BIOFEEDBACK TREATMENT OF GENU-RECURVATUM USING AN ELECTROGONIOMETRIC DEVICE WITH AN ACOUSTIC SIGNAL

One-year Follow-up

N. Basaglia, N. Mazzini, P. Boldrini, P. Bacciglioni, E. Conteniti and G. Ferrentesi

From the Division of Rehabilitation and School for Physiotherapists, U.S.L. 31, Ferrara, Italy

ABSTRACT. The aim was to evaluate the effect of a biofeedback electromyogram in the control of curvature of the knee while walking in patients with neurological diseases. Eighteen patients were trained daily for 12.5 sessions on average with an electromyogram attached to the knee, which gave a signal at a threshold value of 180° in order to avoid hyperextension of the knee. The improvement was statistically significant even after one year.

Key words: hemiplegia, biofeedback, genu-recurvatum.

Genu-recurvatum is frequently observed during stance resulting from lesions to the central nervous system. The recurratum gives a "passive" stability to the affected limb during stance but this condition, in hemiplegic patients, is mostly an excessive compensation which tends to establish itself permanently and to interfere negatively in the recovery process.

In fact, this compensation, besides altering the quality and aesthetics of gait, distorts the afferent information by favouring the acquisition of poorly functional walking patterns and an awareness of abnormal body movements in relation to space. Furthermore, the persistence of a recurratum favours shortening of the calf muscles and thus tends to maintain such a position.

Many authors have drawn attention to the risk of anatomical damage involved, with a persisting recurratum. Such impairment is due to changes in load distribution on the articular surfaces and to straining of the posterior part of the capsule and cruciate ligaments.

Anatomical damage may be negligible in patients with a serious neurological outcome, poor walking autonomy, and a reduced stance phase, whereas it becomes a great problem in younger, or less seriously damaged patients whose walking ability is more favourable, in overweight patients, and in those who must maintain a standing position for long periods.

In 1978 Simon et al. (9), by studying the gait of spastic children with cerebral lesions, were able to distinguish at least two types of genu-recurvatum. They described one group in which the recurratum appears early in the stance at about 20% of the gait cycle and another group with a later appearance of the hyperextension of the knee in the mid stance, at about 40% of the gait cycle.

The abnormal response to the stretching of the calf muscles which occurs during tibial advance ment after the sole of the foot has been firmly placed on the ground, could be responsible for the recurratum only in the first group; in fact, the authors did not detect any increase in electromyographic activity of the calf muscles and hamstring in the second group.

Knutson & Richards (6) noticed that recurratum in hemiplegic adults was mostly observed in association with premature activation due to hyperactivity of the stretch reflex of the calf muscles, but it also occurred in patients with abolition or marked lowering of the EMG activity of the parietal limb, and at times in those who presented abnormal co-activation of several of the limb muscles.

Since 1984 (1), our group has been investigating the treatment of hyperextension of the knee in adults with cerebral lesions, using an electromyographic device with auditory feedback (BFb-EGM), which can provide reliable detection and reveal the degree of atactic extension after a pre-established threshold has been overcome.

Few studies have been found in literature, on the treatment of hyperextension of the knee during the stance phase of gait, with biofeedback.

Hogue & McCandless (5) using an electromyographic feedback in 13 hemiplegic patients obtained
Table 1. General information concerning the patients

<table>
<thead>
<tr>
<th>No.</th>
<th>Age</th>
<th>Sex</th>
<th>Sensitivity tact.–kinest.</th>
<th>Aphasia</th>
<th>Walking aids</th>
<th>Treat. days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>M</td>
<td>Unaffected</td>
<td>–</td>
<td>Stick</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>Stick</td>
<td>14</td>
</tr>
<tr>
<td>I.C.P.</td>
<td>5</td>
<td>19</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Stroke with left hemiparesis 6</td>
<td>67</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>71</td>
<td>M</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>65</td>
<td>M</td>
<td>Unaffected</td>
<td>–</td>
<td>Stick-AFO</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>M</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>10</td>
</tr>
<tr>
<td>Head injury with left hemiparesis 11</td>
<td>61</td>
<td>F</td>
<td>Aphasia</td>
<td>–</td>
<td>–</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>17</td>
<td>M</td>
<td>Aphasia</td>
<td>–</td>
<td>–</td>
<td>6</td>
</tr>
<tr>
<td>I.C.P.</td>
<td>14</td>
<td>19</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Stroke with left hemiparesis 15</td>
<td>45</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>8</td>
</tr>
<tr>
<td>16</td>
<td>25</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>5</td>
</tr>
<tr>
<td>Stroke with right hemiparesis 17</td>
<td>63</td>
<td>M</td>
<td>Unaffected</td>
<td>–</td>
<td>–</td>
<td>11</td>
</tr>
<tr>
<td>18</td>
<td>65</td>
<td>F</td>
<td>Unaffected</td>
<td>–</td>
<td>Stick</td>
<td>24</td>
</tr>
</tbody>
</table>

Good results in the control of hyperextension. Koelle & Mandel (7), using an electromyographic feedback to obtain control of the knee during the stance phase in a well-conducted single case study, noted dramatic improvement of the recurvatum. Fernie et al. (4) utilized a similar device to train 19 above-knee amputees in the safe operation of their prosthesis by maintaining the knee joint in extension throughout the stance phase. The authors observed that 15 patients benefited to some degree from the treatment.

