

Electrical stimulation of the upper extremity in stroke: cyclic versus EMG-triggered stimulation

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Objective: To compare the effect of cyclic and electromyography (EMG)-triggered electrical stimulation on motor impairment and function of the affected upper extremity in chronic stroke.

Design: Randomized controlled trial.

Setting: Outpatient clinic of a rehabilitation centre.

Subjects and intervention: Twenty-two subjects in the chronic stage after stroke were randomly assigned to receive either cyclic ($n=11$) or EMG-triggered electrical stimulation ($n=11$) of the wrist and finger extensor muscles for a six-week period.

Outcome measures: The primary outcome measure was the Action Research Arm test (0–57 points) to assess arm function. Grip strength, Fugl-Meyer Motor Assessment and Motricity Index were secondary outcome measures. Assessments were made at the start of the treatment and after 4, 6 and 12 weeks.

Results: Both groups improved on the Action Research Arm test. The group receiving cyclic stimulation improved by 2.3 points, and the group receiving EMG-triggered stimulation improved by 4.2 points. The difference in functional gain was not statistically significant. Differences in gain on the secondary outcome measures were not significant either.

Conclusion: The present study did not detect a significant difference between EMG-triggered and cyclic electrical stimulation with respect to improvement of motor function of the affected arm in chronic stroke.

Introduction

There is growing evidence that electrical stimulation has a positive effect on motor recovery of the affected arm after stroke.^{1,2} Electrical stimulation might therefore be useful in the rehabilitation of patients with stroke. However, several methods of

application have been reported and this raises the question which method should be applied in daily practice.

In cyclic electrical stimulation, stimulation is applied according to a pre-programmed scheme, resulting in repetitive muscle contractions without active involvement of the subject.^{1,3} In EMG-triggered electrical stimulation, stimulation is provided when volitionally generated EMG signals exceed a preset threshold.^{1,4} In the latter approach the subject is actively involved, and voluntary muscle contraction is reinforced by volitionally triggered electrical stimulation.

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It has been hypothesized that the active involvement in EMG-triggered electrical stimulation maximizes the effect of electrical stimulation, and that EMG-triggered stimulation may therefore be more effective than cyclic stimulation.¹ From a systematic review of clinical trials it was concluded that volitionally triggered electrical stimulation indeed may be more effective than cyclic electrical stimulation.⁵ This conclusion was derived from the finding that the likelihood of a positive outcome was higher in studies which applied volitionally triggered electrical stimulation as compared to cyclic electrical stimulation. However, thus far no randomized controlled trial in which EMG-triggered electrical stimulation was directly compared to cyclic electrical stimulation has been published, so there is no direct evidence that one method is really more effective than the other.

The aim of the present trial is to investigate whether there is a difference in motor recovery and functional improvement in the affected arm of chronic stroke patients when comparing volitionally triggered electrical stimulation of the wrist extensors with cyclic electrical stimulation.

Methods

Subject selection

Subjects were recruited from the outpatient clinics of a rehabilitation centre, the surrounding general hospitals and the patients' association. The local ethics committee approved the study protocol.

Subjects were included if they met the following inclusion criteria: (1) an interval of more than six months since unilateral supratentorial stroke (infarction or haemorrhage); (2) between 18 and 80 years of age; (3) impaired function of the upper extremity due to spastic paresis (spasticity was defined as a synergistic movement pattern or an Ashworth Score⁶ of 1 or more; paresis was defined as wrist extensor strength grade 4 or less (Medical Research Council)⁷); (4) voluntary extension of wrist (at least 10° from resting position); (5) stable general health status; (6) written informed consent.

