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KINESIOLOGICAL COMMENTS ON SUBCUTANEOUS RUPTURES OF THE ACHILLES TENDON

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On the basis of the history given by patients who have sustained subcutaneous rupture of the Achilles tendon, Arner & Lindholm (1959), among others, have described the type of the trauma (landing, push-off, stumbling), but without further assessment of what happens in the individual muscles and joints or the forces which might be involved. Nevertheless, they concluded that an indirect injury would never be able to cause rupture in a healthy tendon. Ljungqvist (1969) quoted Carlsöö who had reported that the stress on the Achilles tendon during fast running might reach 900 kp, but did not state his opinion as to whether this might constitute an adequate trauma.

Stucke (1950) found 400 kp to be the tensile strength of the human Achilles tendon. In 1961 he believed that this limit may be exceeded in skiing accidents.

Grafe, in 1969, photographed the double backward somersault, which is the situation in which rupture of the Achilles tendon is most apt to occur in gymnasts. By measurements on the photographs he found that during the landing and the following push-off both Achilles tendons were exposed to a total stress of 1070 kp. If, unintentionally, the somersault is asymmetrical, the stress on one of the Achilles tendons would exceed $\frac{1070}{2}$ kp. Grafe concluded that the stress was sufficient to cause rupture of a healthy tendon.

Evaluation of the nature of the injury is based upon the history given by the patient. As in other accidents or diseases these data may be inaccurate, possibly misleading. As far as tendon rupture is concerned, the events take place in less than 1/10 second. Very few people,

The film sequence was kindly supplied by Laterna Film.
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if any, are able to give an accurate description of such a course of events. Rasch & Burke (1963) report that when describing their own achievements top athletes often report movements and positions which cannot be found on control film sequences.

Given the chance of analysing in more detail what happened at the moment of rupture, one may get an entirely different impression of the course of events than that formed on the basis of the patient's description. This applied when, in the course of his work (filming), an actor sustained a right-sided Achilles tendon rupture (Barfred 1966).

History: The patient was a 35-year-old male who had always been in good health and had not had any signs of disease in the Achilles tendon or calf. He had previously trained in boxing, riding, football, and fencing (not in competitions), but at the time of the accident he was out of training.

Height 182 cm, weight 78 kp.

The patient stated that while filming he was running with a suitcase weighing about 3 kp in his right hand. He was wearing rubber-soled shoes. While he was running, rapidly according to his physical condition at the time, he suddenly felt pain in the right calf.

When asked whether he had made an unusual movement just before he felt the pain he said no, but stated that in the part he was acting he was to be provocative. In the running scene he did this by heading straight for accidental pedestrians and then, at the last moment, stepping aside.

