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# THE EFFECT OF LOW-FREQUENCY ELECTRICAL STIMULATION ON DENERVATION ATROPHY IN MAN

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**ABSTRACT. The effect of low frequency electrical stimulation (LES) on denervation atrophy and recovery of the muscles was examined in a group of 73 patients with a single or a combined total lesion of the median, ulnar or peroneal nerves. The differences between the patients were evaluated by means of clinical muscle force testing, EMG, dynamometry (ulnar and median nerve lesions), computer tomography (ulnar nerve lesions) and ultrasonography (median and peroneal nerve lesions). A beneficial effect of LES could not be shown.**

*Key words:* electrical stimulation, nerve lesion, muscle atrophy

Nerve lesions cause atrophy of the denervated muscles. This muscle atrophy may have a negative influence on the muscle recovery after reinnervation.

The benefit of low-frequency electrical stimulation (LES) on delaying muscle atrophy has been shown in small mammals by several authors (5, 9, 10, 19). There are only a few publications about the effect of LES on denervation atrophy in man. Some of them (8, 11, 13, 14, 18) showed a positive effect of LES, while others (4, 12, 15) could not confirm this.

Most clinical investigations (4, 11–15) were done on a small number of patients and for that reason have only a limited value. The limitation of the study of Jackson (8) is the way of evaluation of muscle atrophy, by means of measuring the volume of the injured hand, which may be influenced by many other factors than muscle atrophy alone. In the study of Rosselle (18) the patients were not at random divided into the groups with and without LES.

In small mammals a negative influence of LES has been shown on the sprouting of the nerves (3, 7). This LES however was much more intensive than used in the clinical situation.

The aim of our study was to investigate the effect of one of the normally used methods of LES on muscle atrophy and recovery of muscle function in patients with peripheral nerve lesions.

## PATIENTS AND METHODS

The study includes 73 patients with 81 nerve lesions. The patients gave informed consent. All patients with a total ulnar, median and peroneal nerve lesion or a brachial plexus lesion, in our departments or in departments of the hospital in a nearby town (Leeuwarden) were asked to participate in the study from Dec. 1980 to Oct. 1982. Fourteen patients refused their participation immediately or within 3 months after lesion. These patients were excluded. All patients had a total, single or combined peripheral nerve lesion, caused by direct trauma or, in the cases of peroneal nerve lesion, prolonged compression of the nerve. When the continuity of the ulnar or median nerve was interrupted a nerve reconstruction had been performed, mostly primary, sometimes secondary (Table I). The patients with a brachial plexus lesion were only treated in a conservative way. None of the patients with a peroneal nerve lesion had a lost continuity of the nerve.

Mean age of the patients was 28 years (SD 14 years). The patients with a median ($N$=14), ulnar ($N$=15) or combined ulnar and median ($N$=6) lesion, aged above 16 years and admission within 8 weeks after the lesion were at random divided in 5 groups, namely:

1. no treatment (No LES),
2. LES once a day, 5 days a week, 30 contractions a muscle till reinnervation was visible at the EMG (LES 5/R),
3. as 2, but till muscle force grade 2 (LES 5/2),
4. LES twice a day, 7 days a week, 60 contractions a muscle till reinnervation was visible at the EMG (LES 14/R),
5. as 4, but till muscle force grade 2 (LES 14/2).

Because of the expected small amount of patients in the other groups, these patients were divided in two groups:

1. no treatment (No LES)
2. LES once a day, 5 days a week, 30 contractions a muscle till muscle force grade 2 (LES 5/2).

These included 18 other patients with median or ulnar lesions (younger than 16 years or admitted more than 8 weeks after the lesion), 7 patients with a brachial plexus lesion and

Table I. *Number of patients with a median nerve, ulnar nerve, brachial plexus or peroneal nerve lesion; type of suture; number of patients with reinnervation within the research period, shown by EMG, in resp. abductor poll. br. muscle (median nerve), abductor digiti V muscle (ulnar nerve and brachial plexus) and tibialis anterior muscle (peroneal nerve); patients with tendon or muscle lesions in the same extremity; localisation of the nerve lesion*

