

Capillary Filtration in the Equine Digit

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Summary

Previous studies from our laboratory (Kozłowski et al., 1981) indicate that capillary pressure in the digit of the laterally recumbent anaesthetized pony is much higher than in the canine forelimb. Data from the present study indicate that the possible oedemagenic effects of high capillary pressure in the pony digit are opposed by at least two mechanisms: 1. by a decreased microvascular surface area for exchange and/or decreased microvascular permeability to filtered fluid; 2. by a high tissue pressure.

Introduction

We previously reported that skin small vein pressure (P_{ssv}), which represents the lower limit for capillary pressure, is much higher in the digit of the laterally recumbent anaesthetized pony than in the canine forelimb (Kozłowski et al., 1981). Assuming the other Starling forces are similar in the two species, this should result in a greater efflux of fluid from the vascular to extravascular space in the pony digit. However, if the capillary filtration coefficient (CFC) is low in the pony, the rates of filtration might be similar. To test this hypothesis, we measured CFC (which provides a measure of capillary surface area and permeability to filtered fluid), isogravimetric capillary pressure (P_{ci}, which provides a measure of the net sum of all the forces opposing filtration), and P_{ssv} in an isolated equine digital preparation.

Materials and Method

Six ponies were anaesthetized with sodium thiamylal (10 mg/kg), and anaesthesia was maintained with sodium pentobarbital. The ponies were intubated and ventilated with an air-oxygen mixture, using a pressure-cycled ventilator (Mark IX Ventilator, Bird Corp.) which could be triggered by the pony. The left jugular vein was isolated and cannulated for infusion of supplemental doses of anaesthetic and for anticoagulant administration.

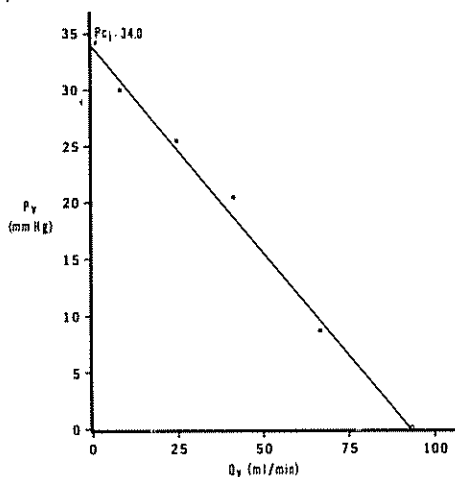
Isolated equine digit preparation. The skin in the mid-metacarpal region of the right foreleg was circumferentially divided. The medial palmar artery and vein were isolated, and the remaining soft tissue was transected. The metacarpal bone was cut, and the cut ends were packed with bone wax. An occlusive clamp was placed around each cut end of

the preparation to prevent haemorrhage. Following administration of heparin (500 U/kg), the medial palmar artery was temporarily occluded (for one to two minutes), and the medial palmar vein was cannulated with a length of PE 320 tubing. Venous outflow was directed through a 0.25 inch fine adjustment needle valve to a reservoir. Blood from this reservoir was returned to the pony via the medial palmar vein. The needle valve permitted the precise venous pressure manipulations necessary for the determination of CFC and P_{ci} . An extracorporeal circuit containing a blood pump was then interposed in the artery, and flow to the digit was maintained constant at a level such that the digit remained in an isogravimetric condition. Following cannulations, the digit was placed on a wire-mesh grid and suspended from a sensitive strain gauge (Unimeasure, Inc.). Rapid changes in weight of the digit reflected changes in vascular volume, whereas slower changes reflected changes in extravascular volume (Pappenheimer and Soto-Rivera, 1948). The sensitivity of the gauge was adjusted so that placement of a 5 g weight on the grid produced a pen deflection of 20–25 mm on the recording paper.

Arterial pressure was monitored from a cannula placed in the facial artery, P_{sv} was monitored in the venous plexus at the junction of the hoof and the skin, and perfusion pressure was monitored from the perfusion catheter just proximal to its entry into the medial palmar artery. Continuous recordings of pressures and limb weight were made with a direct writing oscillograph (Grass model 5D polygraph). Data from the horse digit were compared by Student's *t*-test to data we had previously reported from the dog forelimb. A *p*-value of less than 0.05 was considered significant.

