KINEMATIC GAIT ANALYSIS IN HEMIPLEGIC PATIENTS TREATED WITH PERONEAL FUNCTIONAL ELECTRICAL STIMULATION

Nesrin BÖLÜKBAŞI, M.D., Mehmet BEYAZOVA, M.D., Neşe ÖZGİRGIN*, M.D., Feyza CAYMAZ, M.D., Sevim ORKUN*, M.D.

Gazi University, Faculty of Medicine Department of Physical Medicine and Rehabilitation and Ankara Rehabilitation Center*, Ankara, Turkey
Gazi Medical Journal 5 : 135-140, 1994

SUMMARY: The effect of short-term peroneal functional electrical stimulation (FES) on temporal-distance (TD) variables of gait was investigated in hemiplegic patients with foot drop in a prospective, controlled, before-after trial. 9 patients received peroneal FES for 3 weeks in addition to conventional rehabilitation techniques. A control group of 10 hemiplegic patients were treated only conventionally. TD variables (step and stride length, velocity, cadence, step time and stride length/lower extremity length ratio) were measured by video recording and analyzing technique before and after the trial. The two groups had similar TD values initially. No statistically significant improvement was observed in TD variables in the control group, while step length of the affected side, velocity, cadence and step time of the unaffected side improved significantly in the stimulation group, though FES seemed to increase the gait asymmetry. Peroneal FES proved to be an efficient tool in rehabilitation of hemiplegic gait when gait kinematics was concerned.

Key Words: Hemiplegia, Rehabilitation, Functional Electrical Stimulation, Foot drop, Gait Analysis, Kinematics, Physical Therapy.

INTRODUCTION

Liberson and associates introduced a new era in rehabilitation of hemiplegic patients in 1960, by producing the first portable peroneal functional electrical stimulator (FES) (7). FES has since attracted worldwide interest. It is used in rehabilitation of spinal cord injury, cerebral palsy, multiple sclerosis, as well as hemiplegia (3). Application of FES in hemiplegic patients, as a dynamic orthosis, eliminates foot drop in the swing phase of the gait by stimulating the intact peroneal nerve with the result of ankle dorsiflexion and eversion, thus improving the symmetry of gait. Improvement in ankle dorsiflexion will be reflected in improvement of the movements of hip and knee joints, as well. Disadvantages of surface stimulation have forced to the development of implantable forms which require lower voltage and can be used for longer periods (6, 14, 15, 19, 20). More developed apparatus with three to six channels to stimulate the biomechanically disturbed muscles in hemiplegic gait pattern are currently being used in experimental models (1, 8, 9).

Several studies investigated the effects of peroneal FES on hemiplegic gait by means of quantitative gait analysis which generally involved kinetic assessment (ground reaction force and torque measurements and electromyographical analysis) or kinematic assessment (joint angle measurement and TD variables), or a combination of both (1, 2, 5, 9,
The aim of this study was to evaluate the effects of short-term surface stimulation with peroneal FES on gait kinematics of hemiplegic patients; by a detailed investigation of the TD variables in a prospective, controlled, before-after trial.

**MATERIALS AND METHODS**

**Subjects**: Nineteen hemiplegic patients with a disease duration of at least 3 months were included in the study, 10 as the control group and 9 as the stimulation group. Patient characteristics are presented in Table 1. The etiologic factor was a cerebrovascular accident in all of them. Criteria for applying FES which are published elsewhere were meticulously obeyed (10, 16). Only those patients with the ability to walk on level surfaces for at least 10 m with or without assistance were included in the study. Walking aids were allowed, while orthoses were not, during the study. Locomotor system was evaluated and patients with major limitations or deformities were also excluded. Ambulatory assessment was made initially and at the end according to Functional Ambulation Category developed by the Massachusetts General Hospital (4). Lower extremity length was measured between trochanter major and heel in supine position.

**Electrical stimulation**: A peroneal stimulator with stimulation parameters as 20-60 Hz of frequency, 0.4 ms of stimulus duration and 30-120 V of voltage was used (Microfes, Medikal Elektronik, Ankara, Türkiye). In every subject, the most appropriate electrode position along the peroneal nerve in popliteal fossa and over the head of fibula was determined by electrophysiological testing to produce adequate ankle dorsiflexion and/or evasion, as necessary. The pulse amplitude was adjusted to yield the best functional movement. Surface stimulation with peroneal FES during ambulation was performed in 9 of the patients for half an hour a day, 5 days a week, during a period of 3 weeks. Conventional and neurophysiological rehabilitative measures according to Brunström were pursued in both groups during the trial.

