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THE BLOOD FLOW OF RABBITS' TENDONS

Variation with Age, Activity and Hypoxia

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The Xenon^{133} washout technique was used to measure the blood-flow rate in flexor tendons of rabbits in different conditions. No variation was found with age. On the other hand, activity caused by electrical stimulation of the muscle increased the flow rate in the tendon significantly, confirming that the tendon is a metabolically active structure. Ligation of the vessels to the tendons failed to achieve a decrease of the blood flow rate. This was probably due to a rapid revascularization or biochemical modification of the tissue.

Key words: blood flow; flexor tendons; Xenon^{133}

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There is some controversy regarding the importance of blood flow through intrasynovial tendons. Lundborg (1976) has claimed that the important route of nutrient access to a tendon is via synovial fluid. Matthews (1976) also supports this view, although he does not discount the role of a vascular supply in this respect. On the other hand, Celli et al. (1976), Landi et al. (1980a,b,c), Potenza (1976) and Vailas et al. (1978) stress the importance of the tendon blood supply, and a detailed anatomical study of the vasculature of flexor, and extensor tendons in a number of species was made by Edwards (1946).

Apart from these relatively conflicting views, no experimental evidence has so far been produced to show that a tendon deprived of its blood supply can function normally. We have attempted to make a quantitative study of the blood supply of normal intrasynovial flexor tendons in the foot of the rabbit. Using the Xenon^{133} washout technique, as described by Lassen et al. (1964) and Piaggi & Mingione (1981), we have examined the normal tendons of young and adult rabbits, tendons stretched as a result of continuous electrical stimulations and finally tendons deprived of their blood supply.

MATERIALS AND METHODS

New Zealand white rabbits of both sexes were used in these experiments. The young animals were 3–5 weeks old (200–400 g weight) and the adults were all over 18 months old (3.5–5.0 kg weight). They were kept in cages with wire-mesh floors and fed and watered *ad libitum*.

Operative procedures

After premedication with Largactil, anaesthesia was induced with Sagatal and maintained with nitrous oxide and oxygen. The flexor tendon mechanism of the third toe of the left hind limb was exposed through a longitudinal incision. Care was taken not to damage the digital vessel. The profundus tendon was identified and this alone was used in this study.

(a) *Electrical stimulation of muscle*

This was carried out by stimulating the motor point of the profundus muscle with a Faradic current with a frequency of 50 Hertz and amplitude of 1 mA. Duration of stimulation varied from 4–20 min, with an average time of 8.63 min. The blood supply of the stimulated flexor tendon and also that in the contralateral foot (= baseline) was then measured immediately following cessation of the stimulus, using the method described below. For this part of the study, the Xe^{133} clearance was measured using a sodium-iodide (T) crystal coupled to a ratemeter with a constant time of 2 s with a cylindrical collimeter of 1.5 diameter focused at the point of isotope injection.

(b) *Deprivation of blood supply*

Following identification of the profundus tendon, its synovial sheath was removed, and the sublimis tendon was carefully removed. The vinculum at the metatarsophalangeal joint was then ligated using 5/0 silk thread. The vinculum of the profundus at the distal phalanx was ligated similarly. The wound was closed by an interrupted suture and a light gauze dressing was applied which allowed the animal to use the limb. Blood supply to the deprived tendon and the contralateral normal tendon was measured, as described below, after 2 days, 1 week, 2 weeks and 4 weeks.

(c) *Measurement of blood supply*

The rabbits were anaesthetized as previously described and the profundus tendon to be examined was exposed through an incision on the volar surface of the foot and was cleared by blunt dissection. Care was taken to avoid excessive bleeding and any damaged vessels were clamped or pressure was applied until haemostasis had been achieved. The animal was then positioned adjacent to the scintillation counter and held so that the foot lay on the plate of the collimeter with the dorsal side down and the tendon to be counted immediately over the collimeter aperture. A 25-gauge needle was inserted into the tendon and $Xenon^{133}$ in saline was injected until between 30×10^3 and 50×10^3 counts per second registered on the ratemeter. The needle was then removed and the tendon dabbed with a swab to remove any extruded isotope. Ten-second counts were made at 30-s intervals. This counting process was continued whenever possible until less than 25% of the initial radioactivity remained. In a number of cases this was not possible due, for example, to leakage of blood into the wound. In all cases one half-life of activity was reliably achieved. The resulting counts were plotted against time and the T_{50} was obtained. This was then used to calculate the rate of blood flow according to the following equation (Kety 1949).

$$\text{Blood flow} = \frac{W\lambda \text{ Log.2}}{PT^{1}/_{2}} \text{ ml/100 g/min}$$

where W = weight of tendon (this is assumed to be 100 g); λ = partition coefficient of Xe between tissue and blood = 0.25 (Piaggi & Mingione 1981); P = specific weight of tendon (= 1 g); $T^{1}/_{2}$ = time for removal of 50% radioactivity.

