THE EFFECT OF X-RAYS ON THE IRRITABILITY OF MUSCLES IN THE FROG.

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INTRODUCTION.

In view of the fact that x-rays are at the present time largely used in clinical practice, it seems advisable to investigate the action of the x-rays upon some of the more simple animal processes. Of these, the response of a single muscle to a single electrical stimulus is probably the simplest and best known, and for this reason was chosen for the present research.

Methods.

The usual apparatus for obtaining graphic records of contractions was employed, but certain modifications were found necessary.

(1) Muscle Preparation.—Since the research is essentially one of comparison between an x-rayed and a normal muscle, it is clear that behavior of the normal muscle is of prime importance, and therefore that the difference between the normal and the experimental muscles should be minimal. For this reason, it was determined to employ as a control the fellow muscle preparation from the other leg of the same frog in every case. Even under these circumstances, it was soon found that differences exist between the two legs. Attempts were made to reduce these differences in various ways, on the assumption that section of the sciatic nerve first cut induces a reflex block in the other nerve. All attempts were abandoned in favor of cutting both nerves simultaneously at their entrance into the gastrocnemii muscles. This method gave a more uniform result in that the differences between the two muscle preparations were less than by any other method, and in that it was impossible to forecast which of the two muscles would react more easily.
(2) Mode of Stimulation.—The primary current was obtained from four dry cells. The DuBois-Reymond apparatus was used, applying the make and break shock. The electrodes used were in all instances platinum.
For the purpose of the research, it was important that the stimulus applied to each member of the pair of muscles in any experiment should be the same on any given occasion and the following method was used by means of which both muscles could be stimulated simultaneously.

Attached to the secondary terminals of the inductorium, were two pairs of wires (of equal length, resistance, etc.) with platinum electrodes at their free ends. The purpose was to have as nearly equal as possible the current from the secondary between the two pairs of electrodes. Each muscle was suspended from a clamp and attached to a writing lever which was counterpoised by a weight of 20 gm. In each case one of the electrodes was inserted through the muscle near the attachment of the femur, and the other, inserted near the attachment of the tendon of Achilles (Fig. 1, A, B). It is clear that under the conditions described both normal and exposed muscles received nearly equal stimuli.

In forming an idea of the condition of irritability of the muscle preparation, use was made of the observations on the minimal stimulus necessary to call forth the smallest certainly visible contraction of the muscle. In the case of a muscle in good condition, this was invariably a vigorous contraction sufficient to record itself well upon the drum: with a stimulus less than this (i.e. with the secondary .5 cm. farther away from the primary) not the slightest trace of a contraction even in the isolated fibrils of the muscle was discernible. On the other hand, toward the end of an experiment lasting several hours, under ordinary air conditions, it was generally possible to observe definite muscular twitches under single stimuli over a range of perhaps 3 cm. greater distance of the secondary from the primary than was necessary to afford a contraction sufficiently marked to be recorded upon the drum.

The method adopted in an experiment was as follows: The secondary was run out, after everything was ready, to a point 40 cm. at which it was anticipated that depressing the switch in the primary circuit would fail to be followed by contractions in either muscle. The coil was then moved up a half cm. at a time until either one or both muscles contracted visibly. Then the coil was moved back-

1 Foster, M., History of physiology, London, 1890, 287.
wards in half cm. stages until contraction ceased. This point was determined for both muscles. The point on the cm. scale farthest from the primary at which a muscle just visibly contracts is the "minimal stimulus" point for that muscle for that particular time, i.e. the current produced by a single induction shock when the secondary coil is at this point is the smallest electrical stimulus capable of producing a contraction in the muscle to which it has been applied. The minimal stimulus for each muscle was determined in the same way at intervals of \( \frac{1}{4} \) of an hour and recorded.

**Fig. 2.** L. P., lead plate; F. W., fastening wire; L. F., living frog; B., bandage; S. i. P., slit in plate.
(3) X-Ray Application.—The live frog was strapped to a lead plate .25 cm. in thickness, so that one of the gastrocnemius muscles was exposed to the x-rays. This was done by strapping the animal so that one of the muscles covered a verticle slit in the lead plate, rendering it susceptible to whatever effects the x-rays might produce (Fig. 2). Both control and exposed muscles were fastened in the same manner, and extreme care was taken to serve them both equally in this respect. The plate was placed 10 inches from the Coolidge tube, and the exposure was 10 milliamperes for 3 minutes from a 40,000 volt machine with a spark gap of 2½ inches. After exposure the frog was pithed, and the muscles prepared as mentioned above.

RESULTS OF EXPERIMENTS.

In the experiments recorded in the succeeding paragraphs, the two muscle preparations were exposed to the air after removal from the body till the end of the experiment, drying being avoided as far as possible by periodic washings with normal saline. Care was taken to treat both muscles alike in this respect. In spite of all care the various pairs of muscles did not survive the same length of time, so that a composite curve compiled from all the experiments does not afford an indication of the exact course of events that were obtained in any individual experiment. In the main, however, the two members of a pair of preparations derived from a single frog survived for approximately the same length of time.

(1) Normal Muscle Preparation.—In Fig. 3 is given a composite curve plotted against time of natural behavior of nine muscle preparations examined by minimal stimulus method. This is an average curve and as such approaches the results of the individual experiments. Since, however, the composite curves obtained for the experiments in the succeeding sections are all compiled in the same way, as that for normal muscles, the minor differences between them and the individual curves may be neglected. The two fellow muscle preparations from the same frog, treated in the same way, behave in the same way as far as concerns the curves they yield in respect to successive minimal stimulation.

3 Robertson, J. K., X-rays and x-ray apparatus, New York, 1924, Chapter XI.
(2) Effect of X-Ray Exposure.—In these experiments, the two fellows of the pair of preparations were subjected to identical treat-

![Graph](image-url)

**Fig. 3.** Composite curve of loss of irritability of normal muscle preparations.

![Graph](image-url)

**Fig. 4.** Composite curves of loss of irritability of control and x-rayed muscles.
ment, except that the experimental muscle was exposed to 30 milli-
ampere minutes of x-ray after the manner already described. In
Fig. 4 are given the composite curves representing the means of five
experiments. It is seen that the control muscles yield a composite
curve of normal muscle preparations. The x-rayed muscles, on the
other hand, yield a composite curve of a very different character.

During the first hour and a quarter, the curve rises like that of the
control muscles, then for the next half hour it falls. From this time
onward the curve rises rapidly, more rapidly it appears than the con-
trol. This behavior of the x-rayed muscles is represented with a
considerable fidelity in the individual experiments, particularly the
rise during the period of the first hour and a quarter and then the
succeeding fall.

It is clear that the x-rayed muscle requires a smaller stimulus to
call forth a visible contraction than the non-x-rayed. The pronounced
difference between the x-rayed and control members of the muscle
preparation is an indication that the x-rays exert a distinct influence
on the muscle. It is impossible to say in what this influence consists
because any decomposition of organic substances in the experimental
muscle by the rays, might mean that the x-rayed muscle was being
subjected to a stronger stimulus than the control. However, it ap-
ppears that congestion was brought about in the experimental muscle,
and what effect it produced cannot be predicted. On the other hand
perhaps the increased irritability shown by the frog muscle under the
action of x-rays may be a sign of degradation changes. And, from
this point, the experiments do not indicate whether the action of the
x-rays is to be considered as injurious or beneficial.

CONCLUSION.

Exposure of the muscle preparation of the frog to the x-rays is ac-
 companied by a better maintenance of muscular irritability than in the
case of the non-exposed preparation. This is shown by its response
to a smaller electrical stimulus than the control muscle.