**Gait analysis**: TD variables of kinematic gait assessment were used for gait analysis. Patients were asked to walk with their most comfortable speed, twice, on a 10 m long platform on which metric and centimetric scales were marked. Video recording was performed using both close and distant recording techniques in frontal and lateral planes, prior to and after the treatment. The post-treatment recordings in the stimulation group were carried out first without FES, and then under stimulation, in order to rule out any possible carry-over effect of stimulation. Data were collected and stored so as to analyze TD variables all at once.

Video records were analyzed on a video player with features of frame freezing and slow motion. The steps in the first and last 2 meters of gait were ignored to maintain the stereotypical pattern of gait. The remaining steps in the middle 6 m of the plat-

<table>
<thead>
<tr>
<th>Control Group</th>
<th>Stimulation Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n)</td>
<td>10</td>
</tr>
<tr>
<td>Age (mean ± SD)</td>
<td>54.5 ± 10.7</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
</tr>
<tr>
<td>Female</td>
<td>3</td>
</tr>
<tr>
<td>Disease duration (months, mean ±SD)</td>
<td>3.8 ± 1.3</td>
</tr>
<tr>
<td>(range)</td>
<td>(3 - 7)</td>
</tr>
<tr>
<td>Side of paralysis</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>4</td>
</tr>
<tr>
<td>Right</td>
<td>6</td>
</tr>
<tr>
<td>Lesion</td>
<td></td>
</tr>
<tr>
<td>Cerebral infarction</td>
<td>5</td>
</tr>
<tr>
<td>Cerebral hemorrhage</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1: Patient characteristics.
form were measured one by one, by frame freezing method and mean values were calculated. Velocity and cadence were estimated by the help of chronometrical property of the video recorder.

The TD variables investigated were velocity (m/s), cadence (steps/min), step length (cm, for both sides), stride length (cm), step time (seconds, for both sides, step length / velocity), and stride length/lower extremity length ratio.

**Statistical analysis**: Mann-Whitney U Test was used for statistical comparison of TD values between the two groups in the beginning and at the end of the trial. The effect of treatment on TD variables in each group was assessed by Wilcoxon Matched-Pairs Signed Ranks Test. SPSS software package was used for statistical analyses.

**RESULTS**

As can be seen in Table 1, the two study groups were similar except for disease duration which was significantly higher in the stimulation group (p<0.05).

None of the patients in the stimulation group had any severe complaint or skin reaction resulting from the stimulation.

Table 2 demonstrates the functional ambulatory assessment in both groups prior to and after the treatment period. Two patients in the control group advanced from grade II to grade III, while one patient in the stimulation group showed a progress from grade III to IV, and one from grade IV to V, after the treatment period.

Table 3 displays the mean TD values in both groups in the beginning and at the end of the treatment. The comparison of TD values between the stimulation and control groups are shown in Table 4. All values for TD variables for both of the two groups before treatment were alike, except for step time of the affected side which was longer in the control group (p<0.05). The comparison of the two groups at the end of the trial (TD values obtained without stimulation were used for the stimulation group) yielded significant improvement in step length of the affected side, velocity, cadence, stride length/lower extremity length ratio, and step time of both sides.

Statistical comparison of TD values before and after treatment in each group is demonstrated in Table 5. The effect of conventional treatment on TD values were found to be insignificant (p>0.05) in the control group, while, statistical comparison of TD values in the stimulation group before and after treatment period

<table>
<thead>
<tr>
<th>Control Group</th>
<th>Stimulation Group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BT</strong></td>
<td><strong>AT</strong>*</td>
</tr>
<tr>
<td>Grade I</td>
<td>1</td>
</tr>
<tr>
<td>Grade II</td>
<td>2</td>
</tr>
<tr>
<td>Grade III</td>
<td>2</td>
</tr>
<tr>
<td>Grade IV</td>
<td>5</td>
</tr>
<tr>
<td>Grade V</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10</td>
</tr>
</tbody>
</table>

* Before treatment  ** After treatment

Table 2: Functional ambulatory assessment before and after the treatment period.

