Glaser
Arch. Phys. Med. 29, 559-562 (1948)

IMPORTANCE OF CURRENT FORM AND FREQUENCY IN ELECTRICAL STIMULATION OF MUSCLES

Studies in Retardation of Muscle Atrophy in the Dog *

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In previous publications,[1] we presented evidence that a sinusoidal alternating current of appropriate frequency (25 cycles per second) was more effective than other currents in common clinical usage in maintaining the weight and strength of denervated rat muscles. Although the use of rats for such experimentation has the considerable advantage of a rate of denervation atrophy rapid enough to produce the most marked losses in muscle weight and strength in short periods of time (two to four weeks), the use of a less genetic homogenous animal with a slower rate of atrophy and on which the painfulness of electrical stimulation could be accurately determined, would provide, perhaps, a more suitable comparison with man. For these reasons, the effects of daily electrical stimulation over long periods of time upon the course of atrophy of the denervated gastrocnemius-soleus muscles of the dog were studied.

Methods

As a preliminary procedure it was necessary to determine whether the right and left gastrocnemius-soleus muscles of the dog were of the same mass in any given animal when (1) the innervation of these muscles was intact and (2) at various times following the bilateral destruction of their innervation.

Thirty-four normal dogs adjusted to laboratory conditions for a period of two weeks were killed and the wet weights of their gastrocnemius-soleus muscles immediately determined. In a second group of 28 dogs a large section of the sciatic nerve was removed bilaterally. These animals were sacrificed at periods of three, six or nine months following the denervation and the wet weights of the gastrocnemius-soleus muscles determined. A third group of 23 dogs constituted the treated group. These animals were also subjected to an extensive bilateral section of the sciatic nerve and then the gastrocnemius-soleus muscles of one limb (either left or right) were stimulated twice daily for five minutes with a modulated sinusoidal current with a carrier frequency of 25 cycles per second. The carrier frequency was sinusoidally modulated at a rate of 25 cycles per second. The treatments extended over a period of three, six or nine months, and at the end of these times the animals were killed and both treated and untreated muscles were weighed.

The dogs were neither anesthetized nor restrained in any fashion while they were being stimulated. The intensity of the applied current was adjusted to a value which the dog accepted quietly and with no discernible signs of discomfort. Upon any signs of unrest, the current intensity was decreased until the animal was quiet again. After several days the limits of tolerance for any particular animal were well established and the strength of the stimulating current thus determined was used throughout the

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*Aided in part by a grant from National Foundation of Infantile Paralysis.
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1. (a) Kosman, A. J.; Osborne, S. L., and Ivy, A. C.: The Effect of Various Types of Electrical Stimulation and of Frequency of Stimulation Upon Muscle Atrophy in the Rat, Federation Proc., 4:11, 1945; (b) The Comparative Effectiveness of Various Electrical Currents in Preventing Muscle Atrophy in the Rat, Arch. Phys. Med. 28:7, 1947.

experiment. It was not at all unusual for the dogs to sleep during the period of stimulation. The technic of stimulation was similar to that used clinically — a large dispersive electrode on the abdomen and the smaller stimulating electrode placed over the treated muscle.

When the period of denervation exceeded three months, periodic exploratory operations were performed for any possible reinnervation and any regenerating nervous tissue, if present, was removed. At sacrifice no neurotization of any of the muscles had occurred.

Results

Weights of Normal Muscles. — There are no significant differences in weight between the left and right gastrocnemius-soleus muscles (table 1). The

TABLE 1. — *Weights of Left and Right Normal Gastrocnemius-Soleus Muscles.*

No. of Dogs	Mean Weight in Grams Left	Right
34	29.986	29.600
	$t = 1.24$	$r = 0.98$

correlation of these muscle weights in the same animal is quite high (r = 0.98). An attempt was made to correlate body weight with muscle weights and thus establish a reference point by which the degree of atrophy following various intervals of denervation could be approximated. However, in the dog the correlation between the weight of the gastrocemius-soleus muscles and the body weight is rather poor (r = 0.49), and any approximation of the extent of atrophy by this method would be meaningless.

