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EXPERIMENTAL RUPTURE OF THE ACHILLES TENDON

Comparison of Experimental Ruptures in Rats of Different Ages and Living Under Different Conditions

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Sallefranque, in 1887, performed a minor series of experimental ruptures on a dog anesthetized with ether. He subjected the intact bone-muscle-tendon-bone chain, *inter alia* the biceps brachii and the triceps surae, to stress with simultaneous electrical stimulation of the muscle. The result was avulsion of bone, muscle rupture, and after the dog had died a tendon rupture in the left biceps brachii.

Lindblom (1939), in experiments on a fraction of the supraspinatus tendon on cadavers, obtained tendon rupture in a couple of cases. He mentioned the significance of loading the tendon with the humerus abducted, which strains the articular part of the tendon first.

In all other studies of bone-muscle-tendon-bone chains it has proved impossible to induce tendon rupture. McMaster's study from 1933 on young rabbits is most often cited. He concluded that a healthy tendon never fails as a result of indirect violence. His method was not above criticism. He did not stimulate the muscle, and he applied traction on the foot, so that its long axis was in continuation of the tendon. These drawbacks were corrected by Fink & Wyss (1942) and by Davidsson (1956) without, however, altering McMaster's conclusion.

None of these authors paid regard to the animals' age and fitness, although it is stated concurrently that rupture of the Achilles tendon occurs predominantly in men aged 30–50 who are or have been athletic (Arner & Lindholm 1959, Picaud et al. 1966, Frings 1969).

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Viidik (1969) trained rabbits towards the end of their growth period. Subsequent experiments did not induce tendon rupture, but mainly avulsion of bone from the calcaneus. This worker did not use stimulation of the muscle.

In the present study the author investigated wild and domesticated rats to compare animals living under different conditions. A later study (Barfred 1971 b) was concerned with the effect of the various types of stress to which the bone-muscle-tendon group may be exposed.

MATERIAL AND METHOD

All the rats were of the Norway strain, some being albino and others wild, brown rats. These two types are so closely related that they mate mutually (Donaldson 1924, Richter 1954).

Table 1 gives the sex and weight distribution of the wild rats which had been captured less than two weeks before the experiment. Male rats more than 300 g and female rats more than 250 g made up the control group against other large rats whose conditions of living were different.

Table 1. Distribution of albino rats and of recently captured wild brown rats. The framed figures represent the control group.

Conditions of living		No. of investigated legs			
Group		50–150 g	150–250 g	250–300 g	> 300 g
Domesticated	♂	10	10	0	10
Domesticated	♀	0	0	2	8
Wild	♂	10	10	12	13
Wild	♀	12	17	14	15

Table 2. Distribution by weight, sex, and conditions of living of the large rats. In addition, mean body weight.

Conditions of living			No. of investigated legs		
Group	Average weight g	Total	♂ > 300 g	♀ 250–300 g	♀ > 300 g
Domesticated	386	20	10	2	8
Kept in runs	375	12	8	2	2
Wild	338	42	13	14	15
Inactive	357	14	8	4	2

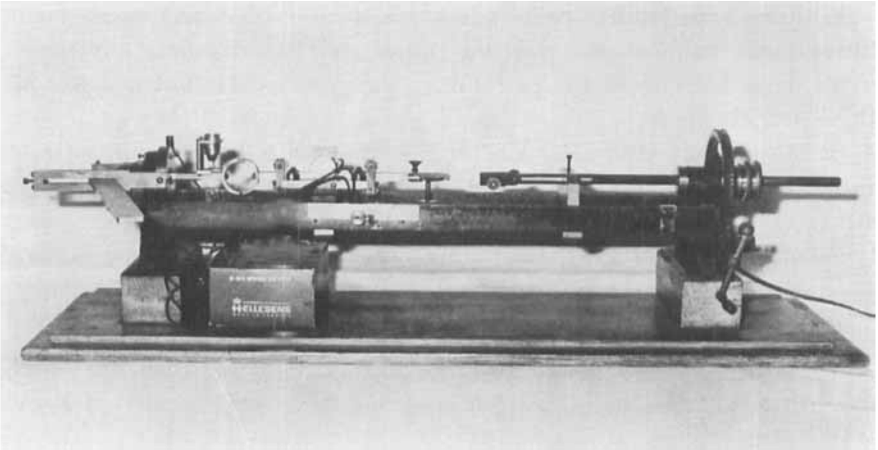

Figure 1. Testing machine. On the right the condylar clamp (Figure 4) which may be adjusted to infinite variability by means of the large cogwheel. On the left the calcaneal clamp (Figure 4), the ball bearing suspension and revolving potentiometer (Figure 2), the steel ring by which the alterations in tension are measured, and on the extreme left the handle by which the calcaneal clamp may be pulled manually away from the condylar clamp.

Table 2 gives the weight and sex distribution in the 4 groups of large rats living under different conditions. One group of rats had been kept in a room 4 × 3.5 m since birth. These rats, hereafter called "run-kept" rats, were the first or second generation of wild, brown rats. The inactivity group consisted of brown rats kept after their capture in a cage 30 × 40 cm. The experiment was performed 3–3½ months after the capture.

For the study of the bone-muscle-tendon-bone organ the anaesthetized rat was fastened in a material testing machine (Figure 1). The anaesthesia was effected by pentobarbitone sodium (Nembutal®), 5 mg/100 g body weight intraperitoneally. For the wild rats the anaesthesia had to be induced by ether. Thereafter half the dose of Nembutal could be administered. The other half was given when the ether had been eliminated. With the following experimental procedure Nembutal cannot be expected to have exerted any major influence upon the contraction level of the muscle (Secher 1951, Kraatz et al. 1953, Sirnes 1954).

Stimulation was performed by exposing the sciatic nerve through an incision on the lateral aspect of the thigh. By dividing the muscle easy access to a 2–3 cm segment of the nerve was gained. The nerve was embedded in a piece of split rubber tube. Inside this tube a double electrode was placed and connected to the stimulator (Disa Multistim). Stimulation was performed by trains of square wave pulses 40–60/sec, amplitude 1 v, duration 0.7 msec. In preliminary experiments it was attempted to place the nerve outside the rubber cuff while the electrode was inside. Stimulation hereafter often failed to induce contraction of the triceps surae or caused only a weak contraction. Thus, despite the short distance from the electrode to the muscle, there was but little direct stimulation.

