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# Conduction Velocity of Action Potential in a Stretched Muscle Fibre

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It is well known that the conduction velocity of the action current suffers some changes when nerves are stretched. Many data concerning the changes were already reported by many authors and a new experiment was done recently by Mazima (7). On the other hand, concerning the muscle fibre, there has been only a few reports. Wilska and Varjoranta (11) have reported the fact that the conduction velocity of the muscle fibre when stretched had an entirely different change from that of the nerve fibre. And recently, Harris (4) obtained the result that the conduction rate of a stretched muscle indicated no change.

When a nerve fibre is stretched, the conduction velocity becomes slower. This result is expected clearly from the findings of Gasser and others (1, 2, 12) that the nerve fibre of a large diameter has conduction velocity faster than that of a small diameter, and also that the diameter of the fibre becomes smaller by stretching.

In order to ascertain the problem of velocity in the case of the muscle fibre, and to obtain the relation of the change of its velociy with the degree of stretching, the following experiments were conducted by the author.

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## Material and Methods

The material used in the experiment was the excised muscle (*M. sartorius*) of japanese toad (*Bufo vulgaris*). It was placed and fixed at natural length in situ at its both end with needle on paraffin bed, and a sheet of filter paper (ca. $7 \times 2$ cm) soaked with Ringer's solution placed between them. To stimulate a single muscle fibre, a piece of silver wire having a small diameter (ca. 30 $\mu$) was used, the tip of which was attached perpendicular to the surface of the pelvic end of the sartorius muscle. Sometimes, the capillary electrode after Pratt and Eisenberger (10) was used for this purpose. By these electrode a single muscle fibre or sometimes a few muscle fibres were stimulated. The peripheral part of filter paper underneath the muscle was used as indifferent electrode. Break induction shocks or squared pulses of a very short duration were adapted as electrical stimulus. Strength of stimuli was regulated to be sufficiently strong but not to be too strong to gain local stimulation.

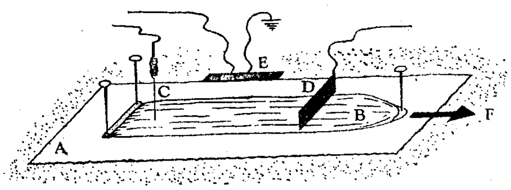



Fig. 1. Shematic illustration of the apparatus. a; filter paper soaked with Ringer's solution on the paraffin bed. b; sartorius muscle, c; stimulating electrode with feeble coil, d; recording electrode of silver platelet edge, e; indifferent electrode for stimulating and recording, f; direction of stretching.

In order to record the action potential, a piece of silver plate which was attached perpendicular to the muscle surface by its sharp edge at some distance from the stimulating point, and the filter paper underneath the muscle were used as lead off electrode. From this, the potential was lead to an ordinary C–R coupled four-stage amplifier and recorded with a Braun tube oscilloscope. To stretch the muscle, its peripheral tendon was pulled to various degrees, after lifting up the knife edge electrode from the muscle surface, and then fixed firmly with a needle on the paraffin bed, while the pelvic bone was fixed throughout the experiment.

The thin wire of the stimulating electrode was so flexible that the tip moved with the movement of the muscle fibre when the muscle was stretched, and its position of attachment was near the pelvic bone, so the displacement of the stimulating point by stretching the muscle was not more than one millimeter, To obtain the conduction velocity, it was assumed that the muscle fibre was uniformly stretched along its whole length. As for reversibility, stretch was released again and the velocity was measured.

Sometimes the whole muscle was stimulated by using an ordinary silver electrode at the pelvic end. And recording electrode, non-polarizable galatin-zinc, at a top of which cotton thread was attached to move with muscle together when it contracted, was applied bipolary at a distance 2 cm or more apart. With these procedure two separated monophasic action potential in opposite direction were recorded as in Fig. 3b. Conduction velocity was calculated by measuring the distance between these peaks or first delflections.