Subjects were excluded if they had: (1) a cardiac pacemaker (on demand); (2) an epileptic seizure less than six months before the start of

stimulation; (3) metal implants in the affected arm; (4) pre-existent functional limitations of the affected upper extremity; (5) serious contractures of shoulder, elbow or wrist (clinical assessment); (6) severe cognitive impairments or severe aphasia resulting in inability to understand the trial; (7) skin problems underneath the electrodes; (8) inadequate motor response to test stimulus; (9) not enough voluntary muscle contraction of wrist extensors to trigger stimulation; (10) no tolerance for surface stimulation. Criteria 8, 9 and 10 were assessed during a single test session with both modes of stimulation before inclusion and randomization.

Baseline characteristics

At baseline the following data were collected: age, gender, diagnosis (infarction or haemorrhage), hemisphere of stroke, time since stroke, dominant arm pre-stroke, cognitive function (Mini-Mental State Examination⁸), neglect (letter-cancellation test⁹) and sensory function (alternating and simultaneous touching of both hands with eyes closed; thumb-finding test¹⁰). Neglect was defined as a difference of two or more between the affected and the unaffected side in the letter-cancellation test. Sensory disorders were considered to be present if a subjects' score deviated from normal on one or both sensory function tests.

Randomization procedure

Subjects were assigned to either cyclic or EMG-triggered electrical stimulation by block randomization. A system of consecutively numbered and sealed envelopes containing a code for one of the two treatment groups was used. Each subject included in the trial retrieved the corresponding envelope.

Intervention

The Automove AM800 (Danmeter a/s, Odense, Denmark) was used to apply electrical stimulation in both groups. Surface electrodes were attached to the dorsal side of the forearm to evoke balanced extension of wrist and fingers. The position of the electrodes was marked with a permanent marker for the duration of the treatment to guarantee the

electrodes were placed consistently across stimulation sessions. The electrodes used could serve for stimulation as well as EMG detection. The Automove can provide stimulation in different modes; in this trial the cyclic- and the auto-mode were used. In the cyclic-mode the stimulation was applied automatically, without active involvement of the subject (cyclic electrical stimulation). In the auto-mode stimulation was triggered by voluntary EMG activity of the subject only if the threshold was reached (EMG-triggered electrical stimulation). Initially the threshold was 50 μ V. If the subject successfully reached the threshold it automatically increased slightly. If the threshold was not met, the AM800 decreased the threshold to a level closer to the EMG activity the subject could produce. In either mode biphasic pulses with a frequency of 35 Hz and pulse duration of 300 μ s were administered for 6 seconds with 1-second ramp-up, 1-second ramp-down and 9-second stimulus off. The setting of the aforementioned stimulation parameters and mode of stimulation was locked in order to avoid accidental changes. Amplitude was individually adjusted to obtain an optimal motor response without any side-effects such as pain or skin irritation.

The subjects received directions in the use of the Automove according to randomization. They applied the stimulation at home, and were instructed to exercise for three 30-minute sessions a day for a period of six weeks. Each subject started with a stimulation time of 15 minutes, which was gradually increased to 30 minutes per session during the first week. The time subjects actually spent with training was recorded by the Automove. The therapist checked the stimulation each week for the first two weeks, and subsequently every two weeks. During these control visits the therapist scored the subjects' opinion with regard to the effect of stimulation on arm function on a 3-point scale: worse, no change, better. The stimulus intensity was adjusted if necessary, and any adverse effects were recorded. Co-interventions were also recorded.

Outcome measures

A therapist blinded for treatment allocation made four assessments: immediately before the

start of the treatment (t0), after four weeks of treatment (t1); at the end of the six-week treatment period (t2), and after a follow-up period of six weeks (t3).