Determination of P_{ci} . P_{ci} was determined by the method of Pappenheimer and Soto-Rivera (1948). Briefly, perfusion pressure was reduced and venous pressure increased until there was no change in weight of the digit. Four to six of these isogravimetric states were produced. P_{ci} was determined by extrapolating to zero flow the curve relating isogravimetric venous pressure to blood flow rate (Fig. 1). Each isogravimetric state was maintained for at least one minute.

FIGURE 1. Relation between isogravimetric venous pressure (P_{vi}) and flow (Q_v) over a wide range of flows. P_{ci} is determined from the Y-intercept of the best fit line (method of least squares).

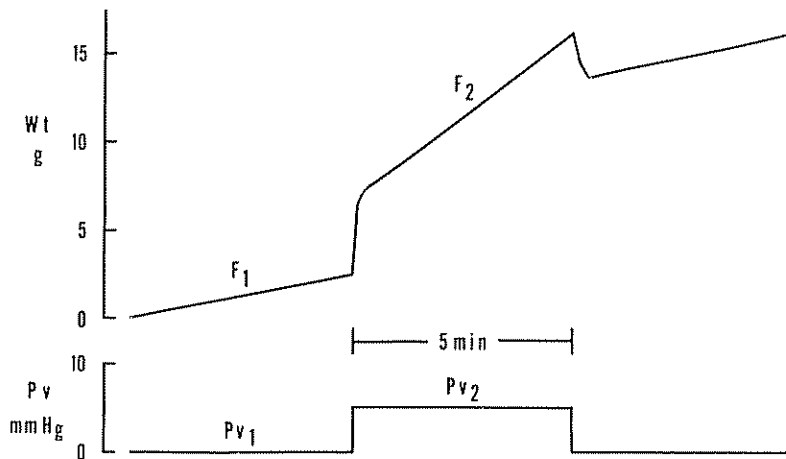


Determination of CFC. CFC was determined by the method of Korthuis *et al.* (1982), a modification of the method of Pappenheimer and Soto-Rivera (1948). After measuring an initial venous pressure (P_{V_1}) and filtration rate (F_1 , g/min), venous pressure was elevated 5–10 mm Hg (P_{V_2}) and following the vascular transient, venous pressure (P_{V_2}) and filtration rate (F_2) were recorded (Fig. 2). CFC was then calculated according to the following formula:

$$\text{CFC} = \frac{F_2 - F_1}{P_{V_2} - P_{V_1}}$$

The filtrate was assumed to have unit density; thus CFC was expressed as millilitres per minute per millimetre mercury per 100 grams of digit.

FIGURE 2. Diagram of digit weight and venous pressure during CFC determination. See text for explanation.



Results

Mean vascular pressures, P_{ci} , and CFC in isolated horse digits and dog forelimbs are presented in Table 1.

In the pony digit, mean arterial pressure (P_a) averaged 91.0 ± 19.0 mm Hg while P_p averaged 99.0 ± 10.0 mm Hg. P_{ssv} averaged 31.0 ± 10.0 mm Hg while P_{ci} averaged 34.0 ± 4.3 mm Hg. In a similar preparation using isolated dog forelimbs, we reported (Kozłowski *et al.*, 1981; Korthuis *et al.*, 1982) average values of $P_a = 123.0 \pm 4.9$ mm Hg, $P_p = 110.0 \pm 4.2$ mm Hg, $P_{ssv} = 12.0 \pm 0.8$ mm Hg, and $P_{ci} = 14.7 \pm 0.6$ mm Hg. CFC averaged 0.0022 ± 0.0008 ml/min/mm Hg/100g in the horse and 0.013 ± 0.001 ml/min/mm Hg/100g in the dog. P_{ssv} and P_{ci} were significantly greater and CFC significantly less in the horse digit than in the dog forelimb.

TABLE 1. Mean vascular pressures, Pci, and CFC in isolated pony digits and dog forelimbs*.