| Nerve lesion | N | Type of nerve suture | | | Neuro-lysis | Mean interval lesion–reinnervation | | N with lesion of tendons and/or muscles | Localisation of nerve lesion | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | None | Prim. | Sec. | | N | In weeks | | Wrist | Fore-arm | Elbow | Upper arm |
| Median nerve | 32 | 3 | 21 | 6 | 2 | 27 | 24 | 24 | 27 | 3 | 0 | 2 |
| Ulnar nerve | 27 | 4 | 18 | 5 | 0 | 24 | 23 | 21 | 20 | 4 | 2 | 1 |
| Brachial plexus | 7 | 7 | | | | 1 | 84 | | | | | |
| Peroneal nerve | | | | | | | | | Knee | Upper leg | Gluteal region | |
| Unilateral | 10 | 10 | | | | 5 | 23 | | 3 | 1 | 6 | |
| Bilateral | 5 | 5 | | | | 4 | 35 | | 3 | 1 | 1 | |

10 patients with an unilateral peroneal nerve lesion. In 5 patients with a bilateral peroneal nerve lesion only one side was treated, while the other side was used as a control.

The pulse intensity was supramaximal, causing a maximal twitch contraction or as high as tolerable. The pulse duration was mostly 70, 100 or 200 msec, dependent on the "Hauptnutzzeit" in the strength-duration curve (the lowest pulse duration with the same intensity as the rheobase). The pulse pause was 1 sec.

Mostly the LES could not be started directly after the lesion, because of immobilisation after the suture or the delay in sending the patients to our department. The start of the LES was on average 6.9 weeks after lesion (SD 4.7 weeks). The mean duration of therapy was 35 weeks (SD 22.1 weeks).

We qualified the performance of the LES in three ways: good, moderate, bad. The qualification concerned the quality of the contractions during the LES and particularly the faithful participation of the patients. Because an objective measurement was hard to find, the qualification had to be subjective and was determined by two of the authors (A. B. and V. P.).

Table II. *Number of patients with (LES) or without electrical stimulation (no LES), number of patients younger (<16 y) or older (>16 y) than 16 years, electrical stimulation 7 days a week, 2 times a day (LES 14/ ), 5 days a week, once a day (LES 5/ ) till reinnervation (LES /R) or muscle force grade 2 MRC scale (LES /2) with a good, moderate or poor quality of electrical stimulation and start of the electrical stimulation within (<8 wk) or after (>8 wk) 8 weeks after lesion*

| Nerve lesion | N | Age of patient | | LES | | | | Quality of LES | | | Start of LES | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <16 y | >16 y | 14/R | 14/2 | 5/R | 5/2 | Good | Moderate | Poor | <8 wk | >8 wk |
| Median nerve | | | | | | | | | | | | |
| No LES | 11 | 3 | 8 | | | | | | | | | |
| LES | 21 | 4 | 17 | 2 | 3 | 4 | 12 | 12 | 8 | 1 | 15 | 6 |
| Ulnar nerve | | | | | | | | | | | | |
| No LES | 12 | 1 | 11 | | | | | | | | | |
| LES | 15 | 1 | 14 | 3 | 4 | 2 | 6 | 9 | 4 | 2 | 12 | 3 |
| Brachial plexus | | | | | | | | | | | | |
| No LES | 2 | 1 | 1 | | | | | | | | | |
| LES | 5 | 1 | 4 | | | | 5 | 1 | 4 | 0 | 5 | 0 |
| Peroneal nerve | | | | | | | | | | | | |
| Unilateral | | | | | | | | | | | | |
| No LES | 5 | 0 | 5 | | | | | | | | | |
| LES | 5 | 1 | 4 | | | | 5 | 1 | 2 | 2 | 5 | 0 |
| Bilateral | | | | | | | | | | | | |
| No LES / LES | 5 | 1 | 4 | | | | 5 | 1 | 1 | 3 | 3 | 2 |

Table III. *The cross-sectional area (CS-area) and X-ray density in computer tomography of the hypothenar muscles and the CS-area in ultrasonography of the thenar muscles and the peroneal nerve muscle group (PNMG) in normal subjects*

Mean value, mean variation-coefficient and residual factor in analysis of variance (6)

| | No. of performance | No. of pictures per performance | No. of normal subjects | Side dom. or non dom. | Mean value | Varc. coeff. (%) | Residual factor |
|---|---|---|---|---|---|---|---|
| Computer tomography hypothenar m. | | | | D | 2.90 $cm^2$ | 5.0 | |
| CS-area | 2 | 3 | 11 | nD | 2.80 $cm^2$ | 4.1 | 0.10 $cm^2$ |
| X-ray | | | | D | | | |
| density | 2 | 3 | 11 | nD | 64 HU | 6.4 | 5 HU |
| Ultrasonography | | | | | | | |
| CS-area | | | | D | 4.47 $cm^2$ | 6.6 | |
| Thenar m. | 2 | 3 | 12 | nD | 4.17 $cm^2$ | 9.6 | 0.39 $cm^2$ |
| CS-area | | | | D | 14.4 $cm^2$ | 5.4 | |
| PNMG | 2 | 6 | 8 | nD | 14.6 $cm^2$ | 4.8 | 0.52 $cm^2$ |