Primary outcome measure

The Action Research Arm test was used to assess manual dexterity of the affected arm.¹¹ In the Action Research Arm test, which consists of 19 items, the subject is asked to grasp, move and release objects of different size and shape and to perform three gross movements. Each item is scored on a 4-point scale, ranging from 0 (no part of the action can be performed) to 3 (the action is performed completely and within the time limits).¹¹ The maximum score is 57. The reliability of the Action Research Arm test has been confirmed and it is able to detect clinically relevant improvement in chronic stroke.¹¹

Secondary outcome measures

Grip strength was assessed with a Baseline hydraulic hand dynamometer (Fabrication Enterprises Incorporated, New York, USA) with a maximum of 90 kg; the adjustable handle was set in the second position for all subjects. Maximum grip strength of the affected and the unaffected hand were measured in turn, three times each. The hand ratio was used for analysis of the grip strength measurements. The hand ratio is the ratio of the mean value of the affected hand to the mean value of the unaffected hand and its reliability is good.¹²

The arm sections of the Motricity Index¹³ and the Fugl-Meyer Motor Assessment¹⁴ were applied for the assessment of motor impairment. In the Motricity Index, pinch grip, elbow flexion and shoulder abduction are tested; the scoring system is similar to the Medical Research Council grades⁷ and the maximum score is 100. The Fugl-Meyer Motor Assessment was applied to assess the ability to move the affected arm out of the synergistic pattern; the maximum score is 66. The reliability and validity of both tests have been confirmed.^{13,15}

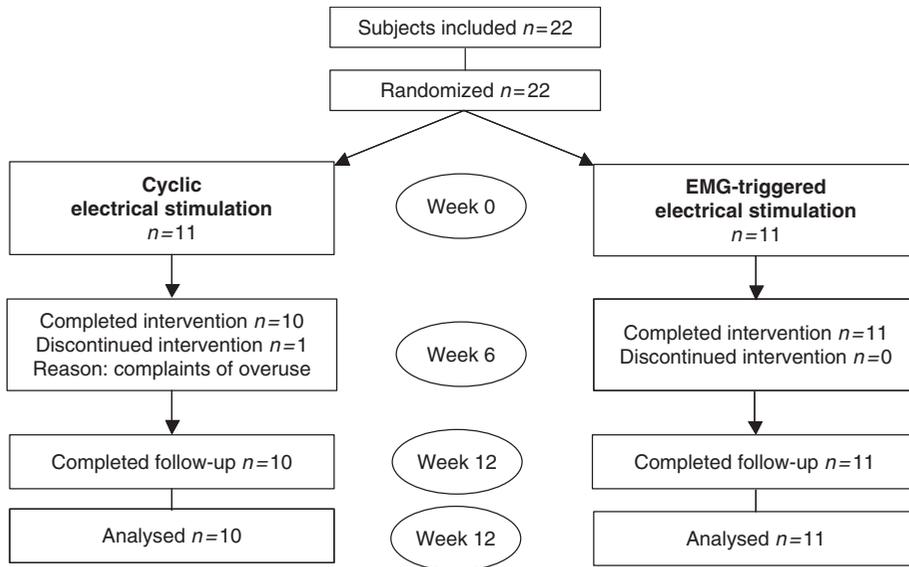


Figure 1 Flow diagram.

Data analysis

Baseline characteristics of the two treatment groups were compared to evaluate the success of randomization. Mean and standard deviations were calculated to summarize scores on the Action Research Arm test, hand ratio, Motricity Index and Fugl-Meyer Motor Assessment.

Separate linear mixed model analyses were conducted to evaluate main effects for each outcome measure over the complete trial period (i.e. treatment and follow-up). Group (cyclic electrical stimulation and EMG-triggered electrical stimulation) and time (outcome assessments) were entered in the model. In addition, the baseline value and time post-stroke were entered as co-variables to correct for the baseline difference.

The percentage of subjects who showed clinically relevant improvement on the primary outcome measure (Action Research Arm test) was determined in each group. Clinically relevant improvement was defined as 10% (i.e. 5.7 points) on the Action Research Arm test.¹¹ Chi-square tests were applied to evaluate the difference in success rate and the difference between the opinions of the subjects. All statistical analyses were performed with SPSS 11.5 for Windows. The significance level was set at 0.05.