Weights of Untreated Denervated Muscles. — As in the case of normally innervated muscles, the differences in weight between left and right muscles in any particular animal three, six and nine months after denervation are insignificant (table 2). The loss of weight following the bilateral denerva-

TABLE 2. — *Mean Weights of Untreated Denervated Left and Right Gastrocnemius-Soleus Muscles.*

Duration of Denervation	No. og Dogs	Mean Weight (Gm.) Left	Right	
3 Months	10	20.362	20.533	$t = 0.192$ $r = 0.82$
6 Months	12	19.506	18.911	$t = 1.13$ $r = 0.95$
9 Months	6	15.328	14.859	$t = 0.443$ $r = 0.82$

tion proceeds at essentially the same rate for the muscles of both limbs.

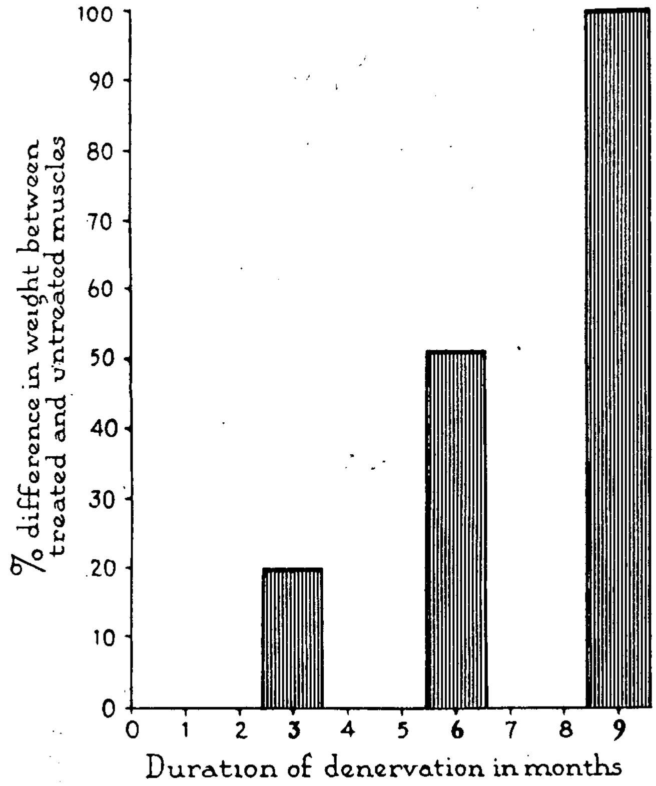
Weights of Stimulated and Untreated Muscles. — It is clear from an examination of table 3 and the chart that daily electrical stimulation effectively retarded the atrophy of denervation. Three months after denervation the treated muscles were 19.5 per cent heavier than their untreated controls. After

TABLE 3. — *Mean Weights of Treated and Untreated Gastrocnemius-Soleus Muscles.*

Duration of Denervation	No. of Dogs	Mean Weight (Gm.) Treated	Untreated	% Diff.	
3 Months	9	22.302	18.672	19.5	$t = 5.29$*
6 Months	7	19.569	12 732	53.5	$t = 4.35$*
9 Months	7	22.770	11.799	93.6	$t = 5.83$*

* Significant on the 1 per cent level of probability.

six months this difference had increased to 53.5 per cent, and at nine months the margin of difference between treated and untreated muscles had widened to 39.6 per cent. Thus, the differences in weight between treated and untreated muscles becomes progressively greater the longer the period of denervation.



Comment

Although ample evidence has been accumulated to show that denervation atrophy can be effectively retarded by electrical stimulation,[2] from a practical point of view it is important to know whether similar results can be obtained under conditions more closely resembling those found clinically. A *sine qua non* of the effectiveness of electrical stimulation is that it produce vigorous contractions of the muscle,[2] and in a previous communication[1b] we pointed out that not all currents are equally capable of fulfilling this requirement at current intensities which could conceivably be tolerated by the average patient. In the denervated gastrocnemius muscle of the rat we found that a modulated sinusoidal current with a carrier frequency of 25 cycles per second developed the greatest muscle tension at the lowest current intensities, and was also the most effective current in the retardation of its atrophy.