*Methods of evaluation*

*EMG.* The denervation-activity and voluntary contraction pattern in electromyography were determined before the treatment and further every 3 months till a mixed pattern was found or till no further improvement could be expected. No further improvement was expected when the same EMG-pattern was found on 3 occasions the first year after lesion or on 2 occasions after more than one year. The maximal amplitude of the denervation activity was determined and its frequency was scored on a 3-point scale from no fibrillation or positive sharp waves, until full pattern (baseline not visible). Extremely high positive denervation potentials were sometimes found. These were ignored at the maximal amplitude determinations, because these were thought to be not representative for the quality of most of the muscle fibres. The maximal voluntary pattern and the maximal amplitude of the contraction pattern were also scored.

*Dynamometry of the handgrip.* Dynamometry of the handgrip of digiti I, II and III was performed with a handhold dynamometer as described by Ploeg et al. (16).

*Clinical muscle force.* The muscle recovery after reinnervation was clinically investigated and the muscle force was coded by means of a 5 point scale (MRC-scale). In this study the muscle force grade 4 was divided in three: $4^-$ muscle force against light resistance, 4 muscle force against "normal" resistance, $4^+$ muscle force against heavy resistance.

*Computer tomography.* Computer tomography (CT) was performed in patients with an ulnar nerve lesion. The cross-sectional area (CS area) and X-ray density of the hypothenar muscles were measured. The CS area of the hypothenar muscles was determined by the muscles, situated ulnar to an artificial line between the tendon of the superficial flexor dig. V muscle and the radial border of the metacarpal V, and included the abductor, opponens, flexor dig. V and a part of the interosseus palmaris III. CT scans were taken of both hands on the levels 1/3 of metacarpal V and 3.1 and 6.2 mm distal from this level.

*Ultrasonography.* Ultrasonography (US) was performed in the patients with a median nerve lesion to measure the CS area of the thenar muscles and in patients with a peroneal nerve lesion to measure the CS area of the peroneal nerve muscle group in the lower leg. The US of the thenar muscles were performed in a plane at the level of the proximal one third of the metacarpal I. The CS area of the thenar muscles without the adductor pollicis was determined.

The CS area of the peroneal nerve muscle group was performed in a plane perpendicular to the tibia on the level of the proximal one third of the distance between the head of the fibula and the lateral malleolus.

The CS area and X-ray density of the injured side of both CT and US determinations were expressed as a percentage of the non-injured side.

The reliability of the mesurements of the CS area and X-ray density determined by CT and the CS area by US was investigated in normal subjects. From repeated measurements the variation coefficient and the residual error in analysis of variance were calculated. The results are listed in Table III.

The methods of CT and US will be described in more detail elsewhere (1, 2).

All patients with and without LES were examined by the physiotherapist (V. P.) every month till muscle recovery force grade 2 was achieved and by the first author (A. B.) every three months.

To facilitate the statistical procedure the investigation period was divided in periods of 12 weeks, measured from 2 weeks after lesion or from 6 weeks before reinnervation was determined by EMG (US, EMG, dynamometry) or clinical investigation (clinical muscle force). The results of the various groups were compared. Significance of the difference were determined by means of the Mann-Whitney-U-test.

## RESULTS

The main results are given in Figs. 1–6 and Table IV. Generally there was no difference between the