Results

Subjects

The study flow diagram is shown in Figure 1. Twenty-two subjects were included and 21 completed treatment and follow-up. The characteristics of the 21 subjects are summarized in Table 1. Notwithstanding randomization, the mean intake scores on the clinical measures were higher in the EMG-triggered electrical stimulation group, indicating that the subjects in the cyclic electrical stimulation group were more severely affected. Mean time post-stroke was longer in the EMG-triggered electrical stimulation group.

Intervention

One subject in the cyclic electrical stimulation group dropped out after two weeks. She experienced complaints of overuse such as swelling and stiffness in her affected hand. She was advised to stop the stimulation protocol, after which the complaints disappeared. One subject in the EMG-triggered electrical stimulation group experienced similar complaints, to a lesser extent and only after stimulating for more than 15–20 minutes. It was decided to reduce the treatment protocol

Table 1 Baseline characteristics and initial values

	Cyclic	EMG-triggered
<i>N</i>	10	11
Age in years ^a	60.6 (10.9)	57.4 (8.0)
Months post stroke ^b	16.5 (6–48)	27 (7–115)
Right hemiparesis (%)	3 (30)	3 (27.3)
Dominant arm affected (%)	3 (30)	6 (54.5)
Non-haemorrhagic stroke (%)	8 (80)	10 (90.9)
Male (%)	8 (80)	8 (72.7)
Mini-Mental State Examination ^b	28 (22–30)	28.5 (23–29)
Neglect present (%)	0 (0)	3 (27.3)
Sensory disorder present (%)	4 (40)	6 (54.5)
Action Research Arm test ^a	14.8 (10.3)	22.8 (11.8)
Hand ratio ^a	0.28 (0.10)	0.42 (0.14)
Fugl-Meyer Motor Assessment ^a	29.0 (10.6)	38.4 (7.7)
Motricity Index ^a	52.3 (15.1)	66.1 (13.4)

^aMean (SD).^bMedian (range).

to 15–20 minutes three times a day, only for this particular patient. From then on he could tolerate the treatment well; he fulfilled the six-week training programme.

Due to technical problems, the time subjects actually spent with the treatment could not be retrieved in six subjects. The data for the other 15 subjects showed no difference between the groups. Mean treatment time was 48.12 hours (SD 14.3) in the cyclic group ($n=7$) and 48.25 hours (SD 9.7) in the EMG-triggered group ($n=8$). Five subjects received other therapies during the electrical stimulation treatment, three subjects in the cyclic group and two in the EMG-triggered group. This additional therapy was mainly aimed at walking.

Only in the first days of the treatment period, a few subjects experienced some temporary redness of the skin under the electrodes or pain during stimulation, both related to stimulation amplitude; others had shoulder complaints related to the position of shoulder and arm during stimulation or some muscular pain after stimulation. Apart from these temporary complaints, no adverse effects were reported. All but one subject were completely independent in application of the treatment, although two needed assistance when changing the batteries.

Clinical outcome measures

Table 2 shows the results of the assessments for both groups on all outcome measures, and the change from baseline to end of treatment and end of follow-up.

Action Research Arm test

Both groups showed improvement of arm function as assessed with the Action Research Arm test, immediately after treatment as well as at follow-up. The overall difference in effect between the groups was not significant ($P=0.731$; 95% confidence interval (CI) -6.48 to 4.64).

At group level the improvement during treatment was clinically significant for neither of the groups. In the cyclic group, 2 out of 10 subjects improved more than the clinically relevant difference of 5.7 points (both improved 7 points), yielding a percentage of success of 20%. In the EMG-triggered electrical stimulation group the percentage of success was 36%, with 4 out of 11 subjects improving more than 5.7 points (6, 6, 9 and 17 points). These percentages were the same for t2 and t3. Differences in success were not significant (chi square test $P=0.635$).