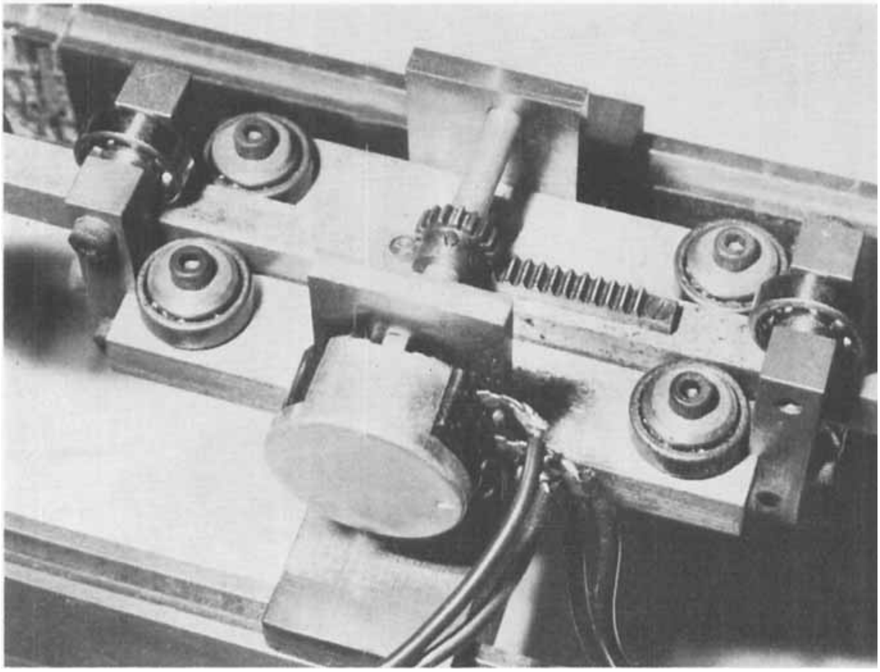

Figure 2. Ball bearing suspension of the rod on which the calcaneal clamp is placed. The rack operates the cogwheel which is coupled to a revolving potentiometer by which the movements of the calcaneal clamp are recorded.

The material testing machine consisted of a strong frame, at one end of which a condylar clamp was fixed to a rod which could be adjusted in an infinitely variable way to the desired length. At the other end of the frame a calcaneal clamp was fixed to a rod, which by a handle could be pulled 25 mm away from the condylar clamp. This elongation always entailed rupture somewhere. The movement was recorded by means of a rack operating a cogwheel placed on a revolving potentiometer (Figure 2).

The tension between the calcaneal clamp and condylar clamp was recorded by deformation of an inserted open steel ring. Between this ring and the calcaneal clamp the rod was suspended in 4 sets of ball bearings (Figure 2), so that the movement occurred with a minimum of friction and so that only the forces acting in the longitudinal direction of the rod were measured.

The deformation of the steel ring was measured by a strain gauge connected to a Philips measuring bridge. The results of the tension variations and the elongation were recorded simultaneously on a Honeywell visicorder. At a calibration within the measuring range used, the tension and elongation curves were linear. On each experimental day the tension recordings were calibrated before and after the experimental series, using a load of 10 kg. Thus, the loading could be determined with an accuracy of 0.2 kg and the elongation with an accuracy of 0.5 mm.

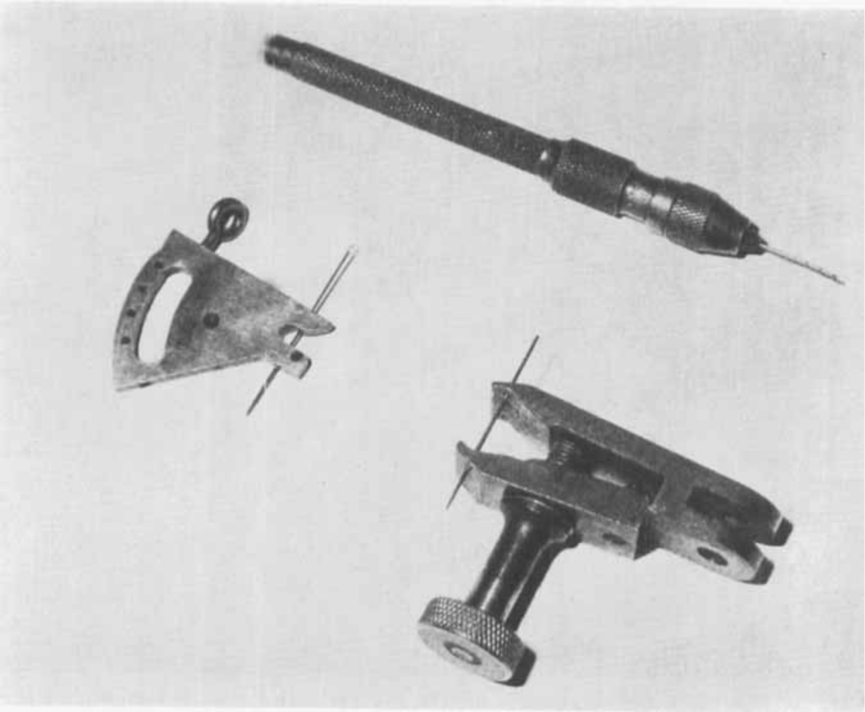

Figure 3. Top: The drill for piercing the calcaneuos and condyle. Bottom left: The plate whose notch fits the calcaneus. The pin is to be passed through the calcaneuos. The plate turns on an axis just beside the notch. Bottom right: Clamp for the femoral condyles with the pin which is to be passed through the condyles.