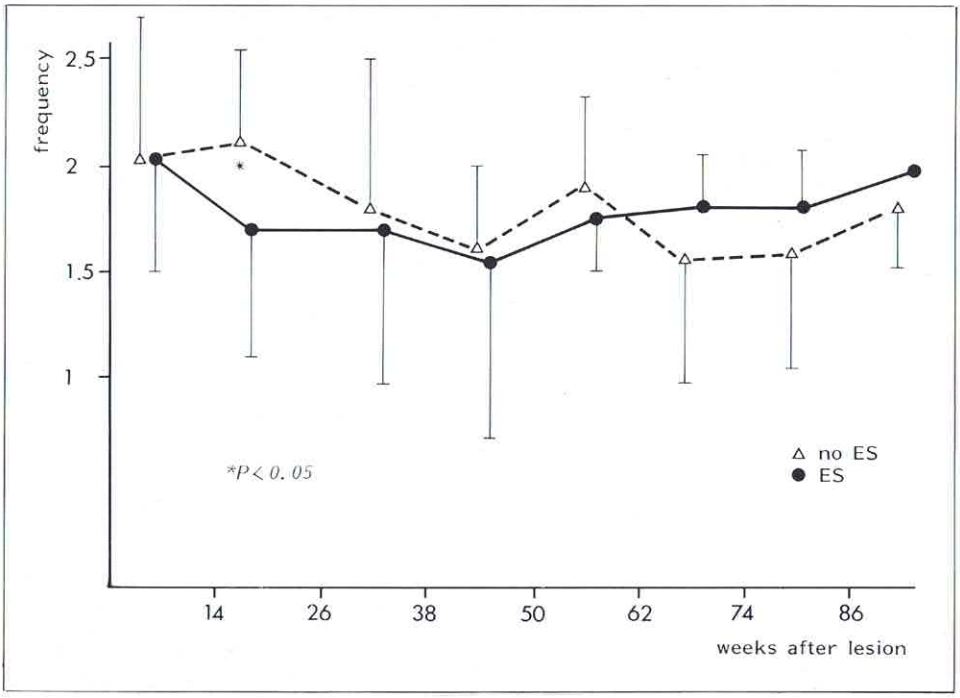


*Fig. 1.* Frequency of the denervation activity in EMG in total denervated muscles (mean and SD). Combined findings in the muscles abductor dig. V, abductor poll. br. and extensor dig. br.

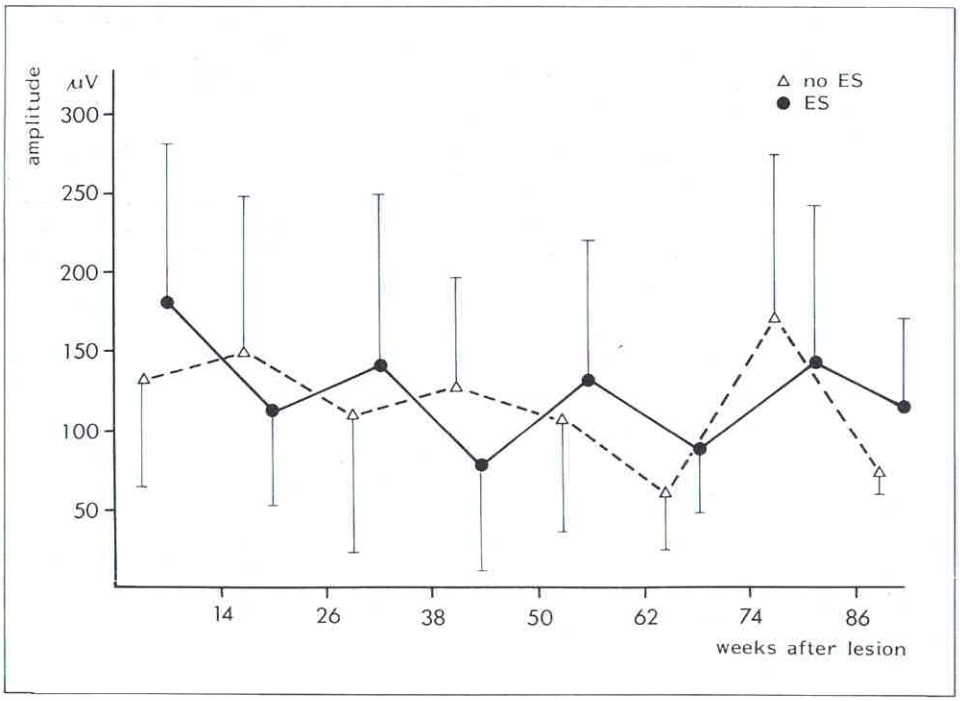


*Fig. 2.* Maximal amplitude of the denervation activity in EMG in total denervated muscles (mean and SD). Combined findings in the muscles abductor dig. V, abductor poll. br. and extensor dig. br.