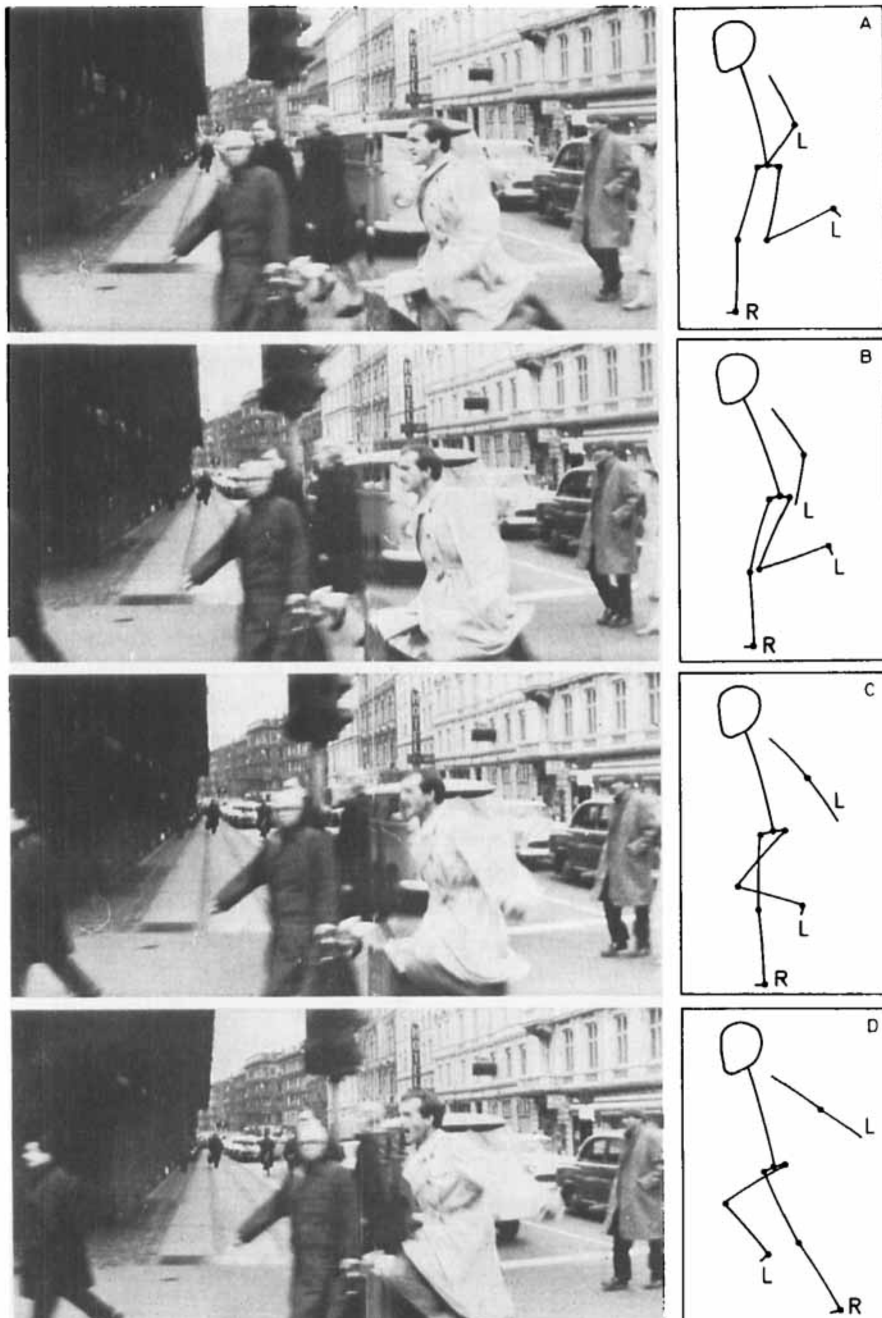
He continued running, with a slight limp, but thereafter felt ill, partly because of the exertion and partly because of the pain.

Together with the others in the cast he then relaxed over a glass of wine in the nearby studio. He felt fit again, had only slight tenderness in the calf and, playfully, made a few boxing steps.

While doing so he collapsed with intense pain in the calf. This happened about 2 hours after the first episode. Three days later he underwent operation for right-sided total Achilles tendon rupture. Biopsy showed mild oedema, but no definite degenerative changes.

Figure 1 shows 4 consecutive photos (24 photos a second) taken from a car driving on a plane-surfaced street beside the patient. It will be noted that the patient has to proceed from the zebra crossing to the pavement.

Each photo is accompanied by a rough sketch of the position of the legs and the left arm. The partial rupture of the Achilles tendon is presumed to have arisen between A and C. On D the right foot has left the ground.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DISCUSSION

From the above it must be concluded that while filming the patient sustained partial rupture of the Achilles tendon which a few hours later became total.

The film sequence (Figure 1) shows that the patient did not do just plain running. After running for about 100 m, he got to the curb which he had to ascend. At the same time he had to step aside to the left of a lady who was just in front of him. At this site the curb curved, so that the patient had to make the step longer, the more he had to draw aside to the left. At this juncture he was supporting himself on his right leg and had to make his next step longer, higher up, and more to the left than in an ordinary running step.

Kinesiological principles of measurement, e. g. goniometry or electromyography, presuppose preceding planning which of course was not possible in this case. Instead, the force used in the push-off was calculated on the basis of the patient's weight and the acceleration in the push-off. The foot has then—according to Newton's 3rd law—been pressed against the ground with an equally great opposed force. In an attempt at lifting the heel from the ground—in the push-off—the ankle axis must be considered as the axis in the lever system. The Achilles tendon would then be stressed by about 2.7 times this force, as the distance from the ankle axis to the metatarsal heads is about 2.7 times greater than the distance from the ankle axis to the Achilles tendon (Haxton 1944, Gertsen 1956).