Hand ratio

The mean ratio of both groups improved over the entire trial period, but the change was only small in the EMG-triggered stimulation group. The mixed model analysis revealed no significant difference between the groups ($P=0.322$; 95% CI -0.04 to 0.12).

Fugl-Meyer Motor Assessment

Both groups improved on the Fugl-Meyer Motor Assessment. The gain was most pronounced for the cyclic electrical stimulation group, but the overall difference in gain was not significant ($P=0.974$; 95% CI -4.98 to 5.15).

Motricity Index

There was no significant difference between the groups with respect to the scores on the Motricity Index ($P=0.390$; 95% CI -9.02 to 3.70).

Table 2 Means and standard deviations of all outcome measures. Treatment was applied between t0 and t2

	t0 0 weeks	t1 4 weeks	t2 6 weeks	Change t0-t2	t3 12 weeks	Change t0-t3
Action Research Arm test (0-57, 0 = no arm function)						
Cyclic (<i>n</i> = 10)	14.8 (10.3)	15.7 (11.5)	17.1 (11.4)	2.3 (2.9)	18.4 (12.1)	3.6 (4.3)
EMG-triggered (<i>n</i> = 11)	22.8 (11.8)	26.4 (13.5)	27.0 (13.2)	4.2 (6.7)	25.0 (12.7)	2.2 (6.4)
Hand ratio						
Cyclic (<i>n</i> = 10)	0.28 (0.10)	0.33 (0.16)	0.33 (0.17)	0.05 (0.11)	0.32 (0.15)	0.04 (0.07)
EMG-triggered (<i>n</i> = 11)	0.42 (0.14)	0.45 (0.16)	0.43 (0.14)	0.01 (0.07)	0.44 (0.15)	0.03 (0.05)
Fugl-Meyer Motor Assessment (0-66, 0 = no voluntary movement)						
Cyclic (<i>n</i> = 10)	29.0 (10.6)	34.2 (11.9)	35.2 (11.8)	6.2 (5.8)	34.0 (12.4)	5.0 (5.9)
EMG-triggered (<i>n</i> = 11)	38.4 (7.7)	40.6 (6.5)	41.9 (6.7)	3.5 (5.2)	41.2 (8.0)	2.8 (6.0)
Motricity Index (0-100, 0 = no voluntary movement)						
Cyclic (<i>n</i> = 10)	52.3 (15.1)	58.5 (12.7)	54.9 (13.6)	2.6 (9.2)	58.1 (17.9)	5.8 (10.0)
EMG-triggered (<i>n</i> = 11)	66.1 (13.4)	70.7 (11.7)	71.5 (8.6)	5.4 (13.2)	66.5 (13.0)	0.5 (4.2)

Subjective scores

The majority of subjects were positive about the effects of their electrical stimulation treatment with respect to arm function. In the cyclic electrical stimulation group nine subjects reported improvement (90%) and one reported no change (10%); in the EMG-triggered electrical stimulation group the numbers were seven (64%) and four (36%) respectively. Functional improvement was mainly described as better ability to grasp objects with the affected hand. There was no significant difference between the two groups with regard to the subjective scores (chi square test, $P = 0.31$).

Discussion

The present trial compared cyclic and EMG-triggered electrical stimulation of the affected arm in chronic stroke, and showed no statistical differences in measures of motor recovery between both methods of stimulation.

Beforehand it was hypothesized that EMG-triggered electrical stimulation may be more effective, because the subject is actively involved in EMG-triggered electrical stimulation but not in cyclic stimulation. However, the active involvement is only required to trigger the stimulation; once the threshold is reached and stimulation evoked no further cognitive effort is required until the next muscle contraction is called for. The contrast between the two methods of

stimulation might have been too small to evoke a significant difference in outcome.

The results of the present study might have been biased by voluntary muscle contraction in subjects in the cyclic stimulation group, anticipating stimulation. Only subjects in the EMG-triggered group were instructed to perform active wrist extensions, but it was not possible to verify that the subjects in the cyclic stimulation group refrained from voluntary contraction.

