CHANGES IN THE VISCO-ELASTIC PROPERTIES OF MUSCLES IN CONTRACTURES AFTER IMMOBILIZATION

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While engaged in the study of the pathogenesis of contractures arising as a result of immobilization of the limbs, several workers have been able to discover a reflex mechanism in the first phase of their development. The problem of the mechanism of their maintenance in later stages is not so clear.

In view of the hypothesis that as a result of prolonged immobilization, changes take place also at the periphery, including in the muscles themselves, we undertook an investigation of the visco-elastic properties of muscles during immobilization, these properties being indirect indexes of the state of the colloid structures of the muscles.

EXPERIMENTAL METHOD

Experiments were performed on isolated muscles of the rabbit, in which one of the hind limbs (the left) had been immobilized for periods of 1 to 5 months as a preliminary measure. Immobilization was accomplished by the application of a plaster cast, fixing the three joints of the limb in the position of either maximum flexion or maximum extension. The muscles of the limb which was not immobilized served as controls. The tibialis anterior and plantaris muscles of the leg were examined. Muscle preparations were carried out on animals in a state of deep anesthesia, in order to remove the influence of strong reflex stimulation on the initial condition of the muscles. The isolated muscles were placed in Ringer-Locke solution, warmed to a temperature of 36-40°C and aerated uniformly with oxygen or, less commonly, with atmospheric air. Both muscles for comparison were placed in the solution at the same time, so that strictly identical experimental conditions were observed.

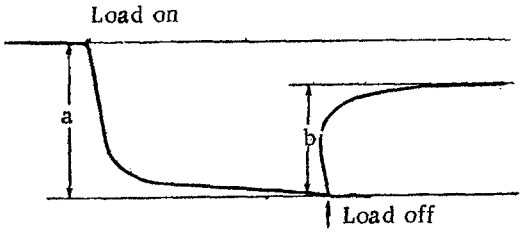

Fig. 1. Scheme of analysis of the curve of stretching.
a) Magnitude of maximum lengthening (degree of stretching); b) degree of restoration of length one minute after removal of the load.

In order to assess the visco-elastic properties, we recorded on a kymograph the curve of change in length of the muscle after the sudden application of a load and after its equally sudden removal. For this purpose the muscle, with its proximal end fixed to a glass rod, was immersed in a glass containing the solution, and its tendon connected to one arm of a myograph; the load was suspended from its other arm. For stretching the plantar muscles the weight applied was usually 25 g, and for the anterior tibial muscles – about 15 g. Each muscle was stretched for one minute, after which the load was removed. The curve of restoration of its length was also recorded for one minute. The curves obtained were analyzed in respect to the following indexes (Fig. 1): 1) the magnitude of the maximum lengthening (Fig. 1,a) as a

Mean Values of the Degree of Stretching and Recovery of the Muscles of the Leg in Normal Rabbits and in Rabbits After Fixation of the Left Hind Limb (in %)

Serial No.	Experimental conditions	Degree of stretching of the muscles				Degree of recovery of the muscles			
		Tibialis anterior		Plantaris		Tibialis anterior		Plantaris	
		left	right	left	right	left	right	left	right
1	Without immobilization (normal rabbits)	20.7	20.5	7.1	7.3	81	81	69	70
2	Immobilization of the left hind limb in a position of flexion	11.4	19.0	4.3	6.2	72	71	70	69
3	Immobilization of the left hind limb in a position of extension	10.7	21.1	4.6	8.2	65	66	61	60

percentage of the initial length of the muscle (degree of stretching) and 2) the degree of restoration of its length one minute after removal of the load (Fig. 1, b) as a percentage of the level of stretching (ratio b:a).

The experimental results were treated by the method of variational statistics. The degree of significance of the variations in the experimental results from the controls was calculated from the tables of Fisher and Student.

EXPERIMENTAL RESULTS

In the first series of experiments to determine the limit of variation of the visco-elastic properties of fellow muscles of the right and left limbs, the curves of stretching of muscles isolated from the limbs of healthy animals were compared. Altogether 15 animals were examined in this series. The experimental results showed that the variations in the level of stretching in symmetrical muscles did not on the average exceed tenths of one percent, although in isolated cases variations of 2-3% were observed in the tibial muscles and of 1-2% in the plantar muscles. Average values for stretching of muscles in the control series of rabbits are shown in the table.

It can be seen from the table that the anterior tibial muscles are approximately 3 times as elastic as the plantar muscles, which is in agreement with their morphological characters: the anterior tibial muscle has long fibers, arranged in parallel, whereas the plantar muscle has a pinnate structure and, consequently, shorter fibers and a larger physiological section.