## Results and Discussions

It must be ascertained preliminary that the method was free from errors caused by the spread of the stimulating current and, if any, the change of the latent period which might be brought about by stretching the muscle. If these errors were not avoided, the velocity diagram which was obtained by relating the response time with the conduction distance could not be a straight line passing through the origin. To see this, placing the lead off electrode at various distances from the stimulating point, an attempt was made to obtain the velocity diagram. The result showed, as Fig. 2, a straight line passing through the origin. Besides this, the result showed the propagation with uniform velocity on the muscle fibre. It was certain from this that the rate of conduction could be obtained only by two values: a conduction length, and a response time.

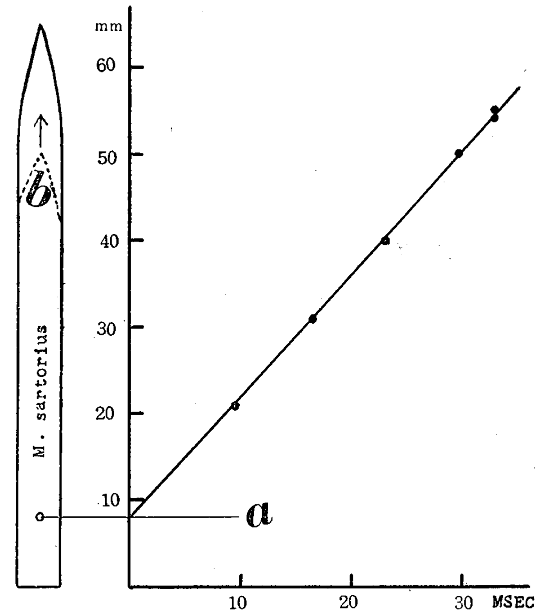



Fig. 2 A. Conduction time along muscle fibre when stretched. (a); position of stimulating electrode, (b); natural length of muscle (50 mm). Fig. 2 B. its oscillogramme, time scale, 500 cycle.

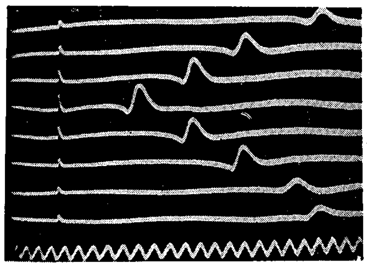
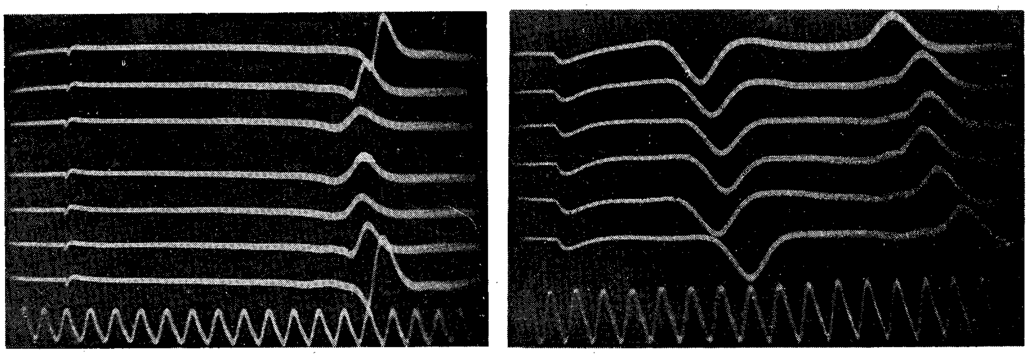


Fig. 2 B.

So subsequent experiments were done under this procedure.

The results which were done to obtain the velocity of the muscle fibre when stretched are shown in Figs. 3, 4 and Table 1. These indicate



(a) (b)

Fig. 3. Effecto of change in length on conduction time. Records were taken from the same fibre and muscle respectively. B; stimulating almost whole muscle. Velocity was calculated from peak to peak of action current in this case.

