STUDIES IN DENERVATION

H.—THE EFFECT OF ELECTRICAL STIMULATION ON THE CIRCULATION AND RECOVERY OF DENERVATED MUSCLE

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One of the commonest adjuncts to the treatment of peripheral nerve injuries is the electrical stimulation of the paralysed muscles. Despite the nearly universal employment of this procedure for over 40 years there is still doubt as to its value. That the experience gained in the last war resulted in no definite decision is evident from the conflicting views expressed by W. J. Turrell, W. R. Bristow, F. Hernaman-Johnson and others in a discussion of a paper by Burke (1918). At present it would appear that the majority of physiotherapists as represented by Kovacs (1940), Cowan (1940), and Mennel (1942) regard the treatment as being of value, however, Langley and Hashimoto (1918) have stressed the difficulty of assessing its worth in the human because of the many variable factors affecting the recovery of function after lesions of peripheral nerves.

A demonstration of this variability of recovery is given in Fig. 1, which is plotted the time to the first return of voluntary power of the extensor carpi radialis in an unselected group of patients with lesions of the musculo-spiral nerve. The cases without division of the nerve show a wide distribution unrelated to the level of the lesion and they are therefore unsatisfactory for evaluating the effects of therapy. The cases in which the musculo-spiral nerve was sutured ran a fairly predictable course, and since the results of therapeutic procedures must be evaluated in the human, such cases are considered the only suitable material for such an investigation.

Observations

The rate of recovery of muscular power in twelve patients following a suture of the musculo-spiral or posterior interosseous nerves is shown in Fig. 2. All patients with adequate records observed in a period of two years have been included, except three who showed a complete failure of recovery twelve months after suture. In each instance the failure was clearly due to difficulties encountered at operation.

Muscle power was assessed according to the recommendations of the Peripheral Nerve Injuries Committee of the Medical Research Council, by the use of a numerical classification wherein 0 indicates no contraction; 1 indicates a flicker of voluntary contraction; 2 indicates strength which is just sufficient to produce movement of the joint; 3 indicates strength to contract against gravity; 4 indicates moderate power; 5 indicates full power. It is obvious that there is a large personal element in such observations and in order to minimize this factor all estimations were made without reference to previous findings. In cases of doubt

![Chart of times of first appearance of voluntary power of the extensor carpi radialis after lesions of the musculo-spiral nerve. Abscissæ are times in months and ordinates the distance of the lesion in cm. above the external epicondyle of the humerus. Empty circles indicate cases which recovered spontaneously and the time is measured from the date of suture. Filled circles indicate cases of suture and the time is measured from the date of suture. ? mark indicates doubt as to exact time of recovery (see cases P. and M. Fig. 2).](http://jnnp.bmj.com/content/jnnp/50/1/136/full)

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* Working on behalf of the Medical Research Council.
Fig. 2.—A series of charts showing the course of recovery following sutures of the musculo-spiral and posterior interosseous nerves. Abscissæ are time in months, while ordinates represent estimates of muscle strength. The continuous line indicates the extensor carpi radialis, the interrupted line indicates the extensor digitorum communis and the dotted line indicates the extensor carpi ulnaris. On the left-hand side of the charts are stated the level of the lesion in relation to the external epicondyle of the humerus and the interval between the injury and the suture. The area of cross-hatching indicates the period during which electrical treatment was given.
intermediate values were used. Attention is directed to the fact that not all muscles are equally easy to assess. It has been found that the extensor carpi radialis offers little difficulty while the extensor carpi ulnaris and the extensor digitorum communis present difficulties in ascertaining the presence or absence of weak contractions. The supinator longus, the recovery of which is very similar to that of the extensor carpi radialis, does not lend itself to this numerical type of assessment and is not satisfactory for the present purpose. Likewise the muscles of the thumb, whose recovery resembles that of the extensor digitorum communis, are unsatisfactory because of the prevalence of trick movements.