In a previous report (2) we presented the markedly positive results we had obtained in 14 patients using the BFB-EGM technique. In the present investigation we aimed at verifying the degree of stability obtained in the control acquired by the patients treated with BFB of genu-recurvatum.

Fig. 1. electromyometer in recurvatum (A) and in correct position in extension (B).

Fig. 2. Histogram relative to 18 patients showing the time taken to walk a free speed and the errors score (deep).

Material and Methods
Eighteen patients with CNS lesions underwent the treatment. Patient selection was based on the following criteria:
- presence of recurvatum of the knee in at least one-third of the steps
- walking unassisted
- no arthritic limitations
- ability to perceive the acoustic signal without presenting sensory difficulties in decoding.

Besides the patient’s personal data, the degree of tactile and kinesthetic sensitivity, presence of disturbed cortical functions, use of walking aids and length of treatment were recorded. Differences in degrees in recurvatum were not taken into consideration. General information concerning the patients is reported in Table 1.

Treatment
The patients were required to put on the electromyo-meter and follow a pre-established walk under the guidance of a physiotherapist. The electromyometer used in our department (3) is a simple device which can be regulated to a "threshold" value equal to the desired joint angle so that the device beeps when the patient exceeds this angle.

It is composed of angular movement compasses whose metallic poles, fixed along the axes of the leg and thigh by means of a velcro strap, articulate on a potentiometer balanced at the level of the fulcrum of the joint (Fig. 1). The potentiometer is connected to an electronic signal processor, whose size and weight are not more than those of a pack of cigarettes, attached to the patient’s belt. In this device there is an auditory signal of varying intensity which emits a continuous, proportional sound every time the patient exceeds a certain degree of extension, and terminates when the knee changes this position.

Initially, the auditory signal was used as a cognitive input capable of activating in the subject the cognitive processes suitable for the acquisition of a specific control of the joint. The patient was therefore asked to concentrate particularly on the behavior of the affected knee by correcting any mistakes indicated by the signal at the moment of activation. Thus, once voluntary control of the knee had been acquired, the patient’s attention was distracted from knee control and the auditory signal was used as a signal for error in a motor sequence which was to become automatic.

The aim was to go from one cognitive activity with careful continuous control of the monitored segment to a rapid, automatic motor activity, less carefully controlled. The tests were carried out for 40 min every day, five days a week. The training was interrupted when the patient achieved a stable reduction in, or elimination of, mistakes for at least 5 consecutive days.

Evaluation
The patients were evaluated at the beginning of treatment, at the end, and 15 days after the end of treatment. 13 patients were also evaluated 30 days, 3 months and 12 months after treatment. The parameters calculated for each patient were:
Table 1. General information concerning the patients

<table>
<thead>
<tr>
<th>No.</th>
<th>Age</th>
<th>Sex</th>
<th>Sensitivity touch–kines.</th>
<th>Aphasia</th>
<th>Walking aids</th>
<th>Treat. days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>M</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>67</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>71</td>
<td>M</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>65</td>
<td>M</td>
<td>Unaffected</td>
<td>-</td>
<td>Stick-AFO</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>M</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>11</td>
<td>62</td>
<td>F</td>
<td>Anesthesia</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>17</td>
<td>M</td>
<td>Anesthesia</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>19</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>43</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>16</td>
<td>25</td>
<td>F</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>17</td>
<td>63</td>
<td>M</td>
<td>Unaffected</td>
<td>-</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>18</td>
<td>65</td>
<td>F</td>
<td>Unaffected</td>
<td>Aphasia</td>
<td>Stick</td>
<td>24</td>
</tr>
</tbody>
</table>

good results in the control of hyperextension. Koehl & Mandel (7), using an electromiographic feedback to obtain control of the knee during the stance phase in a well conducted single case study, noted dramatic improvement of the recurvatum. Fernie et al. (4) utilized a similar device to train 19 above-knee amputees in the safe operation of their prosthesis by maintaining the knee joint in extension throughout the stance phase. The authors observed that 15 patients benefited to some degree from the treatment.

In a previous report (2) we presented the markedly positive results we had obtained in 14 patients using the BFB-EGM technique. In the present investigation we aimed at verifying the degree of stability obtained in the control acquired by the patients treated with BFB of genu-recurvatum.