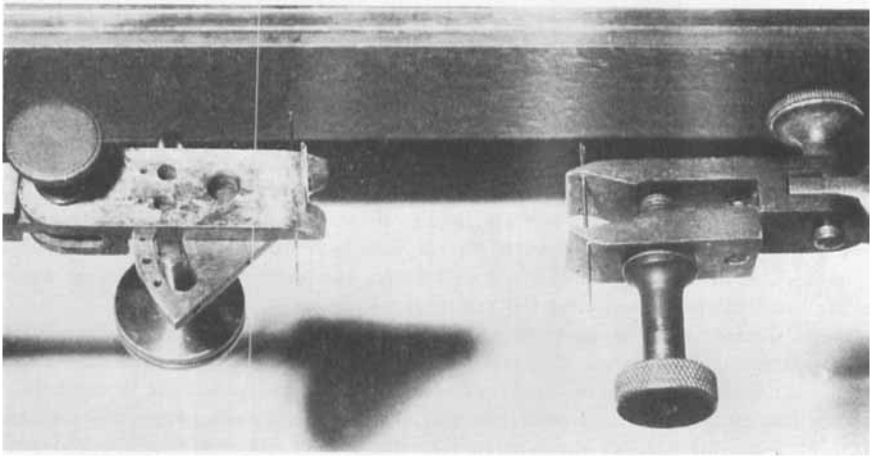

Figure 4. Calcaneal clamp and condylar clamp as placed in the testing machine, seen obliquely from above.

The calcaneus was exposed by a "stirrup" incision which on one side reached a little higher than the muscle-tendon junction. The plantaris tendon—which in the rat passes behind the calcaneus to the sole—was resected. The calcaneus was fixed to a 2.5 mm thick metal plate (Figures 3 and 4) with a notch shaped like the bone (3 different plates were used with different sized notches). At right angles to the notch a hole was drilled through the plate and calcaneus; by an inserted pin the calcaneus could be fixed to the plate. The plate could be turned 30° on an axis at right angles to the leg in the sagittal plane just above and beside the calcaneus. This induced on the right leg a pronation movement and on the left leg supination. The plate was further provided with an angle bar to keep the foot in a right-angled position.

The condylar clamp (Figures 3 and 4) was made according to the same principle as the calcaneal fixation, but instead of a fixed notch there was an adjustable clamp which could grasp the bone. The needle was placed through the bone at the knee axis. The thigh was tied to the apparatus to secure a rigid position of approximately 40° flexion in the knee joint.

The lower leg was cut just above the ankle, so that the Achilles tendon was the only connection between the knee and the foot. The bone-tendon-muscle-bone group could then be elongated until rupture occurred in one of the named structures.

When the rat was placed in the machine the calcaneal clamp was placed in zero position (the position from which a 25 mm elongation was possible), and the condylar traction was adjusted to and fixed in the position which rendered possible the named articular positions (90° flexion in the ankle and approx. 40° flexion in the knee).

All the rats were weighed with an accuracy of 5 g, their sex was determined, and the females were investigated for pregnancy. *Foot length* (distance from heel to longest toe) and *muscle tendon length* (distance from muscle origin to tendon insertion)—at maximum dorsal flexion of the ankle/extension of the knee joint, at 90° flexion of these joints, and at maximum plantar flexion of the ankle/maximum flexion of the knee—were measured with a vernier caliper with an accuracy of 0.5 mm. *Muscle tendon length* is taken to signify the length at maximum plantar flexion in the ankle joint and extension of the knee.

Excursion signifies the difference between the greatest and shortest length of the muscle-tendon group.

After the rat had been fastened, the *muscle force* was measured during tetanic stimulation. Thereafter, the loading experiment proper could be carried out.

Elongation of the bone-muscle-tendon-bone group was always done manually. Thereby, it was possible to carry out an accelerating movement corresponding to natural movements.

The loading experiments were always done with simultaneous tetanic stimulation of the muscle, 30° angulation of the footplate, and rapid elongation of the muscle-tendon group (average 250 per cent of the muscle-tendon length per sec).

The *initial length* is the length of the muscle-tendon group when the foot is in a rectangular position and the knee flexed 30–45°. In numerous experiments this corresponded accurately to the elastic equilibrium length (the greatest length of the relaxed muscle without application of external force). In the large rats this length was about 2 mm shorter than the muscle-tendon length as defined above.

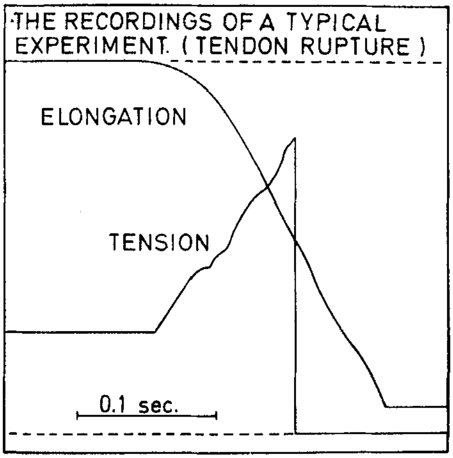

Figure 5. Typical recordings in a rupture experiment. Read from left to right. Top curve (descending) represents the elongation. The horizontal segment of the bottom curve represents the muscle force in isometric contraction induced by tetanic stimulation. The remainder of this curve illustrates the increase in tension until rupture.

Figure 5 gives a typical curve illustrating a rupture experiment. The descending curve indicates the elongation, whereas the ascending one indicates the increase in tension. The graph paper moved at a fixed speed, and it will be seen that at the outset the elongation was performed with a greatly accelerating movement and towards the end at an even speed. The increase in tension was irregular, there being flattenings of the curve, the first one at an increase in tension in relation to the maximum isometric tension of about 50 per cent. In addition to these more horizontal parts of the curve, there were sharper irregularities—occasionally with a slight fall of tension. These "dips" must be interpreted as partial interruptions of continuity (cf. Viidik 1966).

On the curve the author measured the *separation force*, signifying the tension at rupture. *Elongation* signifies elongation at rupture. Moreover, the elongation at an increase in tension up to 1.5, 2.0, 2.5, and 3 times the maximum isometric force was measured on the curves. Thus, $L_{2.0}$ is the elongation at an increase in tension up to twice the isometric force. $\Delta L_{1.5}$, the elongation from $L_{1.5}$ to $L_{2.0}$, affords an impression of the inclination of the steep part of the length-tension diagram.

Statistical Method

All data were entered on paper tapes, and the material was analysed on a GIER computer.

Unless otherwise stated, the linear regression equations were determined for the named parameters and compared between the groups. In comparing the distribution of the site of rupture in the various groups the approximate χ^2 test was used.

Differences were considered significant when $p < 5$ per cent.