Muscle length; (a), 49, 55.5, 59. 62.5, 58, 56, 49 mm, (b), 44(17), 51(20), 57(21), 50(20), 55(22), 47 mm(20 mm) respectively.

Numbers in parenthesis represent the distance between recording electrodes. Time scale, 500 cycle.

that the rate of conduction of the muscle fibre increases when it is stretched, which is contrary to the cases of the nerve fibre. By releasing the stretch to reproduce the velocity-stretch relation, similar results were obtained as indicated in Fig. 3.

Table I.

| Stretch Ratio | Distance between stim. & record. electrode | Conduction velocity | Increase rate of conduction velocity | Square root of stretch ratio |
|---|---|---|---|---|
| 1.00 | 45.5 mm. | 1.91 m/sec. | 1.00 | 1.00 |
| 1.08 | 45 | 1.94 | 1.02 | 1.04 |
| 1.19 | 45 | 2.08 | 1.09 | 1.09 |
| 1.31 | 44.5 | 2.1 | 1.1 | 1.15 |
| 1.19 | 45 | 2.02 | 1.06 | 1.09 |
| 1.07 | 45 | 1.92 | 1.01 | 1.04 |
| 1.00 | 45 | 1.91 | 1.00 | 1.00 |
| 1.00 | 31 | 1.52 | 1.00 | 1.00 |
| 1.11 | 31 | 1.56 | 1.03 | 1.05 |
| 1.23 | 31 | 1.63 | 1.07 | 1.11 |
| 1.34 | 30.5 | 1.66 | 1.09 | 1.16 |
| 1.23 | 30.5 | 1.61 | 1.06 | 1.11 |
| 1.11 | 30.5 | 1.60 | 1.05 | 1.05 |
| 1.04 | 31 | 1.52 | 1.00 | 1.02 |
| 1.11 | 31 | 1.59 | 1.05 | 1.05 |
| *1.00 | 17 | 1.28 | 1.00 | 1.00 |
| 1.16 | 20 | 1.39 | 1.09 | 1.08 |
| 1.29 | 21 | 1.45 | 1.13 | 1.14 |
| 1.36 | 20 | 1.46 | 1.14 | 1.17 |
| 1.25 | 22 | 1.45 | 1.13 | 1.12 |
| 1.07 | 20 | 1.35 | 1.06 | 1.04 |

* The results of this series were obtained by Stimulating almost the whole sartorius muscle. Conduction time was calculated from peak to peak of action potentialis in Fig. 3b.

In Table I it has been shown that the velocity began to increase as a length of the muscle ($l_0$) was being stretched. By using the length and the velocity before stretching ($v_0$), the rate of stretching ($l/l_0$) and the increase ratio of velocity ($v/v_0$) were calculated and tabulated with other quantities in Table I. But in Fig. 4, it seems that the velocity begins to increase at a certain length in a more stretched state than normal. If this length be used as standard length, the obtained result will be much more effective.

Although the rate of conduction increased as the stretched length was increased, the increase ratio ($v/v_0$) is not proportional to the ratio of the stretch ($l/l_0$). And then a longer time was required for the action potential to propagate over the whole length of the muscle fibre after stretching, while the conduction time for unit length of the fibre then became shorter. Besides, in Table I was given the square root of the increase ratio of the muscle length $\sqrt{l/l_0}$. In most case, it was noticed that $\sqrt{l/l_0}$ and $v/v_0$ could be seen nearly equal.