Electrical treatment consisted of 15–30 moderate contractions of each muscle 5–6 times a week induced by interrupted galvanism applied longitudinally to the muscle. Of the 12 cases 6 received treatment for 5 months or longer and the period of treatment is indicated by the cross-hatching in Fig. 2. In all cases a short cock-up splint was applied until extension of the wrist could be voluntarily maintained. In addition, all patients with the exception of P and K received massage 3–5 times a week for a period of 6–8 months.

The cases have been arranged in Fig. 2 in the order of the level of the lesion above the external epicondyle of humerus. It is obvious from this figure and from Fig. 1 that the level of the lesion has been the preponderant factor in controlling the time of appearance of the first voluntary contraction following suture of the nerve. The subsequent progress of recovery is noteworthy for its regularity in the extensor carpi radialis and for the variability from case to case shown by the extensor digitorum communis. This variability is too great to be explained by defects in the methods of examination and is probably referable to inadequate splinting of this muscle. In any event, it is not associated with the presence or absence of electrical treatment. It will be noted in cases K, P, R, D, L, and U, who received little or no electrical treatment, that there was no significant difference from the remaining patients who received treatment for periods of 5–18 months either in the time of the first return of voluntary contraction or in the rate of subsequent recovery. It is also clear from reference to Fig. 2 that the favourable recovery rates in those patients who did not receive electrical treatment cannot be explained on the basis of a shorter interval between the time of injury and suture.

It is concluded, therefore, that electrical treatment in its customary method of application has no beneficial effects on the return of motor power.

The reason for this lack of benefit has been suggested by Fischer (1939) who finds it remarkable that clinicians should prefer weak stimulation of the muscles when all the experimental work indicates the necessity of inducing vigorous contractions. His results on animals and those of Solanad and

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**Fig. 3.—**Charts showing the effect of electrical and voluntary exercise on the blood flow of normal and denervated muscles. Abscissae are time in minutes and ordinates are blood flows measured in ccs. per min. per 100 ccs. of tissue. Empty circles indicate normal muscles and filled circles denervated muscles. The rate and strength of the electrical stimulation is described on the face of the chart in the blocks indicating the duration of the stimulation. The periods of voluntary exercise are limited by vertical lines.
Magladery (1940) and of Gutmann and Guttmann (1942) show that with intensive stimulation atrophy can be diminished and recovery promoted. It is probable, therefore, that the failure in the human is due to the minor degree of work imposed on the muscle. In order to obtain experimental support for this explanation it was necessary to find an index of the amount of work done by the electrically stimulated muscles. As it is generally recognized that an increase in blood flow is caused by muscular work, it seemed that estimations of the increase in blood flow associated with electrically induced exercise might serve this purpose.

Three subjects were therefore examined by the sleeve plethysmographic technique of Grant and Pearson (1937–8). These subjects, who are described in Paper A, were chosen because the nature of their lesions permitted the plethysmograph to be applied to a segment of the limb in which all the muscles were denervated. The blood flow was measured by determining the rate of increase of the volume of the limb during periods of venous occlusion, while the circulation distal to the segment under observation was occluded by a cuff at 200 mm. Hg. The length of the plethysmograph was 15 cm. and the water in it was maintained at 32°C. The limb volume of the segment was estimated from the circumference and no allowance was made for the volume of bone and skin. The rate of blood flow is expressed in c.c. per 100 c.c. of limb volume per min. The denervated muscles were stimulated by rectangular waves of 150 msec. duration and the electrodes were placed over the muscle at each end of the plethysmograph. As it was desired to use strong currents the skin underlying the upper electrode in the subject with a sciatic nerve lesion was anaesthetized, while in the two subjects with brachial plexus lesions this was.