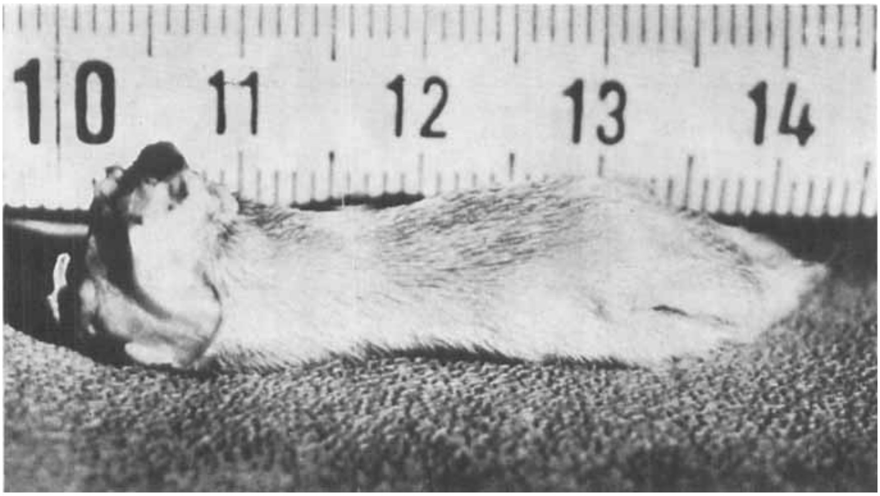

Figure 6. Rat foot after rupture experiment resulting in tendon rupture. Note the tendon end on the left. Only a small part of the lower leg is visible. As stated in the text, it was cut before the rupture experiment.

RESULTS

Site of Rupture

The rupture experiments had one of the following results:

1. Fixation ruptures where the rupture occurred at the site of the inserted pin, either in the calcaneus or in the femoral condyles.
2. Tendon ruptures where the rupture occurred in the tendon proper. Frequently, the site of rupture was close to the insertion, but just as often 1–2 mm from the tendon insertion. The ruptures were often oblique; in that case the tendon remnant on the calcaneus might be 3–4 mm in length on one side (Figure 6). The oblique course of the separation line bore no relation to the lateral or medial side of the tendon or to whether there was a question of a supination or pronation trauma.
3. Muscle rupture where the rupture was localized to the muscle, as a rule at the transition between its middle and lower thirds.
4. Other ruptures which might be combined muscle-tendon ruptures or muscle or tendon ruptures with avulsion of a fragment of bone from the condyle or the calcaneus.

Figure 7 gives the distribution of ruptures in the wild, brown, newly captured rats. The tendon ruptures occurred only in the heavy weight groups. The weight above which tendon ruptures occurred was about

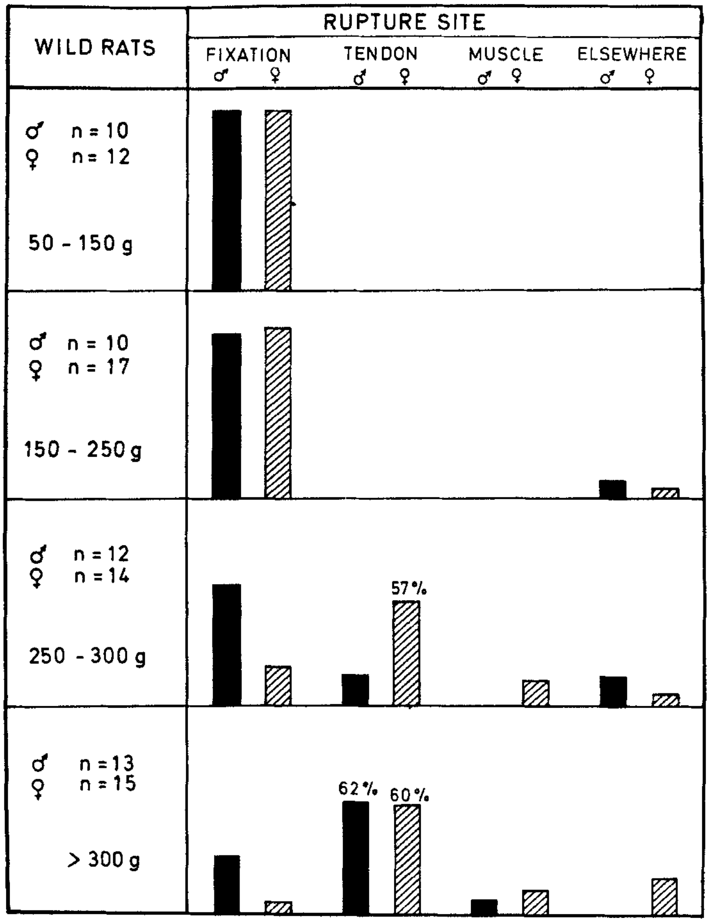

Figure 7. Distribution of rupture site by weight and sex of recently captured wild rats. Height of columns determined by the percentage number of ruptures. It will be seen that tendon ruptures occur with the same frequency in females weighing 250–300 g and in males as well as females weighing more than 300 g.

50 g lower for females than for males. This difference in weight corresponds to the difference in weight between males and females of the same age (King 1923). The frequency of tendon rupture in the last 3 groups was practically identical or 57, 62, and 60 per cent respectively. It was decided, therefore, to consider these three groups as one group which thereafter was used as a control against rats of the same size in which the type of rupture experiment was altered (Barfred 1971 b) and against rats living under other conditions (Figure 8).

