ON THE INITIAL SHORTENING OF A SINGEL MUSCLE FIBER

HIDENOBU MASHIMA*

Department of Physiology, Faculty of Medicine, Juntendo University, Tokyo

The concept of initial shortening, developed by Mashima and Tanaka (1), is essentially as follows: When a twitch curve is recorded by means of an inertia lever instead of an isotonic lever and the tension curve is recorded at the same time by a capacity tension recorder attached to the other end of the muscle preparation, the tension never develops isotonically; it develops, following a latent period, to a far greater level than the resting tension which is equal to the load. Furthermore, the larger the moment of inertia of the lever \( I \) is, the larger is also this initial tension development. The initial tension begins to decrease soon and returns to the level of the resting tension. The shortening which occurs until the moment that the tension curve returns to the resting level (the larger the \( I \) is, the later comes this moment) is designated as the initial shortening and it corresponds to the initial tension development. The later shortening is defined as the excess shortening. The amount of the initial shortening is independent of the inertia or the equivalent mass, that is, the velocity of shortening, within a certain range. The mechanism involved was assumed to be different in the initial and excess shortenings. In our previous experiments whole sartorius muscle of the toad were used (1). In the present experiment muscle fasciculus or a single fiber obtained by the splitting of the whole muscle is used.

METHOD

The material used in the present study is the sartorius muscle of the toad \( \textit{Bufo vulgaris jap} \). The arrangement of the inertia lever system and the system of tension recording is shown in fig. 1. The moment of inertia of the lever is controllable by exchange of the balancing rider \( O \) or by changing the distance \( a \) shown in the figure. Since much time is needed for this adjustment, several wooden or straw levers of various moments of inertia were prepared and the balancing was done prior to the experiment. When the muscle was changed from the whole to the one half split, the lever was changed also to the one with a half of the moment of inertia.

The mechanogram was recorded by phototube mechanograph. The wave form of stimulating current was a square pulse with the duration of 1–3 msec. To prevent the stimulating electrode from becoming a load, a small lead wire

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* 真島英信
FIG. 1. The arrangement of apparatus.

FIG. 2. The sensitizing device for RCA 5734.
a: metal shell. b: appendage. c: cap.

Tension was picked up by RCA 5734 and amplified by two-stage DC-amplifier. The detail of the circuit is reported elsewhere (2). The linearity is satisfactory and the sensitivity is easily controlled from 10 g. to 100 mg. for the full deflection of the light spot of oscillograph. When the tension of a single fiber was recorded, often an appendage shown in fig. 2 was attached to the plate shaft of 5734, whereby the sensitivity was increased about tenfold or more. The shaft and the upper electrode were connected with cotton thread (fig. 1, R).

pH of the Ringer's solution was always 7.2.

RESULTS

First, the tension and shortening during a twitch were recorded simultaneously. One of them is shown in fig. 3, A. The amount of the initial shortening (Si) is indicated by a mark. Then the same experiment was repeated with a half muscle obtained by the splitting of a whole muscle into approximately two halves. This time, the moment of inertia of the lever (I) as well as the load (m) was one half of those used in the previous experiment. These were, however, not precisely the halves, since the cross section of the muscle was not exactly halved. It is fortunate that the value of Si is independent of I, m or equivalent mass (unless it is too large); it depends mainly on the initial length of the muscle (1). Therefore, it was not necessary to decrease the load to an exact half; the initial length was controlled by the load so as to make it equal to that of the whole muscle. Thus, it was made certain that Si is equal in both experiments. In the second experiment, the sensitivity of the tension recorder was raised approximately twofold while that of the mechanograph remained the same as before.

The same procedure was reported for the quarter muscle, one eighth muscle, etc. Since a sartorius muscle of the toad consists of about one thousand fibers,
FIG. 3. The initial shortening in various preparations. Tension curve (top), shortening curve (middle) and stimulus (bottom). Toad's sartorius muscle. 19°C. A: Whole muscle, load 4 g., inertia 6136 g cm². B: 20 fibers, 90 mg., 104 g cm². C: 10 fibers, 40 mg., 40 g cm². D: 4 fibers, 20 mg., 12.4 g cm². E: Single fiber, 10 mg., 12.4 g cm². The initial length was 52 mm. in all cases. The amount of the initial shortening is shown by the mark. (See text.)

the splitting of the muscle several times had obtained a fasciculus of 10-20 fibers. The results of the experiments with 20, 10 and 4 fibers are shown in fig. 3, B, C and D respectively. In every case $S_i$ is equal to that of the whole muscle. It is noteworthy that the courses of the mechanograms, especially after the initial shortening, are different from each other. If all the fibers remain completely uninjured and the various factors such as $I$, $m$ and the friction of the axis of the lever are reduced in exact proportion to the cross section of the muscle, it would be expected that the mechanograms coincide with each other. This however, was not the case. It is remarkable indeed that $S_i$ remains the same in all cases. Extrapolated from the results of these experiments, $S_i$ of a single fiber is assumed to be equal to that of the whole muscle.