The upward movement was measured by the movement of the patient's ear in relation to the roof of the parked car. The movement thus measured corresponds to the movement of the centre of gravity during running (Fenn 1930). The height of the ear (7.5 cm) was used as a yardstick. The movement upward from A to B (L_{AB}) and from B to C (L_{BC}) lasted 1/24 second each. The acceleration (a) may then be calculated according to the formula

$$a = \frac{L_{BC} - L_{AB}}{1/24 \times 1/24} \text{ cm/sec}^2$$

The force was found as the product of mass and acceleration. As the mean of repeated measurements the force was found to be 164 kp.

In this early phase of the push-off the calf muscles would meet a resistance of 164 × 2.7 kp = 442.8 kp. A similar calculation on an ordinary running step shortly before the accident showed a force of

78 kp and thus a resistance of 202.8 kp against a possible contraction of the calf muscles.

To assess whether the force demonstrated would be able to damage the Achilles tendon, it is necessary further to consider (1) the possibility of elongation and thereby also the direction of traction on the muscle-tendon group, (2) the muscle force in the triceps surae muscle, and (3) the muscle function and innervation pattern.

1. *Elongation and Direction of Traction*

Owing to extension in the knee and dorsal flexion in the ankle the muscle-tendon group would be elongated. Whether this strain was sufficient to produce tendon rupture cannot be decided, partly because in this case we do not know the extent of the movements in the knee and ankle joints, and partly because we do not know the strain required in man to exceed the rupture limit.

Statements of the force of an Achilles tendon as 5–10 kp/mm^2 (Cronkite 1936) or 400 kg (Stucke 1950) presuppose that the tendon is strained in the longitudinal direction. This was probably not so in our case, as the sideward movement must have caused some supination of the calcaneus.

At a supination of 30°, straining of 10 per cent, and a 1.5 cm width of the Achilles tendon, the author has calculated that the lateral fibres have reached the 10 per cent strain at the time when straining of the medial fibres begins. Such a calculation means a considerable simplification, as it presupposes that the tendon is homogeneous. However, it is made up of interfibrillar substance and of fibres which are rotated and crossed, with interdigitation between parts of the fibres. All this presumably tends to abolish the unfavourable effect of the supination (Mollier 1937, Altmann 1963). The corrected calculation cannot be carried out, as there are too many unknown factors, but it is unlikely that the effect of supination could be entirely abolished. In experiments, not yet published, the author has found a tendency to a greater frequency of experimental tendon rupture caused by oblique than by straight traction. Even with straight traction on the tendon, i.e. with the calcaneus in the mid-position, there is a possibility that the architecture of the tendon may prove unfavourable. Christensen (1954) feels that the rotation which Cummins et al. (1946) have described may cause a saw-like damage to one part of the tendon (gastrocnemius) by the other part (soleus).

2. *Muscle Force*

If the triceps surae muscle is lax, the first part of elongation of the muscle-tendon group will take place mainly in the muscle—and without major resistance (cf. the length-tension diagram for the resting muscle). If the muscle is contracted and thus less yielding, the elongation of the tendon will make up a greater part of the total elongation. In such eccentric contraction it is possible to affect the tendon by a force which may become at least 50 per cent greater than the maximum isometric force (Buchthal 1951)—how much greater depends upon the speed at which the muscle-tendon group is elongated. The magnitude of the maximum isometric force has been measured by *inter alios* Asmussen & Heebøll-Nielsen (1961) in a large material of normal subjects. Their tables show that plantar flexion in the ankle joint can be carried out with a mean torque of 1280 kg $\times$ cm if the subject is a 35-year-old man 182 cm in height. With a distance from the ankle axis to the Achilles tendon, at right angles to the line of traction, of 4.5 cm (stated to be 3–6 cm by Reys 1915, Elftman 1939, Gertsen 1956, Grafe 1969) the force in the triceps surae muscle will be $\frac{1280}{4.5}$ = 289 kp. Grafe (1969) pointed out that this distance will be shorter the greater the dorsiflexion in the ankle.

Reys (1915) found the maximum force to be 560 kp, and Haxton (1944) reported a mean of 438 kp for the triceps surae. Elftman (1839) calculated a tension of 375 kg during running and 240 kg during ordinary walking.

