peaks in the sagittal, coronal, and transverse planes stratified by trial order. Black triangles indicate the “Wire 1st” group and the gray squares indicate the “Wire 2nd” group.

4. Discussion

The central finding of this study is that fine wire electrode insertion into the posterior tibialis does not alter the gait patterns of children with equinovarus secondary to hemiplegic CP. No differences were observed in temporal-spatial parameters or hindfoot kinematics with the introduction of a fine wire electrode in the posterior tibialis. The similarities between the “with wire” and “without wire” trials were further supported with strong correlations among both the temporal-spatial and kinematic variables. Thus, these findings suggest that electromyographic (including fine wire analysis of the posterior tibialis) and kinematic data gathered during a gait analysis can be collected simultaneously without the risk of data corruption for children with equinovarus due to hemiplegia. When executed in such a manner, simultaneous data collection efficiently provides a comprehensive evaluation of the multisegmental and multiplanar nature of equinovarus, as well as, identifies the potential neuromuscular contributor(s) that can aid in surgical decision making.

It has been postulated that the presence of a fine wire electrode can result in pain, alterations in muscular activity, and changes in gait mechanics [2]. Data from the current study identified two potential outliers presenting with either an alteration in peak motion or timing of peak motion isolated to the end of stance phase. After closer observation of their data, the other parameters were consistent between conditions, and any deviations were not considered clinically meaningful. These individuals consistently presented with more severe gait deviations that extended into proximal lower extremity segments (Winters type III and IV gait patterns) [9]. Without excluding their data from the analysis, strong associations were observed among the temporal-spatial and kinematic parameters.

The current study's findings regarding the effect of fine wire insertion on gait are in contrast to previous reports of children with diplegia who demonstrated reductions in temporal-spatial parameters following fine wire insertion into the posterior tibialis [3]. This discrepancy can be explained when reviewing the fundamental differences in the two patient populations. Damiano et al. demonstrated that among participants with CP at a similar level of functional mobility, i.e. Gross Motor Functional Classification System (GMFCS) Level, children with hemiplegia had a tendency to perform consistently better at tasks associated with gait (including measures of walking speed and stride length) and lower extremity function than children with diplegia [5]. These functional differences may result from the presence of one higher functioning, if not normal, lower limb in

children with hemiplegia [15]. Thus, the potential response to a treatment, or in this case an evaluation technique, is likely to vary with different distributions of limb involvement. These findings are further supported by the current study where the presence of a wire electrode did not impact temporal-spatial or kinematic parameters during locomotion in childen with hemiplegia.

The current study also found no effect of trial order on hindfoot kinematic peaks or ROM. Neither the Wire 1st nor Wire 2nd groups demonstrated obvious trends in kinematic change scores. Thus, this patient population should be able to tolerate walking up to 20–30 trials on a 30 m walkway without alterating their gait pattern.

A limitation in the current study was that localization of wire EMG electrode into the posterior tibialis was not performed with imaging techniques, i.e. ultrasound. Verification was performed with the use of pulsed electrical stimulation and viewing real-time raw EMG output during voluntary contraction of the posterior tibialis and flexor hallicus longus. Also, the results of the current study are based on a relatively small, homogenous group of children with flexible equinovarus deformity due to hemiplegic CP. Therefore, generalization of these results to other patient populations commonly presenting with equinovarus deformity, such as diplegic CP, talipes equinovarus, and Charcot–Marie–Tooth, should be cautioned.

In conclusion, the results of the current study demonstrate that fine wire electrode placement into the posterior tibialis did not affect the gait of children with equinovarus secondary to hemiplegic CP. This allows researchers and clinicians to collect multiple forms of data simultaneously during gait analysis to efficiently and effectively determine the etiology of the equinovarus deformity for surgical decision making as well as to measure post-operative outcomes.

Conflict of interest statement

No author of this paper has a conflict of interest, including specific financial interests, relationships, and/or affiliations relevant to the subject matter or materials included in this paper.

Acknowledgement

The authors would like to thank Diane Damiano, PhD PT, for her valuable help in the preparation of this manuscript.

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