<table>
<thead>
<tr>
<th>Control Group (N=10)</th>
<th>Stimulation Group (N=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BT</strong> Mean</td>
<td><strong>AT</strong>* Mean</td>
</tr>
<tr>
<td>Without Stimulation Mean</td>
<td>Under Stimulation Mean</td>
</tr>
<tr>
<td>step length (cm)</td>
<td></td>
</tr>
<tr>
<td>affected side</td>
<td>33.6</td>
</tr>
<tr>
<td>unaffacted side</td>
<td>26.9</td>
</tr>
<tr>
<td>stride length (cm)</td>
<td>60.7</td>
</tr>
<tr>
<td>velocity (m/s)</td>
<td>0.33</td>
</tr>
<tr>
<td>cadence (steps / min)</td>
<td>87.1</td>
</tr>
<tr>
<td>step time (seconds)</td>
<td></td>
</tr>
<tr>
<td>affected side</td>
<td>1.07</td>
</tr>
<tr>
<td>unaffected side</td>
<td>0.82</td>
</tr>
<tr>
<td>SL / LE strength</td>
<td>0.71</td>
</tr>
</tbody>
</table>

* Before treatment  ** After treatment  *** Stride length / lower extremity length ratio

Table 3: TD values before and after the treatment period (mean ± SD)
<table>
<thead>
<tr>
<th>Before Treatment</th>
<th>After Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td><strong>Step length</strong></td>
<td></td>
</tr>
<tr>
<td>affected side</td>
<td>NS</td>
</tr>
<tr>
<td>unaffected side</td>
<td>NS</td>
</tr>
<tr>
<td>Stride length</td>
<td>NS</td>
</tr>
<tr>
<td>Velocity</td>
<td>NS</td>
</tr>
<tr>
<td>Cadence</td>
<td>NS</td>
</tr>
<tr>
<td>Step time</td>
<td></td>
</tr>
<tr>
<td>affected side</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>unaffected side</td>
<td>NS</td>
</tr>
<tr>
<td>SL / LEL*</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Stride length / lower extremity length ratio

Table 4: Statistical comparison of TD values between the control and stimulation groups before and after the treatment period (Mann-Whitney U Test).

No significant differences were observed in the stimulation group when evaluated under and without stimulation at the end of the trial, though TD values under stimulation were slightly lower

<table>
<thead>
<tr>
<th>Control group (n=10)</th>
<th>Stimulation group (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P</strong></td>
<td><strong>BT vs AT</strong></td>
</tr>
<tr>
<td><strong>P</strong></td>
<td><strong>P</strong></td>
</tr>
<tr>
<td><strong>Step length</strong></td>
<td></td>
</tr>
<tr>
<td>affected side</td>
<td>NS</td>
</tr>
<tr>
<td>unaffected side</td>
<td>NS</td>
</tr>
<tr>
<td>Stride length</td>
<td>NS</td>
</tr>
<tr>
<td>Velocity</td>
<td>NS</td>
</tr>
<tr>
<td>Cadence</td>
<td>NS</td>
</tr>
<tr>
<td>Step time</td>
<td></td>
</tr>
<tr>
<td>affected side</td>
<td>NS</td>
</tr>
<tr>
<td>unaffected side</td>
<td>NS</td>
</tr>
<tr>
<td>SL / LEL*</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Before treatment versus after treatment without stimulation
** Before treatment, under and versus without stimulation.
*** After treatment, under and versus without stimulation.

Table 5: Statistical comparison of TD values after treatment period in each group (Wilcoxon matched - pairs signed - ranks test).

Discussion

Patients with duration of hemiplegia of at least three months were chosen for the study to eliminate the effect of neurogenic recovery occurring in this period. Therefore, the observed improvement in the stimulation group was assumed to be due to the effect of FES to a great extent, whereas neurogenic recovery may have contributed to the improvement in the control group, for the stimulation group consisted of patients with a much longer disease duration.
on (26.6 months versus 3.8 months). However, tho-
ugh statistically insignificant, the stimulation group
was younger (mean age 46.4 versus 54.5 years) which
may have been advantageous for the motiva-
tion and compliance to the treatment and may have
effected the treatment outcome. Functional ambu-
laratory assessment also suggested that the stimula-
tion group was advantageous in the beginning, but
this was presumably attributable to the better ad-
justment of patients to walk because of a longer di-
ase duration. Any argument about the effect of
type, localization, side and extent of insult would
be debatable. However, the groups matched each
other for TD variables initially.