The muscle will not change its volume before and after stretching, so the diameter of the muscle can be expected to be smaller after stretching. Denoting with $r_0$, $r$, the average diameter of the fibre before and after stretching, the volume (V) of the fibre as a cylinder is as follows:

$$V=\pi r_0^2 l_0=\pi r^2 l$$

Hence $$r_0/r=\sqrt{l/l_0}$$

On the other hand, the surface area of the cylinder per unit length being nearly equal to $2\pi r_0$ and $2\pi r$. Consequently, the ration of the surface before and after strecting became $r_0 : r$. It can be said from this,

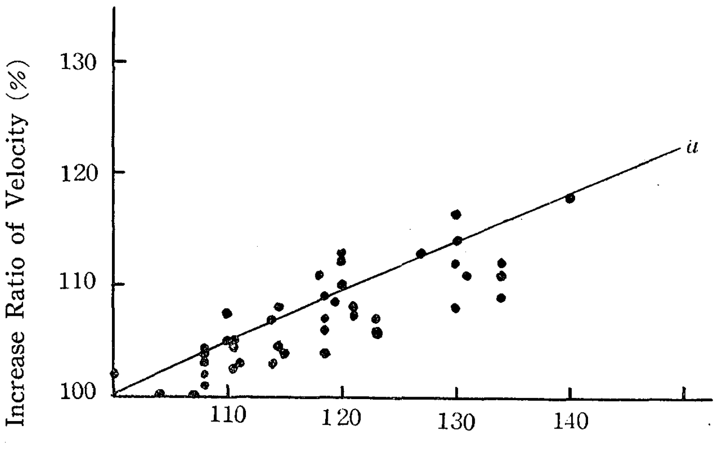



Fig. 4. Relation of conduction velocity to stretching.
(a) represents $(v/v_0)=\sqrt{l/l_0}$

that the increase ratio of velocity $(v/v_0)$ were nearly equal to $\sqrt{l/l_0}$ i.e. $r_0/r$ rather than $l/l_0$. In other words, the increase of velocity was concerned more with the decrease of surface area of the muscle fibre than with the change of its elongation (or its volume per unit length).

At this time, a consideration of the following data may be made in the relation between the velocity of the muscle fibre and the length of the muscle when stretched.

(1) The stretched muscle may be subjected to some extent to pressure. After Grundfest (3), the conduction velocity of the muscle increased under pressure as high as 3,000 to 8,000 pounds and decreased at 12,000 pounds. But such high pressure can not occur under ordinary experimental conditions. Meak and Leaper (8) also investigated the

influence of pressure from 20 to 90 pounds on the conduction velocity of nerve and muscle fibres and they could not obtain any change. Thus the above results can not be regarded as the result of development of pressure in the muscle fibre by stretching.

(2) It has been known since de Meyer (9) that the deformation current is developed by stretching a part of the muscle. This fact suggests that something can occur by deformation on the membrane of the muscle fibre. The result in Fig. 4 shows that the rate of conduction increases with the square root of the muscle length, namely, that with the inverse ratio of the surface area of the fibre. However, Ling and Gerard (5) reported that the stretching of frog's sartorius muscle caused no change of its membrane potential. Then, the increase of velocity may be due to some changes of the surface of the fibre; probably something other than the membrane potential.

The report by Wilska and Varjoranta (11) which was obtained on a single muscle fibre stimulated selectively when stretched, qualitatively agreed with the present result. But recently, Harris (4) reported the result that the rate of conduction of the muscle fibre suffered no change by stretching. This statement did not agree with the result of the author. There is possibility that the details of the experimental condition might have been different. This can be expected to be decided at a later experiment.

## Summary

(1) With the use of toad sartorius muscle, its conduction velocity of action potential was observed, when it was stretched.

(2) When the muscle was stretched, its action potential was conducted faster than before, which was contrary in the case of nerve fibre.

(3) Increase ratio of conduction velocity was slightly smaller than that of the stretch, so that the conduction time along the whole length of muscle fibre became longer.

(4) Increase ratio of conduction velocity almost equalled the square root of stretch ratio, that is the inverse ratio of the surfaces area.

(5) The statement above meant that the change of conduction velocity was due to something happening at the surface of the muscle fibre.

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