MATERIAL AND METHODS

Eighteen patients with CNS lesions underwent the treatment. Patient selection was based on the following criteria:

- presence of recurvatum of the knee in at least one-third of the steps;
- walking unassisted;
- no articulator limitations.

- ability to perceive the acoustic signal without presenting sensory difficulties in decodification.

Besides the patient's personal data, the degree of tactile and kinesthetic sensitivity, presence of disturbed cutaneous functions, use of walking aids and length of treatment were recorded. Differences in degrees in recurvatum were not taken into consideration. General information concerning the patients is reported in Table 1.

Treatment

The patients were required to put on the electromiometer and follow a pre-established walk under the guidance of a physiotherapist. The electromiometer used in our department (3) is a simple device which can be regulated to a "threshold" value equal to the desired joint angle so that the device beeps when the patient exceeds this angle.

It is composed of angular movement compasses whose metallic poles, fixed along the axes of the leg and thigh by means of a velcro strap, articulate on a potentiometer balanced at the level of the fulcrum of the joint (Fig. 1). The potentiometer is connected to an electronic signal processor, whose size and weight are not more than those of a pack of cigarettes, attached to the patient's belt. In this device there is an auditory signal of varying intensity which emits a continuous, proportional sound every time the patient exceeds a certain degree of extension, and terminates when the knee changes this position. Initially, the auditory signal was used as a cognitive input capable of activating in the subject those cognitive processes suitable for the acquisition of a specific control of the joint. The patient was therefore asked to concentrate particularly on the behaviour of the affected knee by correcting any mistakes indicated by the signal at the moment of activation. Then, once voluntary control of the knee had been acquired, the patient's attention was distracted from knee control and the auditory signal was used as a signal for error in a motor sequence which was to become automatic.

The aim was to go from one cognitive activity with careful continuous control of the monitored segment to a rapid, automatic motor activity, less carefully controlled. The tests were carried out for 40 min every day, five days a week. The training was interrupted when the patient achieved a stable reduction in, or elimination of, mistakes for at least 5 consecutive days.

Evaluation

The patients were evaluated at the beginning of treatment, at the end, and 15 days after the end of treatment; 13 patients were also evaluated 30 days, 3 months and 12 months after treatment. The parameters calculated for each patient were:
RESULTS

Free speed walking showed significant improvement in error score at the end of treatment and at the control compared with the beginning of treatment (p<0.01, n=18), whereas the time taken to walk 30 m did not show any statistically significant variations (Fig. 2).

Even at maximum speed the decrease in beeps was statistically significant at the end of training as well as at the first control (p<0.01). Similarly, no changes were observed in the time values (Fig. 3).

Fig. 4 shows the values recorded at free speed for 13 patients at the beginning of treatment, at the end of treatment, after 15 days, and after one month, three months, and one year follow-up. The reduction in the number of errors continued to be statistically significant at the one year follow-up (p<0.01) compared with the beginning of treatment, and the values for speed did not show any significant difference.

Fig. 5 refers to the values recorded during the maximum possible speed for the same group of 13 patients. It may be seen that the results did not differ from those obtained at free speed: the time taken did not change significantly in the various tests; moreover, the error score showed a significant improvement at the end of treatment and at the follow-up as compared with the beginning of treatment (p<0.01).

There are few reports in the literature on a follow-up of over one year in patients given BFB.
Fig. 3. Histogram relative to 18 patients showing the time necessary to walk the distance at maximum speed allowed

- the time taken to walk 30 m on flat ground at free speed;
- the time taken to walk 30 m on flat ground at best possible speed;
- the error score: calculated as the percentage of mistakes (recursively during stance) made by each subject during the trials.

The statistical analysis was carried out using the Wilcoxon test for paired data with a level of significance of p<0.01.

RESULTS

Free speed walking showed significant improvement in error score at the end of treatment and at the control compared with the beginning of treatment (p<0.01, n=18), whereas the time taken to walk 30 m did not show any statistically significant variations (Fig. 2).

Fig. 4 shows the values recorded at free speed for 13 patients at the beginning of treatment, at the end of treatment, after 15 days, and after one month, three months, and one year following treatment.

The reduction in the number of errors continued to be statistically significant at the one year follow-up (p<0.01) compared with the beginning of treatment, and the values for speed did not show any significant difference.

Even at maximum speed the decrease in beeps was statistically significant at the end of training as well as at the first control (p<0.01). Similarly, no changes were observed in the time values (Fig. 3).

Fig. 5 refers to the values recorded during the maximum possible speed for the same group of 13 patients. It may be seen that the results did not differ from those obtained at free speed: the time taken did not change significantly in the various tests; moreover, the error score showed a significant improvement at the end of treatment and at the follow-up as compared with the beginning of treatment (p<0.01).

