Rehabilitation of Walking With Electromyographic Biofeedback in Foot-Drop After Stroke

D. Intiso, MD; V. Santilli, MD; M.G. Grasso, MD; R. Rossi, MD; I. Caruso, MD

Background and Purpose  Alterations of gait cycle and foot-drop on the paretic limb are characteristic of stroke patients. Electromyographic biofeedback treatment has been used in rehabilitation of walking, but results are controversial. We performed gait analysis to evaluate the efficacy of electromyographic biofeedback compared with physical therapy.

Methods  Sixteen patients with ischemic stroke were enrolled in the study. The experimental group (4 men, 4 women) received electromyographic biofeedback treatment together with physical therapy. The control group (5 men, 3 women) was treated with physical therapy only. Clinical and functional evaluations before and after treatment were performed using Canadian Neurological, Adams, Ashworth, Basmajian, and Barthel Index scales. Computerized gait analysis was performed in all patients.

Results  Electromyographic biofeedback patients showed significant increased scores on the Adams scale ($P<.05$) and Basmajian scale ($P<.01$). Gait analysis in this group showed a recovery of foot-drop in the swing phase ($P<.02$) after training.

Conclusions  Our data confirm that the electromyographic biofeedback technique increases muscle strength and improves recovery of functional locomotion in patients with hemiparesis and foot-drop after cerebral ischemia. (Stroke. 1994;25: 1189-1192.)

Key Words  • electromyography  • gait  • rehabilitation

Auditory and visual biofeedback (BFB) has been demonstrated to improve the control and/or learning of unintentional or intentional but damaged physiological functions. In rehabilitation, electromyographic BFB (EMG-BFB) is used. This technique is easy to implement and repeat and provides continuous, direct, and objective communication of information between patient and physiotherapist regarding the recovery of deficit. EMG-BFB was used for the first time in 1960 by Marinacci and Horande in patients with spastic hemiparesis. Progressive studies have shown a decrease of spasticity, as well as an improvement of paretic muscle recruitment and of movement range, in treated patients.

EMG-BFB has been used especially for the recovery of foot-drop after stroke. In fact, the rehabilitation of ankle movement is a fundamental step in restoring walking in hemiparetic patients. As is well known, strokes impair the motor phases characteristic of gait. In normal subjects, EMG patterns during ambulation are formed by angular changes and asynchronous, phasic bursts of pretibial and calf muscle activity. These muscles control the raising and dropping of the tip of the foot in swing at the beginning of the support phase. The hemiparetic ankle lacks the ability to switch rapidly and smoothly from an extension pattern in stance to a flexing pattern in swing phase. Despite the positive data, some authors have been reluctant to accept this technique. Mulder et al indicated that EMG-BFB is useful for decreasing spasticity and increasing muscular power but not for the functional recovery of the paretic limb. Consequently, some authors proposed modifications in the technique.

Until a few years ago, it was very difficult to quantify functionally the recovery of motor deficit, but now modern instruments are available to reach this objective.

The aim of this study is to evaluate the efficacy of EMG-BFB treatment in addition to physical therapy in the rehabilitation of foot-drop after stroke and the effect of EMG-BFB on the functional recovery of ambulation.

Materials and Methods

Patients

From the patients admitted to the Rehabilitation Center (IRCCS S. Lucia), we enrolled in the study those patients (aged 40 to 85) with a first ischemic stroke, as documented by computed tomographic scans, and foot-drop deficit of paretic limb.

Patients presenting with neglect, previous neurological diseases, severe deficit of comprehension, global aphasia, or life-threatening diseases, as well as patients with orthopedic disease such as contracture of Achilles tendon and varus, were excluded. We selected patients with decreased strength of the anterior tibial muscle and mild spasticity of the lower limbs. The patients were evaluated by clinical neurological examinations using the Canadian Neurological Scale, Adams scale, and Ashworth scale and a functional study using the Barthel Index scale. The Mini-Mental State Examination was also administered to each patient. Scores ranged from 0 to 30, with a score below 23 indicating cognitive impairment. Patients with a score of 22 were excluded. The Basmajian scale was used to evaluate walking ability.

Instrumental Evaluation: Gait Analysis

Kinesiological evaluation was performed with the ELITE computerized system. This system is based on the registration

Received August 26, 1993; final revision received February 10, 1994; accepted February 11, 1994.

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of light reflected back by markers illuminated by flashing light sources whose direction of emission is coaxial to television cameras. The lighting system comprises a circular ring of infrared light-emitting diodes coaxial with the lenses strobed to obtain sharp pictures without comet-tail effect. The markers are small plastic supports covered with reflective paper, with dimension varying according to the field of vision.17 The great advantage introduced by this system of adopting passive markers is the ability to implement motion analysis without any encumbrance on the subject.