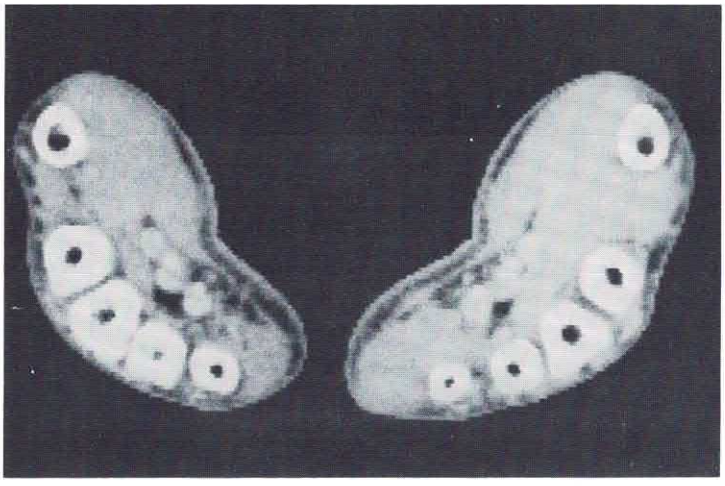


*Fig. 3.* Computer tomography of the hypothenar muscles of a patient with a total ulnar lesion at the right hand 3 months after lesion. 1, subcutaneous fat; 2, hypothenar muscles; 3, metacarpal V; 4, line, dertermining the radiair border of the measured cross-sectional area of the hypothenar muscles; 5, carpal tunnel.

groups of patients treated with LES or without LES. Only two statistically significant differences were found. In the patients with ulnar nerve lesions the mean period in which muscle force grade $4^-$ of the abductor digiti V muscle was reached, was shorter in the patients with LES than in the patients without LES. The number of patients which reached muscle force grade $4^-$ or more at the end of the control period was however not different for both groups. In all patients with totally denervated muscles without

Table IV. *Mean period after reinnervation in which at first at least resp. muscle force $4^-$, 4, $4^+$ and 5 was reached*

The duration of a period is 12 weeks

| | Muscle force | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $4^-$ | | 4 | | $4^+$ | | 5 | |
| | *N* | Mean period | *N* | Mean period | *N* | Mean period | *N* | Mean period |
| M. abductor digiti V | | | | | | | | |
| LES | 6 | 2.0 | 3 | 3.0 | 0 | | | |
| No LES | 6 | 3.8 | 3 | 6.0 | 0 | | | |
| M. abductor pollicis br. | | | | | | | | |
| LES | 13 | 1.9 | 12 | 2.4 | 6 | 3.2 | 2 | 4.0 |
| No LES | 5 | 2.8 | 4 | 2.3 | 3 | 2.7 | 2 | 3.0 |
| M. tibialis anterior | | | | | | | | |
| LES | 5 | 2.8 | 2 | 2.5 | 1 | 3.0 | 1 | 7.0 |
| No LES | 8 | 2.4 | 5 | 2.8 | 5 | 3.2 | 3 | 4.3 |