It can be argued that the number of subjects in the present study was too small to yield a significant difference. Because this trial was the first to compare these two stimulation strategies in chronic stroke, it was not possible to perform a reliable power calculation beforehand. Given the 95% confidence interval for the difference in functional gain (-6.48 to 4.64), we do not consider it very likely that a statistically significant difference would have been found if the study had had more power, let alone a clinically relevant difference.

Recently the results of a similar randomized controlled trial in subacute stroke were published.¹⁶ In this particular trial, the effect of conventional (i.e. cyclic) electrical stimulation was compared with movement imagery-assisted EMG-triggered feedback stimulation. In the latter treatment paradigm the subject was actively involved by concentrating fully on making an imaginary wrist extension. The results of this trial are in line with the present findings, since there was no difference in outcome between the two treatment groups.

Three other randomized controlled trials compared aspects of electrical stimulation strategies.^{17–19} These trials showed improvement on motor impairment and/or functional abilities of the affected arm in chronic stroke, but none of these trials revealed a significant difference between the stimulation groups either. From this it may be hypothesized that electrical stimulation can be beneficial in stroke, regardless of the specific method of application of electrical stimulation. The different electrical stimulation strategies applied all evoke repetitive movements, which are probably more crucial in the effect of electrical stimulation than the specific stimulation parameters evoking the muscle contractions.⁵ However, the strategies compared considerably differed by some specific other aspects, which at least theoretically have different mechanisms of action.^{17–19} For example, one trial compared electrical stimulation of the wrist extensors with alternate electrical stimulation of wrist flexors and extensors.¹⁹ Extensor stimulation is thought to exert its action by recurrent inhibition at spinal level and by increasing extensor muscle strength, resulting in more power to overcome flexor spasticity. Flexor stimulation on the other hand, is described to work by reciprocal inhibition and causing fatigue of the spastic flexor muscles. The theoretical differences in mechanism of action did not result in differences in outcome after six weeks of electrical stimulation of extensors only versus alternate electrical stimulation of flexors and extensors. Possibly the differential effects studied thus far counterbalance each other, resulting in the same net effect. As yet there is no evidence that one method of electrical stimulation is better than another, regardless of theoretical differences between them. This suggests that a specific effect is unlikely. Electrical stimulation may be merely an aid to perform repetitive movement training. In all, the aforementioned emphasizes the importance of further research to elucidate the mechanism of action explaining the effect of electrical stimulation.

The present study confirms that functional gain can be obtained in the chronic stage after stroke,²⁰ although the design of the study does not allow us to contribute this gain to electrical stimulation. Regardless of the specific cause of the gain, it is an important finding especially because the gain is clinically relevant in some individual subjects.

This is important, since the impaired arm function is associated with a low level of well-being²¹ and improvement can decrease the burden of stroke. The question is which subject factors determine whether or not a subject will benefit in a clinically relevant way. As for electrical stimulation, there is hardly any evidence on this issue, although post-hoc subgroup analyses suggest that fewer impaired subjects will benefit more from electrical stimulation.² Further research is necessary to address the issue of the subject characteristics and clinically relevant improvement.

In conclusion, the present study did not detect a significant difference between volitionally triggered electrical stimulation and cyclic electrical stimulation. Future studies should further elucidate the mechanism of action of electrical stimulation and define optimal subject characteristics, in order to optimize the treatment.

Clinical messages

- There is no evidence that EMG-triggered electrical stimulation is more effective in improving motor function of the affected arm in stroke than cyclic electrical stimulation.
- Both methods of stimulation may result in functional gain in chronic stroke; characteristics of subjects who will benefit have not yet been identified.

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Competing interests

None.

Author contributions

JdK obtained the research grant and was the principal investigator responsible for design, monitoring an analysis of the study as well as writing the manuscript. MIJ was substantially involved in all stages of the study and the final version of the manuscript.

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