The markers are applied on specific landmarks of the body according to standard models of kinematic acquisition. The model used in our study consisted of six markers located at the following points: anterior-superior iliac spine, greater trochanter, knee, lateral malleus (ankle), fifth metatarsal base, and calcaneus (heel).18,19

The ELITE system calculated the trajectory of each marker in a sagittal plane and represented the displacement of the body segments as a sequence of stick diagrams.20 We analyzed the speed and the length of steps as well as the angular modifications of the ankle at the precise points of the gait cycle, 0% of the step cycle (heel-off) and 50% of the oscillation phase (swing-through). After giving informed consent, the subjects were randomly assigned either to an experimental group or to a control group. The patients in the experimental group were treated with EMG-BFB and physical therapy. The control group received only physical therapy. Physical therapy for each group consisted of standard exercises according to the Bobath method,21 an approach generally used for stroke rehabilitation. In this method, facilitation and inhibition techniques are used with selected sensory inputs to obtain automatic high-quality motor output. Our approach was based on neurofacilitatory techniques. The EMG-BFB group did not undertake standard exercises for dorsiflexion of the foot, while the control group did. All other standard exercises for lower limb according to the Bobath method were undertaken by both groups. Each treatment session lasted 60 minutes, daily, for 2 months.

EMG-BFB Training

The experimental group was treated using a table Satem PT 1015 and a walking Satem EMG Combintrainer PT 9115. The training consisted of two phases. In the first phase, the patients were briefed during two baseline sessions about the technique and learned to contract the anterior tibial muscle to obtain acoustic feedback. The patients then underwent 15 training sessions. In each session, the patient was requested to perform 20 isotonic contractions lasting 5 seconds, followed by regular intervals of 30 seconds of rest, with flexed knee (30°) and relaxed foot in clinostatic position. The therapist applied one pair of biofeedback electrodes to the patient’s skin at the anterior tibial muscle, after first cleaning it with alcohol and allowing it to dry. Recording was performed by means of an integrated surface EMG signal (rectified and averaged signal).

The second phase was performed by means of a portable integrated EMG-BFB, with two baseline sessions aimed at determining the “threshold value” and 15 training sessions with acoustic feedback activated every time the contraction value of the anterior tibial muscle was higher than the threshold value of the baseline session. Audiomonitoring of the EMG signal was performed, and patients were instructed to activate the dorsal flexion of the foot during the swing phase of the gait cycle. When the patient made errors of less than 20% during the session, the threshold of acoustic feedback was increased to 0.30 μV; if errors ranged between 20% and 50% the threshold was increased to 0.10 μV. Beyond this amount of error, the threshold was not increased.

The patients in the control group were evaluated at baseline with EMG-BFB both before and after the physical therapy program. Neurological, functional, and kinesiological evaluations were performed before and after the treatment by a blinded examiner. The statistical analysis was performed using unpaired Student’s t test, regression, and ANOVA analysis.

Results

Sixteen patients were enrolled in the study: 8 patients (4 men, 4 women) composed the EMG-BFB group, and 8 patients (5 men, 3 women) composed the control group. Two patients of this latter group did not complete the rehabilitation program. A 70-year-old man had a new ischemic cerebral lesion after 2 weeks’ enrollment, and a woman, aged 72 years, had a fractured femur as a result of an accidental fall in the first week of treatment. These cases were not calculated in the final statistical analysis.

The clinical characteristics of both groups are reported in Table 1. The basal and final evaluations of neurological scales are reported in Table 2. We found an improvement between basal and final scores of the Adams (P<.05) and Basmajian scales (P<.01) in the EMG-BFB group. No statistical differences were found in the control group. Scores on both Barthel Index and Canadian Neurological Scale showed no significant final improvement in either group. Analysis of individual

| TABLE 1. Clinical Characteristics of the Experimental and the Control Groups |
|-----------------------------|-----------------------------|-----------------------------|
| Sex                        | Experimental Group (n=8)    | Control Group (n=8)         |
|                            | Male: 4, Female: 4          | Male: 5, Female: 3          |
| Mean age, y                | 61.3 (12.3)                | 53.5 (18.5)                |
| Months from onset          | 11.3 (12.6)                | 8.3 (6.0)                  |
| Side                       | Right: 4, Left: 4          | Right: 5, Left: 3          |

M indicates male; F, female; R, right; and L, left. Values in parentheses are SD.

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<th>TABLE 2. Scores of Neurological and Functional Scales in Control and Experimental Groups Before and After Treatment</th>
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Values in parentheses are SD. *P<.05; tP<.01.
cases, however, showed that 4 patients of the experimental group registered increased scores on the Barthel Index and 3 patients an increased score on the Canadian Neurological Scale, whereas only 1 patient of the control group improved on both the Barthel and Canadian scales. The patients in the EMG-BFB group demonstrated increased values of integrated surface EMG signal, recorded on the anterior tibial muscle, after training either with table BFB \( (P<.005) \) or walking BFB \( (P=.002) \) when compared with baseline data (Table 3).

Table 4 reports the basal and final values of speed and step length as analyzed by the ELITE computerized system. No differences were found in step length and velocity between the two groups. EMG-BFB patients showed a significant recovery of ankle dorsiflexion in swing phase compared with the control group \( (P<.02) \).

