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

Nesrin BÖLÜKBAŞI, M.D., Mehmet BEYAZOVA, M.D., Neşe ÖZGİRGİN*, 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
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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 apparatti 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, 11, 15, 17, 19). 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 eversion, 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 Brunnström 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-

	Control Group	Stimulation Group
Patients (n)	10	9
Age (mean ± SD)	54.5 ± 10.7	46.4 ± 15.9
Sex		
Male	7	8
Female	3	1
Disease duration		
(months, mean ±SD)	3.8 ± 1.3	26.6 ± 37.4
(range)	(3 - 7)	(3 - 120)
Side of paralysis		
Left	4	6
Right	6	3
Lesion		
Cerebral infarction	5	8
Cerebral hemorrhage	5	1

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 af-

	Control Group		Stimulation Group	
	BT*	AT**	BT*	AT**
Grade I	1	1	-	-
Grade II	2	-	-	-
Grade III	2	4	1	-
Grade IV	5	5	5	5
Grade V	-	-	3	4
TOTAL	10	10	9	9

* Before treatment ** After treatment

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

	Control Group (N=10)				Stimulation Group (N=9)					
	BT*		AT**		BT*		AT**			
							Without Stimulation		Under Stimulation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
step length (cm)										
affected side	33.6	8.7	30.2	9.3	38	14.5	43.5	18.8	43	15.8
unaffected side	26.9	10.8	25.8	7.8	36.3	16.9	37.7	18.5	36.1	18.1
stride length (cm)	60.7	15.8	56.7	14.1	74.8	31.1	81.5	32.5	79.7	33.6
velocity (m/s)	0.33	0.1	0.29	0.07	0.46	0.21	0.57	0.26	0.54	0.23
cadence (steps / min)	87.1	12.7	64.1	6	76.3	10.5	88.8	14.7	86.9	11.2
step time (seconds)										
affected side	1.07	0.31	1.03	0.17	0.85	0.12	0.8	0.14	0.81	0.13
unaffected side	0.82	0.3	0.88	0.23	0.79	0.15	0.65	0.18	0.65	0.14
SL / LEL ***	0.71	0.17	0.66	0.41	0.88	0.36	0.96	0.37	0.93	0.39

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

Table 3 : TD values before and after the treatment period (mean ± SD)

	Before Treatment	After Treatment
	P	P
Step length		
affected side	NS	< 0.05
unaffected side	NS	NS
Stride length	NS	NS
Velocity	NS	< 0.05
Cadence	NS	< 0.001
Step time		
affected side	< 0.05	< 0.005
unaffected side	NS	< 0.05
SL / LEL*	NS	< 0.05

* 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).

	Control group (n=10)		Stimulation group (n=9)	
	P	BT vs AT*	BT vs AT**	AT vs AT***
		P	P	P
Step length				
affected side	NS	< 0.05	< 0.05	NS
unaffected side	NS	NS	NS	NS
Stride length	NS	NS	NS	NS
Velocity	NS	< 0.05	< 0.05	NS
Cadence	NS	< 0.05	< 0.05	NS
Step time				
affected side	NS	NS	NS	NS
unaffected side	NS	< 0.05	< 0.02	NS
SL / LEL ratio	NS	NS	NS	NS

* Before treatment versus after treatment without stimulatin ** Before treatment versus after treatment under 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).

ter treatment, without and under stimulation showed significant improvement in most of the variables. The step length of the affected side in the control group was slightly reduced after treatment ($p>0.05$); however, in the stimulation group, the same variable increased significantly ($p<0.05$), both under and without stimulation, while step length of the unaffected side remained unchanged. No significant changes were observed in stride length in either group, though it increased slightly in the stimulation group due to the increase in step length of the affected side, as described above. Velocity and cadence increased significantly in the stimulation group after the treatment period both under and without stimulation ($p<0.05$), in contrast to the control group where it showed a negligible decline. Stride length / lower extremity length ratio was insignificantly higher in the stimulation group when compared to the control group, both initially and at the end (under and without stimulation, $p>0.05$). The temporal asymmetry was obvious in the control group and step time was longer in the affected side, as was the case with step length, both initially and at the end. The step time in the stimulation group displayed a rather symmetrical pattern initially, while significant decrease in the unaffected side was encountered at the end.

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 ($p>0.05$).

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 (26.6 months versus 3.8 months). However, though statistically insignificant, the stimulation group was younger (mean age 46.4 versus 54.5 years) which may have been advantageous for the motivation and compliance to the treatment and may have effected the treatment outcome. Functional ambulatory assessment also suggested that the stimulation group was advantageous in the beginning, but this was presumably attributable to the better adjustment of patients to walk because of a longer disease 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 efficient for an objective follow-up of walking ability of hemiplegics during rehabilitation (11). Videorecording and analyzing technique for TD variables, although time-consuming, provides reliable data and is inexpensive. The auhors, 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 suggested 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 continuous stimulation of ankle dorsiflexors between heel off and heel strike. The similar results obtained without 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 decreased in both sides, both under and without stimulation, consistent with the results of Radil who concludes that FES shortens the step duration (13).