In these previous experiments it was difficult to evaluate the painfulness of the stimulating current. These difficulties are overcome in the present studies and without question a modulated sinusoidal current with a carrier trequency of 25 cycles per second can elicit strong contractions of the dener-

2. (*a*) Fischer, E.: Effect of Faradic and Galvanic Stimulation Upon Course of Atrophy in Denervated Skeletal Muscles, Am. J. Physiol. **127**:605, 1939; (*b*) Guttman, E., and Guttmann, L.: Effect of Electrotherapy on Denervated Muscles in Rabbits, Lancet **1**:169, 1942. (*c*) Solandt, D. Y.; De Lury, D.B., and Hunter, J.: Effect of Electrical Stimulation on Atrophy of Denervated Skeletal Muscle, Arch. Neurol. & Psychiat. **49**:802, 1943. (*d*) Hines, H. M.; Thomson, J. B., and Lazere, B.: Physiological Basis for Treatment of Paralyzed Muscle, Arch. Phys. Therapy **24**:69, 1943. (*e*) Grodins, F. S.; Osborne, S. L.; Johnson, F. R.; Arana, S., and Ivy, A. C.: The Effect of Appropriate Electrical Stimulation on Atrophy of Denervated Skeletal Muscle on the Rat, Am. J. Physiol. **142**:222, 1945. (*f*) Eccles, J. C.: Investigations on Muscle Atrophies Arising from Disuse and Tenotomy, J. Physiol. **103**:253, 1944.

vated muscles and maintain its weight over a period of nine months at current intensities easily and comfortably tolerated by the dogs.

Statements[3] that current intensities sufficient to produce vigorous contractions of denervated muscle cannot be used clinically is not at all true when there is the proper selection of the current form and frequency.

Summary

Daily stimulation of the denervated gastrocnemius-soleus muscles of twenty-three dogs with a modulated sinusoidal current with a carrier frequency of 25 cycles per second effectively maintained the muscle weight over a period of nine months. The current intensities used were accepted by the unanesthetized, unrestrained animals without pain and without discomfort.

3. Doupe, J.; Barnes, R., and Kerr, A. S.: The Effect of Electrical Stimulation on the Circulation and Recovery of Denervated Muscle, J. Neurol. & Psychiat. 6:136, 1943. Hines, Thomson and Lazere.2d.

ATROPHY OF DISUSE *

A Definition

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Atrophy of disuse is a difficult topic to discuss because of the lack of an adequate definition. This can be attributed to the facts that there exist many concepts of disuse and that knowledge of the microscopic anatomic and chemical changes is scant. Knowledge concerning the protein molecular changes occurring in the various types of atrophy is still less complete. One need only to examine one or two definitions that have found their way into the literature to realize their weaknesses and to highlight the points at which present day knowledge fails in an attempt to understand the process of disuse.

Chor and Dolkart felt that in skeletal muscle disuse produced a wasting of muscle tissue due solely to the curtailment of its specific function of contraction. They further stated that this wasting occurred without any accompanying disturbances of nerve and blood supply.[1] This definition would exclude completely the atrophy occurring in denervation. This seems paradoxic, since denervation itself curtails the specific function of contraction and creates perhaps the most favorable conditions for disuse. It is obvious that the stumbling block here is that the vague concept of "neurotrophic influence" has again interjected itself into the argument. An attempt will be made to show that such an influence plays a rather insignificant role in atrophies resulting from diverse sources and that the lack of function is the determining factor in decrease in size of tissues that are not being used.

A much more general, but at the same time more acceptable, definition is that expressed by Carey and his co-workers.[2] In their opinion, parts of the living body increase and decrease in size in proportion to the functional

* Read at the Eastern Section Meeting of the American Congress of Physical Medicine, Philadelphia, Pennsylvania, April 10, 1948.

* From the Department of Physical Medicine, Veterans Administration Hospital, Bronx, N. Y. Published with permission of the Chief Medical Director, Department of Medicine and Surgery, Veterans Administration, who assumes no responsibility for the opinions expressed or conclusions drawn by the authors.

1. Chor, H., and Dolkart, R. E.: Am. J. Physiol. 117:626, 1936.

2. Carey, E. J.; Haushalter, E.; Massopust, L. D.; Gakofuld, F.; Lynch, J.; Tabat, D., and Socoloff, E.: Proc. Soc. Exper. Biol. & Med. 64:193, 1947.