In the second and third series of experiments the visco-elasticity of the muscles was investigated in limbs subjected to immobilization. In evaluating the results of these series of experiments it was essential to take into consideration that as a result of immobilization there takes place at times a considerable diminution in the mass of muscles, as expressed by loss of weight and reduction in volume. On the basis of reports in the literature [2, 5] and also of the results of our own observations, it must be mentioned that the diminution in mass of functionally different muscles is expressed to a different degree, and depends on the length of immobilization and the position in which the limb was fixed. Thus in this particular series of experiments we found a greater diminution in the muscles, and at earlier periods, when the limbs were fixed in the position of extension, and always to a greater degree in the plantar muscles. It follows from the above that on stretching symmetrical muscles of the control and experimental limbs with equal loads per unit cross section, different forces acted on each of them. For this reason the level of stretching reflected not only the visco-elastic properties of the muscle but also the size of the load acting per unit cross section.

To be able to compare the results it was necessary to calculate the magnitude of stretching of the control and experimental muscles, taking into consideration the cross section of the muscle. The area of cross section was calculated from photograms of the muscles, in natural size, in which the width of the muscles was measured. In view of the hypothesis that diminution of volume takes place uniformly in all directions, the thickness of the muscle can be calculated from its width. The average ratio of width to thickness was determined on the basis of measurements in 10 control experiments. The shape of the cross section was taken conventionally to be an

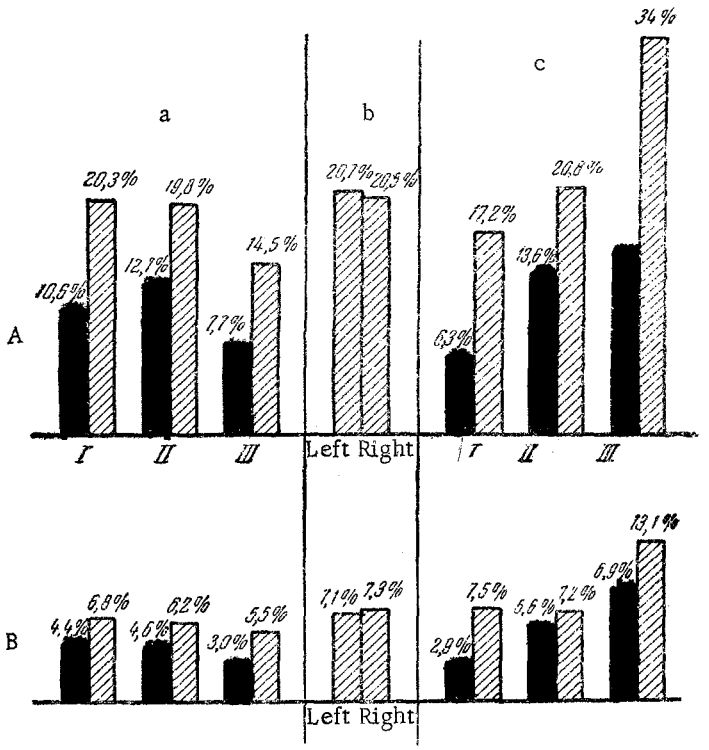

Fig. 2. Changes in the stretching of muscles after different periods of immobilization.
A -Anterior tibial muscles: a) in a position of flexion; b) average degree of stretching of muscles in normal rabbits; c) in a position of extension. Periods of fixation: I – 2 months; II – 3-4 months; III – $4\frac{1}{2}$ -5 months. B - plantar muscles: a, b, c) as in A. Periods of fixation: I – 1 month; II – 2 months; III – $4\frac{1}{2}$ months.

ellipse, and the area calculated by the well-known formula. The size of the load per 1 mm^2 section, and the degree of stretching, which is proportional to this, were subsequently calculated.

In the second series of experiments observations were made on animals whose limbs had been fixed in a position of flexion. The series consisted of 24 experiments on rabbits with varying periods of fixation: $4\frac{1}{2}$ -5 months – 4 rabbits, 3-4 months – 16 rabbits, and 2 months – 4 rabbits.

The table shows the average values of stretching for the muscles of the control and experimental limbs.

As seen from the table, the degree of stretching of the muscles of the unimmobilized limb almost coincides with the results of the control experiments. The stretching of the muscles of the immobilized limb was reduced by comparison with the muscles of the control limb by 1.7 times for the tibialis anterior muscle and by 1.2 times for the plantaris muscle. The difference in stretching of the plantar muscles was less significant. If the degree of stretching is examined without consideration of the changing cross section of the muscle in the immobilized limb, then this difference is reduced for the anterior tibial muscles: the muscle of the immobilized limb has an average extensibility of 14.9% (in place of 11.4%) with an extensibility of the muscles of the control limb of 19.0%. For the plantar muscles, if the extensibility is compared without taking into consideration the changing cross section of the muscle, this difference does not in general take place: the muscle of the control limb is stretched on the average by 6.2%, and the muscle of the immobilized limb by 6.3% (in place of 4.3%). This may be explained by the fact that, because of the pinnate structure of the plantaris muscle, the alteration in its physiological cross section is far greater than could have been estimated by the method of calculation described.