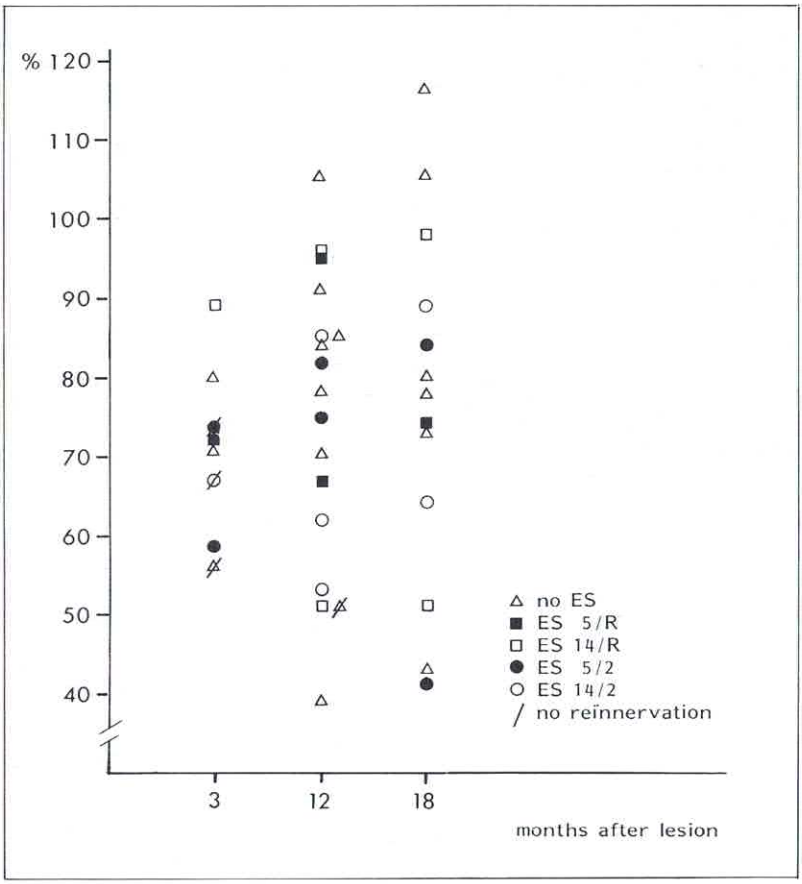


*Fig. 4.* CS area of the hypothenar muscles of patients with a total ulnar nerve lesion, determined by means of computer tomography. CS area of the injured hand as percentage of the CS area of the contralateral hand, 3, 12 and 18 months after lesion.

reinnervation a significant difference was found for the frequency of the denervation activity between the patients with and without LES. The frequency of the denervation activity was in the period from 14 till 26 weeks after lesion higher in patients without LES.

## DISCUSSION

From this study it can be concluded that LES as performed in our study has no delaying effect on denervation atrophy and no beneficial effect on muscle recovery. A better effect of more intensive LES could not be shown. Neither a negative influence of LES given after reinnervation on nerve sprouting could be demonstrated. The regeneration period of a nerve after suture is of long duration (several months). In time the atrophy becomes worse. It may be difficult, especially in severely atrophied muscles, to elicit a good strong twitch contraction. Furthermore it was sometimes not easy to motivate the patient to endure this recurrent daily therapy. Not optimal performances of the LES may have influenced the therapeutic result. However, if the treated patients are divided into groups of different quality of LES, no differences could be found either.

As in most clinical studies, the number of patients is relatively small and there always exists some differences in localisation and type of nerve lesion, age and complicating factors between the patients in the different groups. However, if LES, as performed in the described way, has a beneficial effect on denervated muscles some tendency in this direction should have been shown in the results of our study.

The study of Jackson et al. (8) is the most important of the studies, which show a positive effect of LES on muscle atrophy, because of the rather large number of patients. The study included 54 patients with an ulnar nerve lesion. This larger number of patients is maybe the reason, why they found a positive effect of LES. Perhaps, their method of LES, namely 3 times 30 contractions a day, is important. It cannot be concluded either that they showed another