There are few reports in the literature on a follow-up of over one year in patients given BFB

Scand J Rehab Med 21
REFERENCES
2. Basaglia, N., Ferraresi, G., Boldrini, P., Contessi, E. & Faccidom, T.: Geno-reeducation in adult stroke pa-
tients: BFEG goniometric treatment. Preliminary res-
4. Ferone, G., Holdren, J. & Sato, M.: Biofeedback train-
6. Knutsson, E. & Richards, C.: Different types of dis-
7. Kobell, R. & Mandel, A. R.: Joint position biofeed-
8. Songer, B. R. & Cusbaray, D. J.: Biofeedback therapy to achieve symmetrical gait in children with hemip-
9. Simon, S. R., Deutsch, S. D., Nazoo, R. M., Mas-
seer, M. J., Jackson, J. L., Kaushik, M. & Rosen-
thal, R. K.: Geno reeducation in spastic cerebral pa-

KNEE EXTENSOR MUSCLE FUNCTION BEFORE AND AFTER RECONSTRUCTION OF ANTERIOR CRUCIATE LIGAMENT TEAR
Lars-Gunnar Elmqvist,1 Ronny Lorentzen,1 Christer Johansson,1 Mats Långström,2 Markku Fagerlund3 and Axel R. Fugl-Meyer1
From the Departments of Orthopaedics, Rehabilitation Medicine and Diagnostic Radiology, University of Umeå, S-901 85 Umeå, Sweden

ABSTRACT. Knee extensor performance, in 17 subjects with chronic anterior cruciate ligament (ACL) tear, was investigated preoperatively and on four different occasions postoperatively, using isokinetic measurements and electromyography of single maximum and repetitive movements. Preoperatively, maximum mechanical output was comparatively low (internal leg), deteriorating further by 50% in fifteen weeks postoperatively. Endurance also falls markedly. Thereafter knee-extensor performance improved nec-
tensively, mostly during intensive training (14-28 weeks postoperatively) irrespective of the training program used. After one year, maximum performance was still un-
equal but the injured leg had achieved the "normal" pro-
gressive muscular curve. Fatigability/endurance level im-
proved over preoperative values. Muscular work/integrated EMG was stable while EMG's increased. Twenty weeks postoperatively quadriceps area was decreased to 69%, if compared to normal. The early postoperative loss of perform-
ance was evidently caused by loss of muscle mass. Neuro-
muscular relearning appears to be a sizable factor in later recovery. Isokinetic training does not offer any specific advantage in the early muscle rehabilitation after ACL reconstruction.

Keywords: knee joint; exercise therapy; ligaments, artic-
ular; electromyography; muscle contraction; muscular at-
rophy.

Mechanical output of the knee extensors at single maximum manoeuvres has been described in pa-
ients with chronic anterior cruciate ligament (ACL) tear both before (13, 25) and up to about 8 years after reconstruction of the ligament (1, 21, 22). In our previous report (13), we found that before reconstruction of the ACL there was a re-
duced active range of motion and mechanical output, i.e. peak torque (PT) and contraction work (CW). Furthermore, the decrease in mechanical output was not primarily dependent upon muscular hypotrophy or morphological changes. Further inves-
(13) tigations (3) indicated that changes in the nerv-
ous afferent flow from the knee joint could ex-
plain this reduction in performance, probably through a decreased neuromuscular drive.

Fatigability/endurance level (14) of the knee ex-
tensors in patients with ACL tears have hitherto not been thoroughly investigated, either before or af-
after surgical reconstruction. Different postope-
1

terative regimes such as casting and carefully in-
creased motion exercises (19), early mobilization with hinged cast (22) or brace (18), progressive resistance exercises (8) and isokinetic exercises (26) have been used to train this category of pa-
tsients. The advantage of isokinetic training over progressive resistance training has also been shown by some workers (7), although others found no difference between various training programmes (8).

The aim of this study was to analyze the me-
chanical output of the knee extensors at single maximum isometric contractions (90%), and espe-
cially the fatigability of these muscles up to 100 repetitive contractions (90%), before, and on four different occasions during one year of physical re-
habilitation, after ACL-reconstruction. The analy-
sis used several isokinetic dimensions (peak torque, contraction work and manoeuvre time—active range of motion) and electromyographic tech-
niques. Furthermore, the investigation was de-
signed to compare the short and long-term influ-
ences of two different postoperative training pro-
grams, used during weeks 14 through 19 postop-
eratively, on these parameters and on quadriceps muscle size.

MATERIAL AND METHODS
Seventeen patients, who had had reconstruction of the anterior cruciate ligament performed by one orthopaedic surgeon (L-GE) according to the method described by Marsh et al. (16), were included. Postoperatively, the operated lig was immobilized for six weeks in a cylinder cast, with the knee in either 90° (9 patients) or 70° of flexion (8 patients). Isometric quadriceps exercises were