If the changes in the visco-elastic properties are examined in relation to the periods of fixation of the limbs, the relationships shown (in Fig. 2, a) are observed. As the duration of immobilization increases, the

elasticity of the muscles is diminished not only in the immobilized limb but also to some extent in the control limb which is not immobilized; for this reason the difference between the elasticity of compared symmetrical limbs does not change so sharply or even remains constant as the period of immobilization is increased. This is characteristic of both the plantar and anterior tibial muscles.

In the last, third, series of 9 experiments, the visco-elastic properties of muscles were investigated after fixation of the left limb in a position of extension. The periods of fixation were as follows: 1 rabbit for $4\frac{1}{2}$ months, 5 rabbits for 2 months and 3 rabbits for 1 month.

It must be pointed out that after fixation of the limb in this position, a contracture develops after only one month, i.e. sooner than after fixation in a position of flexion, when signs of a persistent contracture appear only after $2\text{-}2\frac{1}{2}$ months. The animals tolerated prolonged immobilization in a position of extension with difficulty, and often died. Thus after a period of fixation of $4\frac{1}{2}$ months it was possible to keep only one rabbit out of five. The summarized results of this series of experiments are shown in the table (in series 3).

As seen from the table, the muscles of the control limb were stretched on the average to almost the same extent as the corresponding muscles of normal animals. The difference in elasticity between the control and experimental animals is greater here than in the case of fixation in the position of flexion. The elasticity of the anterior tibial muscles of the immobilized limb is reduced roughly to half, and that of the plantar muscles 1.8 times.

In the study of the character of the changes in the visco-elastic properties in relation to the period of fixation, the following regular feature is observed: the muscles of both the control and the experimental limbs show increased elasticity as their period of fixation is lengthened (Fig. 2, c). Thus in the muscles of the immobilized limb the least degree of stretching is observed after a period of fixation of one month (in the tibialis anterior muscle – 6.3%, in the plantaris – 2.9%), and the greatest – after a period of fixation of $4\frac{1}{2}$ months (in the tibialis anterior muscle – 15%, in the plantaris – 6.9%). In the muscles of the control limb, after prolonged fixation (for $4\frac{1}{2}$ months) the elasticity is increased by more than $1\frac{1}{2}$ times in comparison with normal (i.e. the mean level of stretching in the control experiments).

Attention must be directed to the fact that fixation of one limb is not without an effect on the state of the muscles of the other limb. Examples of this fact have been observed in the literature [3].

In comparing the results of the second and third series of experiments (Fig. 2, a and c) it can be seen that the changes in the elasticity with increasing periods of fixation in flexion and extension are opposite in nature: after fixation in flexion the elasticity falls, but after fixation in extension it rises, although it remains for long periods below normal. As the elasticity of the muscles of the immobilized limb changes, so also correspondingly does the elasticity of the muscles of the control limb. The difference in elasticity between the muscles of the control and the immobilized limbs is greater in the case of fixation in the position of extension.

Comparison of the degree of restoration of the initial length of the muscles of the control and immobilized limbs (see table) shows that in all cases it is almost the same in the symmetrical muscles. Consequently the relationship between the "viscous" and the elastic properties is the same in the muscles compared. Comparison of the degree of recovery of the muscles in the fixation experiments (Fig. 1, a and c) with the results of experiments on normal muscles (Fig. 1, b) confirms that as a result of immobilization the degree of recovery falls, and again to a greater degree in experiments in which fixation is carried out in the position of extension.

Thus a comparison of the degree of the changes caused by immobilization in positions of flexion and extension demonstrates that fixation in the position of flexion is accompanied by smaller disturbances in the muscles of the immobilized limb than is fixation in the position of extension, and after longer periods of fixation it has a smaller effect on the visco-elastic properties of the muscles of the control limb.

The explanation of this fact may be that flexion is more natural for the rabbit.

A state of full extension is practically never observed. Presumably when a limb is put into an unnatural position, disturbances of the properties of its muscles develop more rapidly and to a greater degree.

SUMMARY

The author compares the degree of extension of the isolated symmetrical muscles of rabbits, one of the

extremities of which was subjected to immobilization in the position of flexion or extension for the period of 1-5 months. Immobilization causes the decrease in the stretching capacity in muscles of the fixated extremity, as compared to control. This difference was greater in cases of fixation in a position of extension. In prolonged periods of immobilization the changes were noted in the stretching extension capacity of the control extremity, i. e. an increase in the stretching capacity in fixation in the position of extension and its decrease in the position of flexion. The degree of these changes was also found to be greater in fixation in the position of extension, i. e. in the position less "physiological" for rabbits.

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