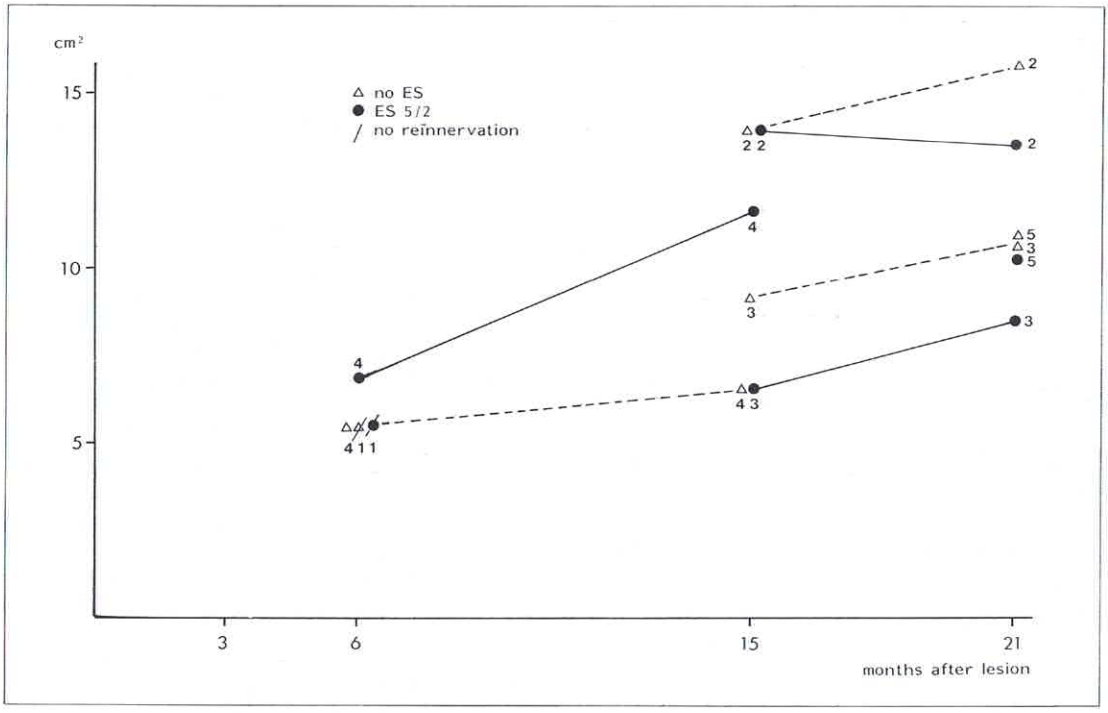


*Fig. 5.* CS-area of the peroneal nerve muscle group of 5 patients with a bilateral total peroneal nerve lesion, determined by means of ultrasonography.

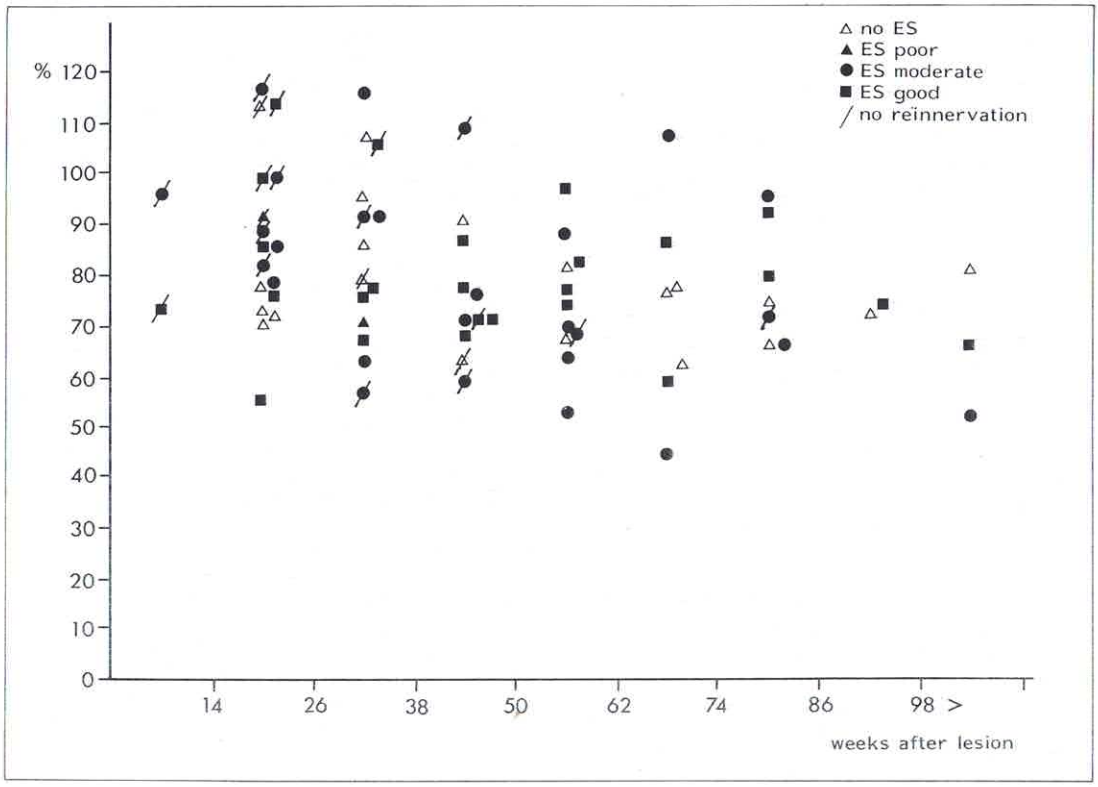


*Fig. 6.* CS area of the thenar muscles of patients with a total median nerve lesion without LES and with various quality of the performance of the LES. CS area determined by means of ultrasonography. CS area of the injured hand as percentage of the CS area of the contralateral hand.

effect of LES rather than an effect on the muscle atrophy, because of their way of evaluation of the muscle atrophy by measuring the volume of the injured hand.