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**Fig. 4.**—Records (×1/4) of blood flow estimations in subjects S.B. and A.R. showing the effects of voluntary and electrical exercise. The blood flow is measured by the rate of increase of the volume of the arm during periods of venous occlusion by the cuff. Time is 1-sec. intervals with a double mark every tenth sec. The down stroke in the respiratory tracings indicates inspiration. The stimulus line is drawn by a galvanometer in series with patient. A downward movement indicates the passage of current and its amplitude the intensity. The frequency cannot be discerned at the faster rates, but in subject A.R. the period of tetanus was initiated and terminated by a few stimuli at about 30 per min. The line inscribing the volume of the arm moves in an upward direction with an increase in volume, while the upper position of the cuff line indicates the application of a pressure of 50 mm. Hg. to the arm above the plethysmograph. The duration and frequency of the voluntary exercise is shown by variation in the volume of the arm, while during the periods of electrical stimulation the volume in the plethysmograph is increased by the contraction of the muscles.
not necessary as the whole limb was insensitive. The blood flow of the opposite normal limb was measured at another time after resting for one hour and the muscle was stimulated voluntarily or by electrodes applied over the nerve.

The results of the experiments are shown in Fig. 3. It may be noted that the resting flows are greater in denervated muscles than in normal muscles. This confirms the observations of Langley and Itagaki (1917) on animals and of Wilkins and Eichna (1941) on a subject with an old-standing brachial plexus lesion. It is also in conformity with the findings of Abramson et al. (1943) in cases of long-standing anterior poliomyelitis. It is probable that this increased circulation is related either to the fibration as suggested by Langley or to the inflammatory processes found by Tower (1937) to be associated with the atrophy of the muscle fibres.

The effect of electrically induced exercise on the circulation is minimal. In the case of R.A. strong contractions of the peroneal and some of the calf muscles for 4 minutes at rates of 30 and of 60 per minute produced no appreciable effect on the blood flow of the denervated muscle. Similar stimulation of the normal muscle for 2.5 min. also produced no effect. This is in contrast to the marked increase produced by voluntary flexion and extension of the ankle against slight resistance for 0.5 min. In subjects S.B. and A.R. the effect of stimulating the denervated flexor muscles of the forearm at a rate of 240 per minute for 6 minutes and 4:5 minutes was compared to the effect on the normal muscle of squeezing a valveless sphygmanometer bulb 15 times in 30 seconds. Fig. 4, which shows the records of these experiments and Fig. 3 in which the values are plotted, indicate that the amount of exercise as judged by the rates of blood flow is relatively small in electrically induced contractions as compared to that produced by very moderate voluntary exercise. That an increased blood flow in denervated muscles is not prevented by an inability of the vessels to dilate has been shown by finding that after arterial occlusion for 1 min. the blood flow was increased tenfold or more.

In these experiments the threshold of the denervated muscles varied from 4 to 8 ma. while the exciting currents used were 20 to 40 ma. Thus, not only were the muscles readily stimulated, but the exciting currents were much greater than could have been tolerated on normal skin and the number of contractions was considerably in excess of that usually employed in electrical therapy. From this it is concluded that this form of therapy produces no significant degree of muscular exercise.

Comment

The present observations show that electrical therapy in an otherwise well-treated case is of little benefit. It is possible, however, that in the absence of other measures designed to maintain the mobility of the tissues, electrical therapy would be beneficial, not through its exercising effect, but by virtue of the movements induced. Electrical therapy has a well-established place in aiding in the re-education of muscular movements and no comment on this aspect of the problem is required here.

The failure of the conventional type of electrical therapy to promote the recovery of denervated muscle is attributed to the fact that the treatment does not impose a strain on the muscles. The importance of the element of "strain" in the production of hypertrophy of normal muscles is well recognized, and if the same factors operate in denervated muscle it is apparent that in the human it would be nearly impossible to induce a useful degree of exercise by electrical means.

Summary

A series of cases of suture of the musculo-spiral nerve has been studied in order to assess the value of electrical treatment of denervated muscles.

The conventional type of treatment was found to be without significant value.

This was explained by the finding that even much more intensive stimulation than is possible therapeutically was accompanied by only a relatively light increase of blood flow, indicating that the degree of the exercise was slight and imposed no strain on the muscle.

It was concluded that electrical therapy does not aid the recovery of denervated muscles except in so far as it assists in re-education and in maintaining the mobility of the tissues.

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