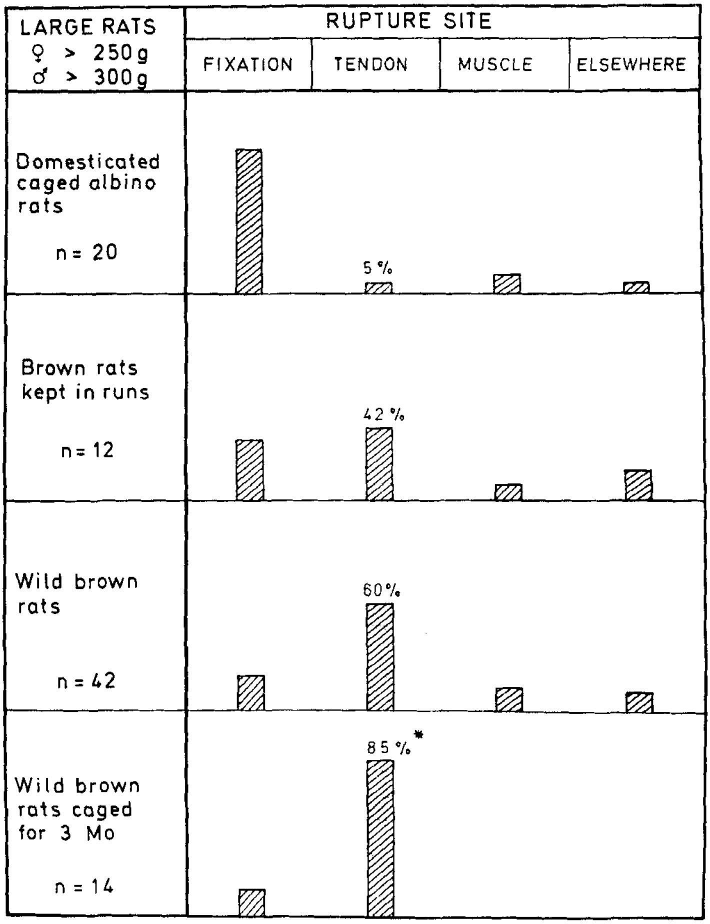

Figure 8. Distribution of rupture site by large rats' conditions of living (♂ > 300 g, ♀ > 250 g). Height of columns determined by the percentage number of ruptures (stated for the tendon ruptures only).

** significantly different from "run-kept" rats (p = 4 per cent), but not from the recently captured wild rats (p = 12 per cent).*

Among small albino rats (up to 300 g) no tendon ruptures occurred. Nearly all the ruptures observed were fixation ruptures. Among the large albino rats only one tendon rupture occurred.

The frequency of tendon ruptures was greatest in the inactivity group, significantly greater than in the "run-kept" group, but not significantly different from the control group (p = 12 per cent).

None of the females weighing between 250 and 300 g was pregnant.

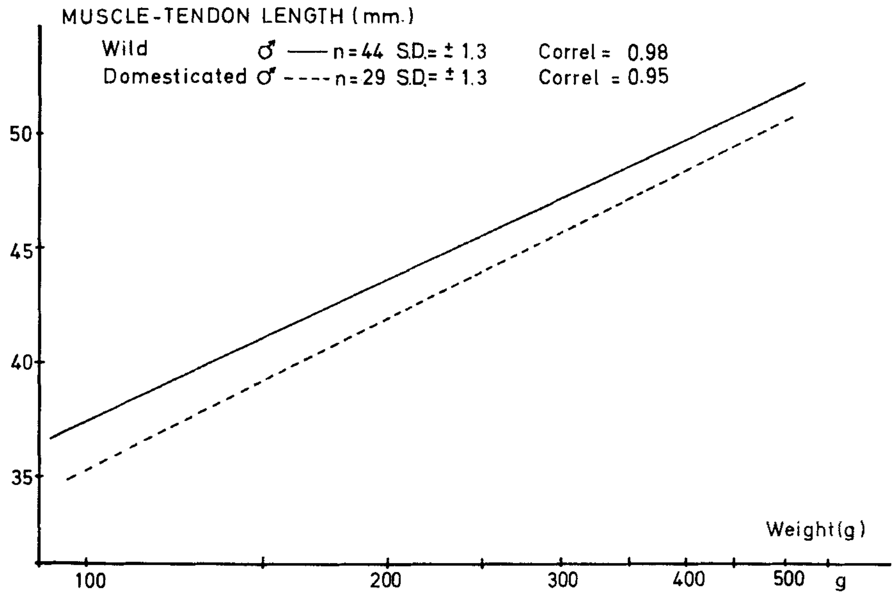

Figure 9. Correlation between muscle-tendon length and body weight. Weight scale logarithmic. The lines represent the regression equations for domesticated rats and for recently captured wild rats. Force unit: Kp = 9.81 × 10^5 g cm/sec^2 = 9.81 N (Newton).

Among females weighing more than 300 g 4 were pregnant. Among 5 investigated legs 2 tendon ruptures occurred.

Foot Length, Muscle-tendon Length, and Excursion

The length of the foot and the muscle-tendon group was found to be rapidly increasing for the small rats, the growth rate decreasing in the large rats.

The relationship between the muscle-tendon length and the log. weight may reasonably be described as a linear function (Figure 9). The length of the muscle-tendon group was significantly greater in the wild than in the domesticated rats and greater in males than in females. The muscle-tendon length-log. weight relation also showed that the muscle-tendon length at the same weight in the inactivity group and in the "run-kept" group was greater than in the control group.

The longitudinal growth of the foot appears to decrease at a lower weight than does the longitudinal growth of the muscle-tendon unit.

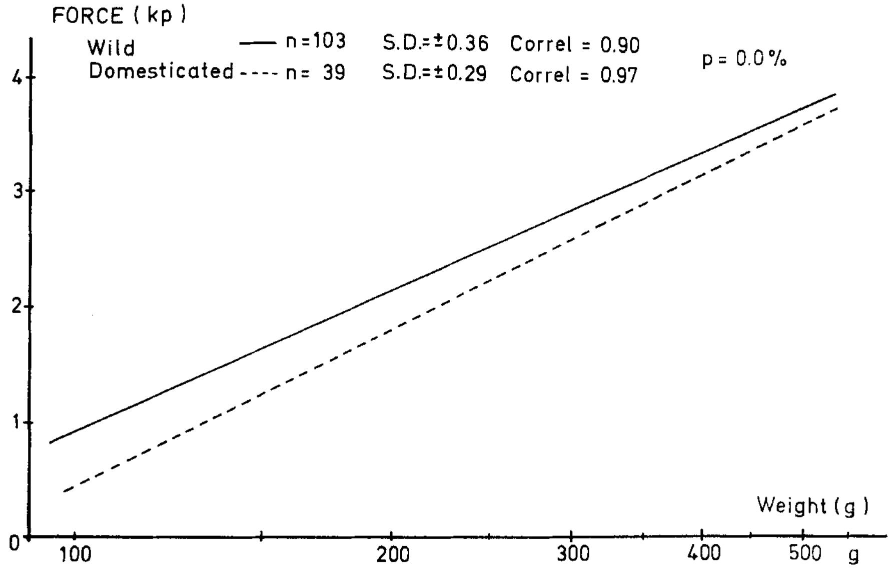

Figure 10. Correlation between muscle force and body weight of domesticated rats and recently captured wild rats. The lines represent the respective regression equations. Weight scale logarithmic.