The differences between our study and most of the other studies in man and the good results of LES in small animals may be caused by species differences between the muscle fibres (17). In most of the animal studies the denervated muscles were stimulated with faradic stimuli, causing tetanic contractions. Also in the case of the galvanic stimulated muscles, with stimuli of long duration a galvanotonus may have been performed. The differences may be explained therefore by a more intensive stimulation in the case of small mammals. It may also be more easy to reach all the muscle fibres with the electrostimulation current in the small muscles of animals than in men.

In conclusion a beneficial effect of LES on muscle atrophy could not be demonstrated. It has not been conclusively demonstrated in other studies in man up to the present time. Therefore in our opinion there is no indication to use this therapy in patients with peripheral nerve lesions.

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## REFERENCES

1. Boonstra, A. M., v. Weerden, T. W. & Overbeek, W. J.: Computer tomography of hypothenar muscles (submitted for publication).
2. Boonstra, A. M., v. Weerden, T. W., te Strake, L. & Hillen, B.: Ultrasonography of the peroneal nerve muscle group in normal subjects and patients with peroneal paresis (submitted for publication).
3. Brown, M. C. & Holland, R. L.: A central role for denervated tissues in causing nerve sprouting. Nature *282:* 724–726, 1979.
4. Doupe, J., Barnes, R. & Kerr, A. S.: The effect of electrical stimulation on the circulation and recovery of denervated muscle. J Neurol Psych *6:* 136–140, 1943.
5. Girlanda, P., Dattola, R., Vita, G., Oteri, G., Lo Presti, F. & Messina, C.: Effect of electrotherapy on denervated muscles in rabbits: an electrophysiological and morphological study. Exp Neurol *77:* 483–491, 1982.
6. Hull, C. H. & Nie, N. H.: SPSS-Manual. McGraw-Hill Book Company, 1982.
7. Ironton, R., Brown, M. C. & Holland R. L.: Stimuli to intermuscular nerve growth. Brain Research *156:* 351–354, 1978.
8. Jackson, S.: The role of galvanism in the treatment of denervated voluntary muscle in man. Brain *68:* 300–330, 1945.
9. Kosman, A. J., Osborne, S. L. & Ivy, A. C.: The effect of electrical stimulation upon the course of atrophy and recovery of atrophy and recovery of the gastrocnemius of the rat. Am J Phys *145:* 447–451, 1946.
10. Kosman, A. J., Osborne, S. L. & Ivy, A. C.: The influence of duration and frequency of treatment in electrical stimulation of paralysed muscle. Arch Phys Med *28:* 12–17, 1947.
11. Liu, C. T. & Lewey, F. H.: The effect of surging currents of low frequency in man on atrophy of denervated muscles. J Neur Men Dis *105:* 571–581, 1947.
12. Merletti, R., Burzio, M., Granero, L. & Rolfo, M. F.: Tomographic evaluation of size and X-ray density of normal and denervated human muscles. J Rehab Med *3:* 193–200, 1981.
13. Osborne, S. L., Kosman, A. J., Bouman, H. D., McElvenny, R. T. & Ivy, A. C.: Anterior poliomyelitis; early and late electrical stimulation of the muscles. Surg Gynaecol Obstet *88:* 243–253, 1949.
14. Osborne, S. L.: The retardation of atrophy in man by electrical stimulation in muscles. Arch Phys Med *32:* 523–528, 1951.
15. Pinelli, P.: Diffuse versus localized excitation of denervated muscle fibres. A follow-up clinical investigation. ISEK Regional Meeting, Dubrovnik, 1978, ISEK newsletter, *12:* 14, 1979.
16. Ploeg, v.d. R. J. O., Oosterhuis, H. J. G. H. & Reuvekamp, J.: Measuring of muscle strength. J Neurol 231: 200–203, 1984.
17. Pollock, L. J., Arieff, A. J., Sherman, I. C., Schiller, M., Tigay, E., Hiller, F., Liebert, E. & Yarcorzynski, G. K.: Electrotherapy in experimentally produced lesion of peripheral nerves. Arch Phys Med *3:* 377–387, 1951.
18. Rosselle, N., Schellens, N., Ghesquiere, F., Diniz, P., Geerinckx, P. & Meirsman, J. de: Electromyographic evaluation of therapeutic methods in complete peripheral paralysis. Electr Clin Neurophys *17:* 179–186, 1977.
19. Wehrmacher, W. H., Thompson, J. D. & Hines, H. M.: Effects of electrical stimulation on denervated skeletal muscle. Arch Phys Med *26:* 261–266, 1945.

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