Assessment of TD variables is proved to be effi-
cient for an objective follow-up of walking ability
of hemiplegics during rehabilitation (11). Video-
recording and analyzing technique for TD varia-
bles, although time-consuming, provides reliable
data and is inexpensive. The authors, in a previous
study (12), concluded that most TD variables are
well correlated with velocity which is known as the
best parameter to reflect ambulatory capacity (18).
Increases in velocity and cadence in the stimulation
group both under and without stimulation sugges-
ted that improvement in gait was not just functional,
but also due to some therapeutic effect.

In stimulated patients, the increase in the step
length of the affected side seemed to increase the
asymmetry of gait, which was probably due to:

a. The anxiety of patient due to application of an
electrical equipment which resulted in a reflex self-
protection (prolongation of the step),

b. Activated flexor synergy which causes knee
and hip flexion resulting in a delay for propagating
the leg.

c. The delay in extensor mechanism by continu-
ous stimulation of ankle dorsiflexors between heel
off and heel strike. The similar results obtained with-
out stimulation remains to be explained, however.
Stimulation terminating in the middle of the stance
phase might be preferable to eliminate this effect.
Nevertheless, the step duration was slightly de-
creased in both sides, both under and without stimula-
ton, consistent with the results of Radil who con-
cludes that FES shortens the step duration (13).

Stride length/lower extremity length ratio de-
monstrates whether a subject is taking a stride
length appropriate for his height and the optimum
ratio is around 1.5 for normals. This ratio also im-
proved to a great extent in the stimulation group whi-
le it deteriorated slightly in the control group after
the treatment period.

Long-term stimulation with peroneal FES is
claimed to have therapeutic effect, by decreasing
the tonic activity of the calf muscles, increasing iso-
metric strength of dorsiflexors and reducing Achil-
les reflex activity, resulting in improvement of vo-
nuntary control of ankle movements, probably due
to central reciprocal neurogenic mechanisms (2,
10, 14, 16). The non-selective effect of electrical sti-
umulation adjusted to produce the maximal move-
ment could be expected to improve the disturbed
muscle metabolism as well (10). Therefore, both a
central and also a peripheral mechanism are invol-
ed in the therapeutic effect of electrical stimula-
tion. Although the post-stimulatory improvement
has been clinically observed in many instances, the-
re are few papers that verify its existence by objecti-
ve measurements and controlled trials (2). Merletti
gave statistical support for muscle force recovery
after electrical stimulation (10). Strojinik et al obser-
vied improvement in symmetry investigating the
ground reaction forces by force sensors (15). Boga-
taj et al reported improvement in posture and endur-
ance, as well as a faster and more efficient gait; ac-
cording to several TD variables such as stride time,
stride length and velocity and ground reaction force
measurements (1). According to Takebe who in-
vestigated the effect of peroneal stimulation on gait
by electrogoniometric and electromyographic as-
sessments, the recovery of the dorsiflexion of the
ankle during the swing phase was not due to the use
of the flexion synergy with the excessive flexion of
the hip and knee joints; but it was due to the recov-
ery of the tibialis anterior muscle, and with improve-
ment of the function of the affected side, func-
tional improvement of the unaffected side is also ob-
erved. The improvement of the gait even without
the stimulator, suggested that the effect of the sti-
umulator was not due to immediate effect but due to
some accumulated training or biofeedback effect
during five weeks (17). The results of this study
strongly confirmed the therapeutic effect of pero-
neal FES on gait kinematics, as well as its func-
tional contribution, in a fairly short period.

In conclusion, peroneal FES, although seemed
to increase the asymmetry of gait, is an appropriate
rehabilitation technique in selected hemiplegic pa-
tients who have practically normal strength but who
lack control, and is useful in the neurogenic recovery period for longer durations, both as a walking aid and for muscle reeducation as a proprioceptive neuromuscular facilitation technique.

Acknowledgement: The authors express their appreciation to Ahmet Balci M.D and Ayşen Türeç for their invaluable technical support for this study.

Correspondence to: Dr. Nesrin BÖLKBAŞI
Gazi Üniversitesi Tip Fakültesi
Fiziksel Tıp ve Rehabilitasyon
Anabilim Dalı
Beşevler
06500 ANKARA - TÜRKİYE
Phone: 312 212 10 00 / 5214

REFERENCES