The foot length-log. weight relation cannot be considered a linear function. Foot length was shorter in domesticated than in wild rats and shorter in females than in males.

Otherwise, foot length did not exhibit any major relationship to the basic parameters (muscle force, muscle-tendon length, and body weight) in the different groups. The same applied to the excursion, whereas a comparison of foot length with excursion showed a reasonable relationship. This relationship was the same for all groups except the one from the runs, which showed a greater excursion at the same foot length than the other groups ($p = 0.7$ per cent).

Muscle Force

In most groups the force was about 10 times greater than the body weight. This force-weight relation decreased with age, so that the relationship between force and log. weight may be reasonably described as linear (Figure 10) without this form of comparison being interpretable as a biological law.

There was no sex difference in the force-log. weight relationship. Considered together, the wild rats were stronger than the domesticated

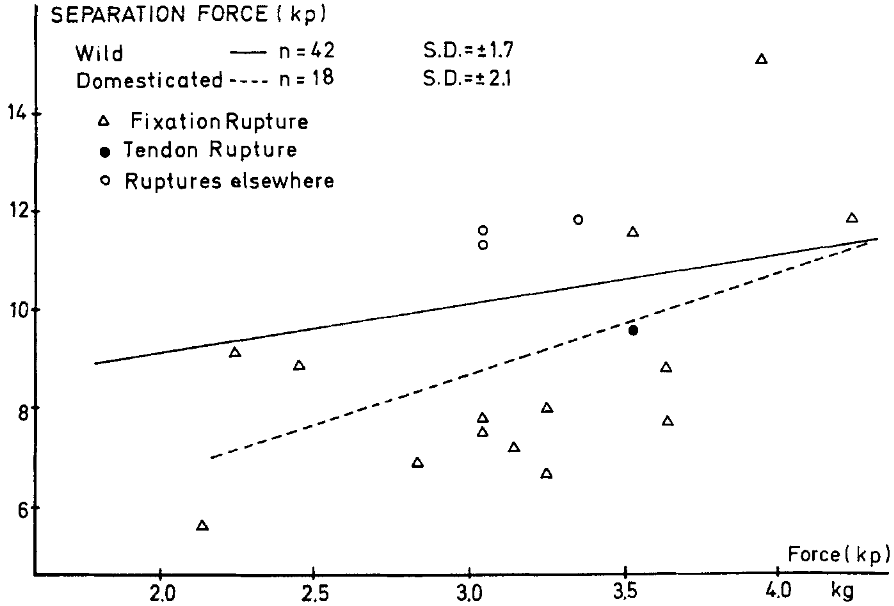

Figure 11. Correlation between separation force and muscle force of large domesticated rats and large, recently captured wild rats. The lines represent the respective regression equations. The position of the individual rupture experiments is marked, only for large domesticated rats, by symbols according to the site of rupture. These marks form the basis of the broken line.

rats of the same weight (Figure 10), but if only the large rats were compared there was merely a tendency to greater force in the wild rats (p = 10 per cent). The inactivity group exhibited no difference from the control group, but the "run-kept" group showed a tendency to greater force.

Comparison of the force-muscle-tendon length relationship between the different groups showed a very stable relationship, except that the pregnant rats were found to be a little weaker at the same muscle-tendon length. Pregnancy appears to involve weakening of the muscles.

Separation Force

The absolute separation force was in the order of magnitude 3 times the muscle force and about 30 times the body weight.

The separation force-muscle force relationship was almost linear, but with a distinct tendency to flatten off in the largest rats (Figure 1, Barfred 1971 b).

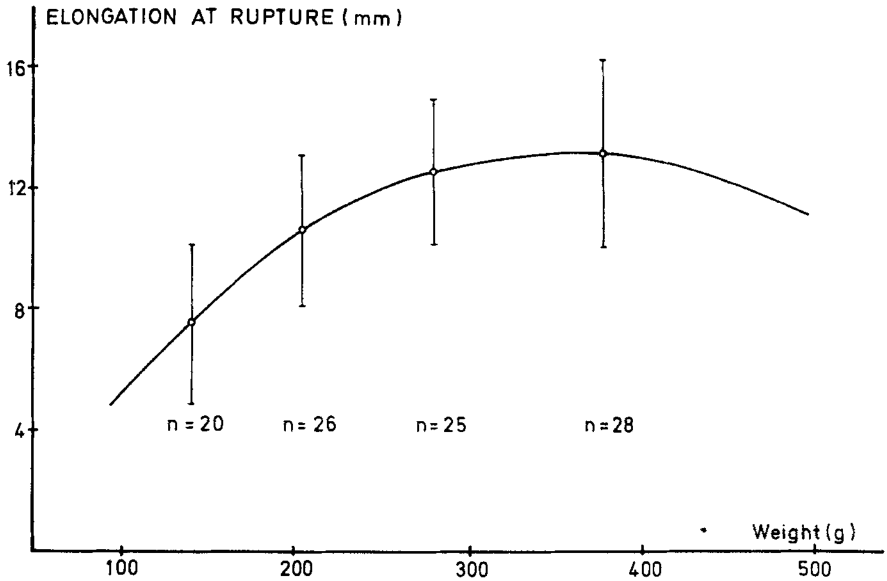

Figure 12. Elongation at rupture. Standard deviation given for 4 groups: 50–150 g, 150–250 g, 250–300 g, and > 300 g, but the curve was drawn on the basis of all the marks.

In relation to log. weight there was no difference between the control group and the inactivity or "run-kept" group, but in relation to muscle force there was a tendency to a lower separation force in the "run-kept" rats and a significantly lower separation force in the inactivity group. There was no difference in these relationships between males and females.

In relation to muscle force as well as log. weight the separation force was significantly greater in wild than in domesticated rats.

Figure 11 illustrates the position of the individual experiments on large albino rats in a muscle force-separation force diagram. The separation force was in one-third of the cases above the regression line for the wild rats. In 3 of these 6 cases rupture occurred outside the fixation sites. The only tendon rupture in this group occurred at a separation force which was below the regression line for the albino group.

Elongation

The elongation was about 25 per cent of the muscle-tendon length. The elongation had been carried out at a rate of about 250 per cent/sec.

The elongation-weight relationship increased up to a body weight of 300–350 g, whereupon it decreased (Figure 12).