### Discussion

Our data confirm that the EMG-BFB technique increases muscle recruitment and improves recovery of functional locomotion in patients with hemiparesis and foot-drop after cerebral ischemia. Stroke patients frequently present with foot-drop consisting of a loss of angular dorsiflexion and plantar flexion motion. Their gait cycle is slower with lack of heel strike and toe-off propulsion, while the foot falls in the swing and early stance phases. Very strong spasticity of gastrocnemius and soleus muscles may cause foot-drop counteracting activity of the tibial anterior muscle. In these patients the best use of EMG-BFB is the inhibition training technique to decrease spasticity of the posterior leg muscles. To avoid the influence of spasticity on the activity of anterior tibial muscle, we selected stroke patients with foot-drop who presented mild spasticity of the paretic leg and decreased recruitment of anterior tibial activity. Our results did not show modification of spasticity before and after treatment in either group.

It is well known that ankle-foot orthosis or orthopedic shoes may correct foot-drop. However, the main goal of rehabilitation is the complete recovery of disabled patients. Because of the cumbersome and unaesthetic qualities of orthopedic shoes and ankle-foot orthosis, these measures are generally not acceptable for young and female hemiparetic patients. Orthosis should be used when physical therapy or other treatment does not provide recovery. However, ankle-foot orthosis and orthopedic shoes carry a heavy cost for the national health scheme, and consequently a complete functional recovery in walking rehabilitation is a justifiable objective.

EMG-BFB has been used since 1960 in the rehabilitation of stroke patients, but results and efficacy were questionable. Our results concur with previous studies confirming increased muscle strength and improved range of movement in EMG-BFB-treated patients.\(^2,3,4,9\)

The real issue is whether this improvement can be transformed into a relevant increase of functional competence such as locomotion.

Mulder et al have pointed out that EMG-BFB has not been demonstrated to have a generalized effect in functional gait. However, we performed computerized gait analysis that showed improvement of kinematic parameters after treatment in both groups. Step length and velocity did not increase significantly in either the EMG-BFB patients or the control group.

Mandel et al found a significant increase in speed of walking in EMG-BFB-treated patients compared with control subjects, but they concluded that “it is unclear exactly what the mechanism of change was that accounted for the improvement of the walking speed.”\(^10\)

We quantified dynamic angular modification of the ankle during the gait cycle. Our results showed that EMG-BFB patients showed recovery of ankle dorsiflexion in the swing and early phase of gait despite the fact that they had greater foot-drop than the control group in the baseline examination. Case-by-case evaluation showed that 2 patients in the study group presented a decrease of step length; however, kinesiological analysis showed an improved motor pattern of the gait cycle.

Before treatment these patients presented the loss of heel strike and swing phase in the paretic limb. They clumsily and uncertainly walked on the forefoot, shuffling the foot on the ground. After training, typical kinematic sequences of gait resulted in more skilled locomotion and a shortened stride.
We suggest that EMG-BFB patients learned to insert this acquired motor pattern in a more functional movement in the retrained limb and obtained better results compared with the patients who received only physical therapy. Instead, we noted that during walking EMG-BFB training some patients were more attentive in controlling the specific sequences of deambulation, especially during the swing phase. Sustained attention could condition speed performances.

Furthermore, we found that EMG-BFB patients presented significant recovery on the Basmajian and Adams scales. These data reflect the results of gait analysis. The Adams scale is a global, neurological instrument for cognitive, motor, and sensorial evaluation. EMG-BFB patients improved their score particularly in the motor section of the lower limb. The Basmajian scale can be useful to evaluate locomotion when kinematic parameters cannot be calculated by means of a computerized system. The Canadian Neurological Scale and Barthel Index scores did not increase after treatment in either group. These results could have been accounted for by the clinical characteristics of patients enrolled in the study. We admitted fairly chronic stroke patients in whom changes in functional recovery may occur with more difficulty. A possible bias could be produced by using standard exercises for dorsiflexion of the foot not monitored by EMG-BFB in the control group. Bobath’s exercises are generally used to facilitate motor activity and decrease spasticity, but in some cases this intervention could increase spasticity in the calf and worsen function of the foot during gait. Furthermore, the Ashworth scale would not have picked up only a mild alteration of spasticity. Extra physical therapy during the time the other groups learned EMG-BFB may have provided an alternative basis for evaluation. The EMG-BFB technique together with added physical therapy improved functional recovery of walking ability in stroke patients. However, it should be noted that this technique is very difficult or impossible to perform in patients with neuropsychological dysfunction or sensory disorders.

Contrasting results in previous studies can be explained by differences in EMG-BFB techniques, kinematic evaluation, and the clinical characteristics of patients.

Further studies examining a larger number of patients and focusing on time from stroke, as well as kinesiological analysis to evaluate movement sequences in the hip and knee rather than the paretic ankle, are now required.

Acknowledgments

The authors gratefully acknowledge the collaboration of the physiotherapists E. Cugini and G. Petrini in carrying out this research.
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Stroke. 1994;25:1189-1192
doi: 10.1161/01.STR.25.6.1189

Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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