Stride length/lower extremity length ratio demonstrates 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 improved to a great extent in the stimulation group while 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 isometric strength of dorsiflexors and reducing Achilles reflex activity, resulting in improvement of voluntary control of ankle movements, probably due to central reciprocal neurogenic mechanisms (2, 10, 14, 16). The non selective effect of electrical stimulation adjusted to produce the maximal movement could be expected to improve the disturbed muscle metabolism as well (10). Therefore, both a central and also a peripheral mechanism are involved in the therapeutic effect of electrical stimulation. Although the post-stimulatory improvement has been clinically observed in many instances, there are few papers that verify its existence by objective measurements and controlled trials (2). Merletti gave statistical support for muscle force recovery after electrical stimulation (10). Strojnik et al observed improvement in symmetry investigating the ground reaction forces by force sensors (15). Bogataj et al reported improvement in posture and endurance, as well as a faster and more efficient gait; according to several TD variables such as stride time, stride length and velocity and ground reaction force measurements (1). According to Takebe who investigated the effect of peroneal stimulation on gait by electrogoniometric and electromyographic assessments, 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 recovery of the tibialis anterior muscle, and with improvement of the function of the affected side, functional improvement of the unaffected side is also observed. The improvement of the gait even without the stimulator, suggested that the effect of the stimulator 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 peroneal FES on gait kinematics, as well as its functional 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 patients 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.

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

REFERENCES

1. Bogataj U, Gros N, Malezic M, Kelih B, Kljajic M, Acimovis R : Restoration of gait during two to three weeks of therapy with multichannel electrical stimulation. Phys Ther 1989; 69 : 319-327.
2. Carnstram B, Larsson LE, Preves TS : Improvement of gait following functional electrical stimulation. Scand J Rehab Med 1977; 9 : 7-13.
3. Gracanin F : Functional Electrical Stimulation. In : Kottke FJ, Stillwell GK, Lehmann JF (eds) Krusen's Handbook of Pysical Medicine and Rehabilitation. Philadelphia : WB Saunders 1982; pp. 372-385.
4. Holden MK, Gill KM, Magliozzi MR, Nathan J, Piehl-Baker L : Clinical gait assessment in the neurologically impaired (Reliability and meaningfulness). Phys Ther 1984; 64 : 35-40.
5. Kljajic M, Bajd T, Stanic U : Quantitative gait evaluation of hemiplegic patients using electrical stimulation orthoses. IEEE Transac Biomed Eng 1975; 22 : 438-441.
6. Kljajic M, Malezic M, Acimovic R, et al : Gait evaluation in hemiparetic patients using subcutaneous peroneal electrical stimulation. Scand J Rehab Med 1992; 24 : 121-126.
7. Liberson WT, Holmquest HJ, Scot D, Dow M : Functional electrotherapy : Stimulation of the peroneal nerve synchronized with the swing phase of the gait of hemiplegic patients. Arch Phys Med Rehab 1961; 42 : 101-105.
8. Malezic M, Kljajic M, Acimovic-Janezic R, Gros N, Krajnik J, Stanic U : Therapeutic effects of multisite electric-stimulation of gait in motor-disabled patients. Arch Phys Med Rehab 1987; 68 : 553-560.
9. Marsolais EB, Kobetic R : Functional walking in paralyzed patients by means of electrical stimulation. Clin Orthop 1983; 175 : 30-36.
10. Merletti R, Zelaschi F, Latella D, Galli M, Angeli S, Sessa MB : A control study of muscle force recovery in hemiparetic patients during treatment with functional electrical stimulation. Scand J Rehab Med 1978; 10 : 147-154.
11. Mizrahi J, Susak Z, Heller L, Najenson T : Variation of time-distance parameters of the stride as related to clinical gait improvement in hemiplegics. Scand J Rehab Med 1982; 14 : 133-140.
12. Özgirgin N, Bölükbaşı N, Beyazova M, Orkun S : Kinematic gait analysis in hemiplegic patients Scand J Rehab Med 1993; 25 : 51-55.
13. Radil T, Syndrova I, Hacik I, Pfeiffer J, Votava J : Attempts to influence movement disorders in hemiparetics. Scand J Rehab Med (Suppl) 1988; 17 : 157-161.
14. Stefanovska A, Gros N, Vodovnik L, Rebersek S, Acimovic-Janezic R : Chronic electrical stimulation for the modification of spasticity in hemiplegic patients. Scand J Rehab Med (Suppl) 1988; 17 : 115-121.
15. Strojnik P, Acimovic R, Vavken E, Simic V, Stanic U : Treatment of drop foot using an implantable peroneal underknee stimulator. Scand J Rehab Med 1987; 19 : 37-43.
16. Takebe K, Kukulka C, Narayan MG, Milner M, Basmajian JV : Peroneal nerve stimulator in rehabilitation of hemiplegic patients. Arch Phys Med Rehab 1975; 56 : 237-240.
17. Takebe K, Basmajian JV : Gait analysis in stroke patients to assess treatments of foot-drop. Arch Phys Med Rehab 1976; 57 : 305-310.
18. Wagenaar RC, Beek WJ : Hemiplegic gait : A kinematic analysis using walking speed as a basis. J Biomech 1992; 25 : 1007-1015.
19. Waters RL, McNeal D, Perry J : Experimental correction of foot drop by electrical stimulation of the peroneal nerve. J Bone Joint Surg 1975; 57-A : 1047-1054.
20. Waters RL, McNeal D, Faloon W, Clifford B : Functional electrical stimulation of the peroneal nerve for hemiplegia. J Bone Joint Surg 1985; 67-A : 792-793.