Between wild males and females there was no difference in the elongation-weight relationship, whereas elongation at the same weight was significantly lesser in domesticated than in wild rats. The "run-kept" rats behaved like the wild rats, whereas in the inactivity group the elongation was significantly less marked.

The relationship between elongation and muscle-tendon length was the same in domesticated as in wild rats, with the same tendency to a decrease at high muscle-tendon length as well as at high weights (cf. Figure 12). Between the wild rats and the "run-kept" rats there was no difference, but the elongation at the same muscle-tendon length was significantly lower in the inactivity group.

The separation force-elongation relationship may reasonably be described as linear. The drop or flattening of the elongation seen at high weights and at great muscle-tendon lengths was not found at high separation forces. The separation force-elongation relationship showed that the separation limit was reached at a lesser elongation in the inactivity group and in the "run-kept" group, whereas no difference was observed between wild and domesticated rats.

$L_{2.0}$ in relation to muscle-tendon length or log. weight showed no difference between the groups.

$\triangle L_{1.5}$ was significantly lower for domesticated than for wild rats, corresponding to greater rigidity in this part of the length tension diagram.

Direct comparison of the above-mentioned parameters between the inactivity and "run-kept" groups showed that the groups were to a marked extent similar. However, a very essential difference was found in the frequency of tendon ruptures, which was significantly higher among the inactivity rats. The only other difference found was in the separation force-muscle force relationship, which showed that the regression line was steeper for "run kept" than for inactivity rats ($p = 4.7$ per cent). If it is assumed that the lines nevertheless have the same inclination, further analysis shows the lines to be identical.

Supplementary Experiments

In all the above experiments the layers of skin and fascia overlying the muscle were intact. This might have stabilized the muscle so much in relation to the entirely exposed tendon that the rupture pattern might be displaced in favour of the tendon. This might perhaps have been the factor which rendered it possible at all to induce tendon rupture. For this reason a few experiments were performed on large, wild rats in which the muscle too was exposed by the incision. In 3 such experiments 1 muscle rupture and 2 tendon ruptures occurred.

In addition, a series of 10 experiments was performed with a straight traction on the calcaneus of large, domesticated rats, i. e. without supination or pronation. Tendon ruptures might have been masked when an oblique traction was applied to a weak bone. However, in this group also only one tendon rupture occurred.

DISCUSSION

The Achilles tendon in the rat is 1–1.5 cm in length, made up like all tendon tissue of densely arranged collagen fibres interspersed by slender fibrocytes. Close to the insertion the fibrocytes get to resemble chondrocytes ever more, being gradually arranged in columns, so that the distance between the fibres widens. There are no signs that this reduces the total cross sectional area of the tendon fibres (Cooper & Misol 1970). Close to the junction to the bone there is a saline track, forming the demarcation between the juxta-insertional part in which there is precipitation of calcium salts and the free part of the tendon which as a rule contains no calcium salts.

In histological examinations of the proximal tendon stump, performed in all cases of tendon rupture, this track of saline was decisive in ascertaining whether the rupture was interpreted as a tendon rupture or—if the track of saline was present—as a tendon rupture with a bone fragment. In nearly all cases the fragment of bone attaching to the tendon stump was clearly visible on gross inspection, and it was only in one case that histological examination was needed to make this decision.

The explanation why in the present study the rupture site was 0–2 mm from the calcaneus and not, as in man, 2–6 cm from the insertion of the 10–15 cm long Achilles tendon, may quite possibly be the difference found in the architecture of the tendons (cf. Barfred 1971 b). It was reasonable, therefore, that ruptures showing tendon tissue proximally as well as distally to the rupture site were interpreted as tendon ruptures.

Davidsson (1956) did not accurately describe the ruptures which he called insertion ruptures, but according to the above criteria some of them would presumably have been classified as tendon ruptures.

Many workers (Davidsson 1956, Arner & Lindholm 1959, Lang & Viernstein 1966, Könn & Everth 1967) have considered degeneration to be the main cause of tendon ruptures. In the present experimental series histological studies did not reveal any degeneration at the rupture site (Barfred 1971 a).

The failure of previous authors to induce tendon rupture of healthy, uninjured tendon may have been due to an erroneous procedure.

McMaster (1933) strapped the calcaneus in a way so that the long axis of this bone was in continuation of the tendon, and this unnecessarily attenuated the bone at the site of insertion. He also did not use stimulation of the muscle. But the most important factor of all was probably that no regard was paid to age or conditions of living in selecting the experimental animals. Viidik (1968, 1969) tried to remedy this by training the experimental animals, but nevertheless did not succeed in inducing tendon ruptures. He trained 3-month-old rabbits in running through 40 weeks. The rabbits ran about ½ km every day. This does not seem much compared with the distance that a wild animal covers in 24 hours, although the speed in the training was as high as possible. Slonaker (1912) found that domesticated albino rats in a revolving cage moved spontaneously from 2 to 5 miles a day.

It is questionable whether such one-sided training of young animals can be compared to wild animals in regard to separation force in bone, tendon, and muscle and in regard to maximal isometric muscle force. Ingelmark (1945) reported that by training young animals increased their muscle weight as well as tendon weight, whereas older animals increased mainly their muscle weight. It has been emphasized by Elliott (1965) and by Elliott & Crawford (1965) that the cross section of the tendon is determined by the total tension to which the tendon is exposed in the course of time, not by the contraction force of the appurtenant muscle.

To increase the muscle force, training has to be severe, meaning that it must be performed with more than 50 per cent of the maximum isometric force (Bonde Petersen 1960, Hettinger 1964). In rats Saville & Smith (1966) and Smith & Saville (1966) have studied the effect of increased demands on the hind legs cuased by early amputation of the forelegs. Apart from an increased specific gravity of the femur, a greater separation force, and an increased Ca content, they found the mass of muscle on the hind leg to be increased. By intense training of the plantaris muscle (after cutting the Achilles tendon of rats) van Linge (1962) found that the muscle underwent violent hypertrophy. At the same time, he noticed a marked increase in the connective tissue of the muscle. However, this latter finding was not studied in any detail, neither quantitatively nor qualitatively.

On the basis of the above studies it is not possible to set up any definite laws applying to the development of muscles, tendons, and bones—at any rate not to the extent that it is possible to evaluate the effect of a running exercise programme, and even less that of the increased physical activity which may be expected to be found in a wild animal as compared with a domesticated one.