According to the above it is evident that the force of the triceps surae may easily approach—and even exceed—the values reported as the tensile strength of the tendon.

3. *Muscle Function*

In the present case the upward movement may be performed by extension in the knee and hip and by plantar flexion of the ankle joint, the sideways movement by supination in the subtalar joint and by the aid of gravity, if the centre of gravity is on the same side of the supporting leg as the direction of the movement. Forward movement may take place by dorsal flexion in the ankle, extension in the knee, and flexion in the hip. Some of the muscles to be activated in the push-off will be antagonists. To prevent antagonism the timing of the muscles must be very accurate.

The best utilization in a jump may be expected when the joints wich are farthest from the ground are moved first, while th nearest joints are stabilized. Last but one the knee is to be strongly extended, and the last movement is the plantar flexion in the ankle (Kamon 1971). Both these movements can be effected by the gastrocnemii. The gastrocnemii are two-joint muscles which by guided movements may exert a paradoxical effect, i.e. act as knee extensors, although their usual role is flexion (Molbech 1965). In this case the forward movement must be considered to be guided by the inertia of the body. This paradoxical effect may contribute to incoordinated innervation.

To given movements there belong innervation patterns which vary but little from individual to individual. Walking and cycling have been investigated by multi-electromyography by *inter alios* Houtz & Fischer (1959). In this way it was found that the quadriceps femoris and the triceps surae are not strongly innervated at the same time. In an investigation of cycling Houtz & Fischer (1959) found the innervation pattern to be so firmly established that it was preserved, even though the resistance on the test bicycle was increased.

The literature does not appear to contain any report on EMG studies of sudden movements, e.g. running which suddenly is to be converted to jumping, as occurred in our case. It is probable that this causes a disorder of the pattern, leading to unfavourable stress.

Whether an incoordinated innervation occurs depends upon many factors: partly the motive for altering the direction of the movement and partly the suddenness at which the motive arises and has to be converted into action. A third factor must be the patient's ability to perform the movement, i.e. his previous training in running and jumping. Lastly, there is no doubt a psychological factor which is difficult to define but whose importance is perhaps elucidated by a study performed by Ikai & Steinhaus (1961). They investigated the voluntary maximum muscle force in human subjects. This force increased by 12 per cent on stimulating shouts and by 25 per cent under hypnosis. Hettinger (1964) reported that this increase was more marked in untrained than in trained persons.

The incoordinated innervation which must be considered dangerous to the tendon is simultaneous innervation of the triceps surae and of the quadriceps femoris. In Asmussen & Heebøll-Nielsen's tables the quadriceps femoris was found to affect the knee flexed at right angles by an isometric torque of about 2000 kg × cm. The lever arm in relation to the knee joint axis for the triceps surae is 3 cm with extended knee and about 2 cm with flexed knee (Bugnion 1892). In other words, the triceps surae may be affected by a force of 666–1000 kp.

Thus, without forces external to the body an incoordinated innervation may be sufficient to exceed the tensile strength of the Achilles tendon.

CONCLUSION AND SUMMARY

The author reports a case of subcutaneous Achilles tendon rupture in which the patient, at the time of the accident, was acting the part of a provocative, restless character. He had a sudden motive for altering the direction of this movement, and thereby the innervation of his muscles has possibly been incoordinated. During a push-off he achieved a force of 164 kp, a force which has been able to stress the triceps surae by 443 kp. Presumably he could have produced an isometric force of 289 kp in the triceps surae, a tension which by eccentric contraction might be increased to 435 kp. He made a movement which strained the triceps surae muscle and tendon. During the push-off he had a more or less supinated hindfoot. Whether he innervated the triceps surae at an unfortunate moment is not known. It is also not known whether the strain of the muscle-tendon group has been great enough to induce rupture. However, the possibilities for rupture were present, although the patient said that he only came running. This is by no means a proof that the tendon rupture occurred on a traumatic basis in a healthy tendon. But it emphasizes that there are possibilities of extremely great forces acting in the human body—also without external influence. At the same time, it emphasizes that a patient's statement that no trauma has occurred in connection with a tendon rupture ought to be regarded with considerable skepticism.

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