In fig. 3, E is shown the result with a single fiber. The $S_i$ in this case is smaller than in other cases by about 15%. This decrease is intelligible by reason of injury to the fibers. However, another true reason is considered as follows: Although it may be thought that the single fiber should be treated in Ringer's solution rather than in air, the simultaneous recording of the tension and shortening is impossible in such a way. For this reason, three fibers were isolated together and then the two fibers on either side were cut by sharpened needle
tips, leaving the one in the middle intact (fig. 4). The two fibers which were cut were left in place to prevent the middle intact fiber from being injured or dried. Since the excised fiber on the anode side would not be excited or contracted, it would hinder the shortening of the intact fiber. Consequently, the resistance to the single fiber would increase and $Si$ decreases. When the fibers on both sides were split away, a greater amount of decrease was observed. The reason is that it is impossible to remove them without injury. The conclusion is that, concerning a twitch, $Si$ of a single fiber is equal to that of the whole muscle.

DISCUSSION

In muscles such as the sartorius, where the fibers run parallel with each other, and all fibers are excited and contracted synchronically, the mode of contraction of single fiber is considered to be the same as that of the whole muscle in so far as the $Si$ value of a twitch is concerned. This suggests that the property of the whole muscle or a single fiber (particularly the $Si$ value) applies also to its constituent parts—the filament or the fibrous protein, for these are considered to be arranged in parallel in the muscle fiber (3) (4).

In a previous report (1) the following results were obtained in regard to the initial shortening of the whole muscle: (a) $Si$ is independent of $I$ (velocity of shortening) and the course of tension curve. (b) $Si$ depends chiefly on the initial length. (c) During the initial shortening, the larger the equivalent mass is, the greater is the amount of work done. This relationship does not exist during the excess shortening. (d) When the interval is most effective, double shocks produce a twofold increase in $Si$ value.

Assuming that these represent the property of the contractile substance consisting of a series of functional units, we may advance the following two possible hypotheses: There are two types of functional units, one the rapid and the other the slow element. The initial shortening is due to the contraction of the rapid element and excess shortening is due to the slow element. The characteristics of $Si$ are, therefore, the property of the rapid element and not of the slow element. An alternative interpretation is: The functional unit is only of one kind and it does not obey the all or none law. The contraction of each unit takes place in two steps and a state of semi-stability exists between the two. The mechanism of contraction changes at this state from the rapid to slow. At present it is not intelligible that the contractile unit has two different mechanisms of contraction and that all units contract simultaneously in exactly the same way. Rather, the striated muscles consist, histologically, of isotropic and anisotropic bands. According to Buchthal et al. (5) or Natori (6), the aniso-
tropic band shortens first during a twitch. Contrary, Engelmann (7), Huxley and Niedergerke (8) or Fujiwara (9) reported that the isotropic band shortened more rapidly. At any rate, both bands are different in contractility. The first is, therefore, considered more plausible than the second.

The cause of the initial tension is the strong contractile force developed in the rapid element, and by this force the work is done so as to overcome the external resistance. Since the tension is equal to the resting tension, the length of the passive elastic component is the same as before the stimulation, and the $S_l$ represents purely the active shortening of the rapid element. And following this, the slow element contracts. Double shocks induce, at a proper interval, twice as many units in the rapid element into a state of contraction, as a single shock. This dualistic hypothesis well explains the phenomenon of contraction which has been explained hitherto by the viscous-elastic or contractile-elastic models. In Buchthal's transmutation theory (10), the fixation factor is assumed in addition to the chain, and in Polissar's physico-chemical model (11) also, the U-state is assumed to explain the dualistic properties of muscular contraction.

**SUMMARY**

1. The tension and shortening relation was investigated for a single fiber of the sartorius muscle of the toad by means of RCA 5734 and the phototube mechanograph.

2. When the initial length is not changed and the equivalent mass is adjusted according to the cross section of the muscle, the amount of the initial shortening of a single fiber is found to be the same as that of the whole muscle.

3. A dual hypothesis was advanced to account for all the observed results from the whole muscle and single fiber. The hypothesis is based on the assumption of the existence of the rapid and slow element in the fiber.

**REFERENCES**