	Pony digit	Dog forelimb
Pa (mm Hg)	191.0 ± 19.0	123.0 ± 4.9
Pp (mm Hg)	99.0 ± 10.0	110.0 ± 4.2
Pssv (mm Hg)	131.0 ± 10.0	12.0 ± 0.8
Pci (mm Hg)	134.0 ± 4.3	14.7 ± 0.6
CFC (ml/min/mm Hg/100g)	10.0022 ± 0.0008	0.013 ± 0.001

* Dog forelimb data from Kozlowski *et al.*, 1981, and Korthuis *et al.*, 1982

†p < 0.05.

Values represent mean ± standard error of the mean.

Pa = mean arterial blood pressure, Pp = perfusion pressure, Pssv = skin small vein pressure, Pci = isogravimetric capillary pressure, CFC = capillary filtration coefficient.

Discussion

The data from the present study clearly show that skin small vein pressure, which represents the lower limit for capillary pressure, is much higher in the pony digit than in the canine forelimb. Assuming the other Starling forces are equal in the two species, this should result in a greater efflux of fluid from the vascular to extravascular space in the digit. However, the data from the present study indicate that the high capillary pressure in the horse digit is opposed by at least two mechanisms: 1. a decreased CFC, 2. an elevated tissue pressure (Pt).

Measurement of CFC provides a direct measure of transcapillary hydrodynamic conductivity which, in turn, is a product of the microvascular surface area available for exchange and the microvascular permeability to filtered fluid (Landis and Pappenheimer, 1963). CFC in the horse digit was 6.5 times smaller than that of the dog forelimb. This indicates that the product of microvascular surface area and/or permeability is 6.5 times less in the pony digit than in the dog forelimb. Thus this low CFC in the digit acts to oppose the high capillary pressure.

Our earlier studies (Robinson *et al.*, 1975; Kozlowski *et al.*, 1981) showed that digital lymph protein concentration was higher than dog forelimb lymph protein concentration. If lymph can be taken as representative of interstitial fluid (Renkin 1979), these data suggest that the colloid osmotic pressure gradient ($\pi_c - \pi_t$, where π_c and π_t represent capillary and tissue colloid osmotic pressures) and the reflection coefficient (σ) in the pony are less than in the dog. Thus the product of $\sigma(\pi_c - \pi_t)$ is less in the pony digit than in the dog forelimb. Because Pci is defined as the net sum of all the forces opposing filtration or as $P_{ci} = P_t + \sigma(\pi_c - \pi_t)$, the high Pci in the digit must be due to high tissue pressure.

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MUSCULAR SYSTEM

Skeletal Muscle Adaptations: A Review

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Introduction

For most people involved in equestrian sports it has long been believed that the capacity of the lungs and the cardiovascular system, together with muscle mass, were the determinant factors governing performance. Although the rôle of muscle in determining speed of locomotion is obvious, and its importance in both factors controlling speed; stride length and frequency are described by Gunn (1983) elsewhere in these Proceedings, it has only been in the last decade that the composition of the myofibres making up the muscle mass has been examined in detail. It is the purpose of this review to consider what is presently known about equine muscle and its adaptations with training. However, because the studies so far undertaken are limited to those in the Standardbred by Lindholm and coworkers in Sweden, and in the Thoroughbred by Snow and coworkers in Scotland, relevant information gained from investigations in man and laboratory animals will be discussed, as the basic responses of muscle are similar.

Technique of Percutaneous Needle Biopsy

The technique of needle biopsy was first introduced for diagnostic purposes by Duchenne (1855), but until its reintroduction by Bergström (1962) to study muscle electrolytes, open biopsy techniques were preferred for pathological investigations. However, during the 1970s, extensive studies using this technique were carried out in man to elucidate the demands of specific exercise and the effects of training. The advantage of this technique is that both cross-sectional and longitudinal investigations can be safely carried out, rather than relying on information obtained in laboratory animals.

Although there are several types of muscle biopsy needles marketed now, they all consist of three parts (Fig. 1). Prior to taking the biopsy, an area of skin of approximately 2.5 cm² is closely shaved, washed and cleaned with surgical spirit. One ml of local anaesthetic (e.g. 2% lignocaine) is then injected subcutaneously along the line of the proposed incision and into the fascia overlaying the muscle, but not into the muscle itself.

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