A Nuclear Enterprises 2'' NaI scintillation counter with a lead collimeter of 1 cm external diameter was used to measure the values in the experiments involving ligation of the blood vessels in adult animals and in normal young animals.

RESULTS

(a) *Effect of age on blood flow*

Determinations of normal blood flow were made using tendons from five young rabbits. The mean flow rate was 2.88 ± 1.22 ml/100 g/min. Normal values were also obtained for 10 adult rabbits and the mean of these was 2.40 ± 0.99 ml/100 g/min. The difference between young and old animals was not significantly different.

(b) *Effect of electrical stimulation on blood flow*

The data obtained in this experiment are shown in Table 1. From these data, it may be seen that the blood flow in the tendon stimulated by activity was significantly greater than that in the normal tendon ($P = < 0.001$, Student's *t*-test). There was no correlation between the blood flow rate and the duration of the electrical stimulus, and hence the period of activity.

(c) *Deprivation of blood supply*

The flow rates in tendons deprived of their blood supply were compared with normal tendons on the contralateral side. For comparison purposes, a ratio of the flow rate in the devascularized:normal tendons was calculated. This accounted for variation in local conditions during the counting procedure. The results, shown in Table 2, indicate that in most instances the devascularization procedure carried out had little effect on the blood flow rate in the tendon and revascularization was apparently rapidly established. Reduced flow rates were found in one rabbit in each of the 2-day and 4-week groups (2 and 8) and slightly reduced rates were found in each of

Table 1. The effect of electrical stimulation of muscle on blood flow through the flexor tendon

Rabbit no.	Baseline flow rate (ml/100 g/min)	Duration of stimulation min	Poststimulation flow rate (ml/100 g/min)
1	0.78	12	2.47
2	0.88	15	2.16
3	1.14	4	2.13
4	0.69	4	2.01
5	0.91	6	1.28
6	0.80	7	2.28
7	0.76	4	1.33
8	0.74	4	1.73
9	0.93	7	2.47
10	0.75	20	1.60
11	0.78	12	2.40
Mean	0.831	8.63	1.99
S.D.	±0.13		±0.44

Table 2. The effect of ligation of the vincula of the profundus flexor tendon upon blood flow at various times after surgery

Period post devascularization	Rabbit no.	Blood flow rates (ml/100 g/min)		Ratio Devasc. Control
		Devasc. tendon	Control tendon	
2 days	1	2.97	2.97	1.00
	2	0.53	1.88	0.28
	13	2.89	2.43	1.19
1 week	12	2.60	3.58	0.73
2 weeks	4	1.50	1.62	0.93
	5	1.51	1.84	0.82
	6	1.93	1.71	1.13
4 weeks	7	4.18	1.60	2.61
	8	2.47	4.18	0.59
	9	3.14	3.58	0.88

the 2-week plus 1-week devascularized tendons (5, 12). These last two instances however, are not significant.

DISCUSSION

The results presented in this paper have failed to show any difference in tendon blood flow in normal active rabbits of different ages. The values we have obtained, i.e. 2.4–2.8 ml/100 g/min, are very similar to the flow rates of 0.5–1.5 ml/100 g/min, which have been reported in the Achilles tendon of mongrel dogs (Gross, quoted by Vailas et al. 1978) and in the flexor tendon of rabbits (Celli et al. 1976). Activity of the tendon by continuous electrical stimulation of its muscle has been shown, by the above data, to increase the rate of flow of blood. This finding suggests that in the stretched tendon there is an increased call for metabolites, presumably reflecting increased activity by the tenocytes, during their

"maintenance work" activity. This could also possibly explain why early protected mobilisation in humans would improve the biomechanical characteristics (strength and tendon's excursion) at the repair site (Gelberman et al. 1982). The data obtained during the experiments in which the vincula of the tendons were ligated gave little evidence of any lasting impairment of blood flow in the tendon. This finding is surprising and would suggest that either the devascularization was incomplete, or that a rapid revascularization occurred. The latter, if it occurred must have been very fast as there was little evidence of reduced blood flow 2 days after operation in two of the three animals studied. A third possibility is that there was an alteration in the structure of the devascularized tendon, which significantly changed the partition coefficient for the tendon. Histological and histochemical examinations of these tendons tend to support this hypothesis (Landi et al. 1980c). The devascularized tendons show marked structural alteration, with extensive necrosis in the central part and survival of only a few tenocytes on the surface (Landi et al. 1980). The assumption that the partition coefficient in the altered tendon is normal must now be questioned. A combination of all three factors is also a possibility.

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