There is also the difference relating to the food, not only qualitative and quantitative, but also the difference in the rhythm with which the food is taken and perhaps also in the environmental temperature. Chvapil (1967), in particular, has studied the influence of these factors upon connective tissue. He found domesticated rats to age more quickly than wild rats and the process of ageing to decrease at intermittent *versus* free intake of food. Physical training caused a lower calcium/hydroxyproline ratio and an increased content of hydroxyproline in the bones, a difference also found between the femora of wild and domesticated rats (Chvapil & Roth 1964). Chvapil shares the view of Donaldson (1924) who claimed that nearly all differences between wild and domesticated rats were caused by conditions of living. This deduction was based upon training of domesticated rats as well as taming of wild rats.

A description of the different behaviour of the animals has been rendered by Richter (1954):

"The wild Norwegian rat lives in an environment in which it must constantly be on the alert and ready to fight for its existence. It has to defend itself against all kinds of enemies: other rats, dogs, cats, owls, and snakes as well as man. It is a fierce, aggressive, suspicious animal that attacks at the least provocation and in captivity takes advantage of the least opportunity to escape, remains suspicious and tense, and breeds poorly.

In marked contrast, the healthy domesticated Norwegian rat is tame, gentle, and trusting, does not bite unless frightened or hurt, and makes no attempt to escape. It lives placidly in the controlled environment of the laboratory where food, water, shelter, and safety are constantly assured. Its only contributions to its own survival are its feeding, drinking, grooming, and mating activities. It reproduces at an early age and with a rapid rate."

The characteristic of the "run-kept" rats is approximately like that of the wild rats. They are far from having been domesticated in the course of the generation or two that they have been in captivity, and they still keep up a "pecking order" by sporadic fights.

This difference in activity between domesticated, wild, and "run-kept" rats would be expected to be reflected in their muscle force. True, the wild rats were found to be significantly stronger than the domesticated rats (Figure 10), but between the large rats alone this difference was not significant. Since, moreover, the relation between force and muscle-tendon length was the same for all 3 groups, the role of muscle force in the difference between the frequency of tendon rupture in the 3 groups must be assumed to be very slight.

Muscle-tendon length, foot length, and excursion were least among the albino rats. The explanation may be an adaptation to walking function in the domesticated as compared with running and jumping function in the wild rats.

The separation force was found to be significantly higher in the wild than in the domesticated rats, but owing to the numerous fixation ruptures, the results do not permit the conclusion that the tendons or muscles of the wild rats are definitely stronger than those of the domesticated ones. The same reasoning applies to an evaluation of the elongation.

The explanation of the fixation ruptures must be the soft bones of the domesticated rats. It was distinctly felt that the manually operated drill slid easily through the calcaneus of the domesticated rats, whereas it took both strength and patience to drill through the calcaneus of the wild rats. This is in keeping with Smith & Saville (1966) and Saville & Smith (1966) who found an increased calcium content and increased separation force in the bone after training.

The distribution of the rupture site shows that the frequency of rupture increased from a single tendon rupture in the domesticated albino rats to about 40 per cent tendon ruptures in the brown "run-kept" rats and about 60 per cent in the recently captured rats. This distribution corresponds to the finding that athletic people are most exposed to tendon rupture (Arner & Lindholm 1959, Picaud et al. 1966, Frings 1969).

The group of rats showing the highest frequency of tendon ruptures was that of wild rats that had been kept caged and inactive for 3 months after being captured. This group too did not show histological changes to explain the increased frequency of tendon rupture (Barfred 1971 a). Arner & Lindholm (1959) claimed that tendon ruptures in athletes who are out of training were caused by involution of the vessels, resulting in avascular necrobiotic changes. This theory cannot be supported by the present histological findings. In this group the separation force in relation to body weight and elongation in relation to muscle-tendon length were significantly below the findings in the control group. Thus, inactivity has led to greater rigidity and reduced separation force of the tissue.

Rollhäuser (1953–54) found a simultaneous decrease in the birefringence, an increase in water content, and a reduction of separation force in relaxed tendons.

Akeson et al. (1968), after 3 months' immobilization of canine knees, found a 30 per cent reduction of mucopolysaccharides in the inferior patellar ligament. According to Mathews (1967) the mucopolysaccharides combined with non-collagen protein are important factors in the mechanical properties of the tissue.

It is possible that changes in the ground substance of the tendon have caused the increased rigidity and reduced separation force in the inactivity group as compared with the control group. These changes would not be detected in the histological examination performed (Barfred 1971 a).

Despite a significant difference in frequency of tendon rupture between the "run-kept" rats and the inactivity rats, the present study showed an amazing conformity between the measured parameters. Thus, there is no indication of where to find the explanation of the difference in the frequency of tendon ruptures between these two groups, but as already mentioned bone strength may be a contributory cause.

SUMMARY AND CONCLUSION

Rupture experiments on the bone-Achilles tendon-muscle-bone unit in rats were performed on domesticated and on wild Norway rats of all ages and of both sexes. In addition, one group of wild rats was investigated after having been in cages for 3 months following capture (inactivity) and one group of brown rats (first or second generation of wild rats) kept in a run all their lives.

The experiments were carried out on anaesthetized rats by rapid elongation of the muscle-tendon group with the calcaneus in 30° supination (or pronation), tetanic stimulation of the muscle, and an initial length corresponding to the elastic equilibrium length. The muscle force, separation force, and elongation at separation were measured in a material testing machine which is described.

The findings were as follows:

1. Tendon rupture could be induced only in large rats.
2. Tendon ruptures were found with increasing frequency in the order domesticated rats, rats kept in runs, wild rats, and lastly the inactivity rats.
3. Tendon rupture could be induced at a lower body weight on females than on males.
4. Muscle force was the same in males and females of the same body weight.
5. Muscle force was less among domesticated than among wild rats.
6. The muscle force-muscle-tendon length relationship was the same in all groups.
7. Separation force was significantly greater in wild than in domesticated rats.
8. Separation force was lower in the inactivity group than among the wild rats.
9. Elongation at separation was less in the inactivity group than among the wild rats.

It must be concluded: The claim that a healthy tendon never ruptures on indirect violence does not hold for experiments on rats.

An important cause why rupture experiments have not previously given rise to tendon rupture is that the experimental animals have not been selected with a view to their previous conditions of living.

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