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VASODILATATION AND BODY WARMING IN THE RAT

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In the course of observations on the blood vessels of skeletal muscle in the rat, need arose for an index of the calibre of skin vessels in relation to body temperature. In the rabbit ear skin temperature is a useful index to the calibre of the ear vessels, which are largely controlled by body temperature (Grant, 1935). In the rat, however, observation showed that ear skin temperature did not seem to respond to changes of body temperature as it does in the rabbit. The matter was investigated further. Among other things, it was found that the vessels of the rat's ear do not dilate when the body is warmed and that the ear lacks arterio-venous anastomoses.

METHODS

Animals. Rats and guinea-pigs were anaesthetized with pentobarbitone sodium, 1·5–3·0 mg/100 g body weight, injected intraperitoneally. The animals were warmed with an electric pad.

Temperature was measured by thermo-electric thermometer, the junctions being made of fine (36 S.W.G.) copper and constantan wire. Body temperature was recorded from a junction covered in polythene and inserted into the colon 6 cm beyond the anus. To record skin temperature the hair was clipped short and the skin cleaned with ether; junctions were attached by adhesive zinc oxide plaster to the ear, feet and the rat's tail. These parts were shielded from the heat of the electric pad.

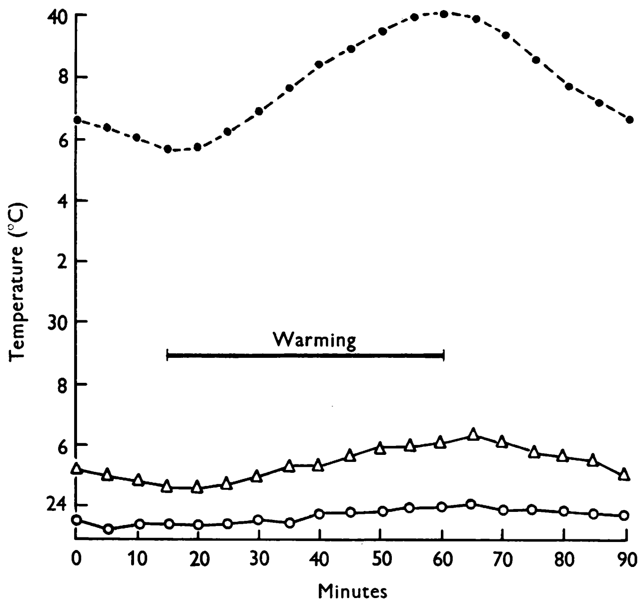
The blood vessels were examined during life in the transilluminated ear by the naked eye and with a stereoscopic microscope (heat-filtered light). For microscopic examination (× 12·5 and × 25 diam.), the depilated ear was spread on a Perspex sheet and covered with liquid paraffin. Change of vessel calibre was judged subjectively; in some instances, photomicrographs were taken.

Sympathectomy. In the neck the sympathetic trunk was removed from the root of the neck up to and including the superior cervical ganglion. In the rat's abdomen both sympathetic chains were removed from below the coeliac ganglion to as far as they could be followed between the caudal muscles.

Histological preparations were made by various methods suitable for detecting arterio-venous anastomoses. In the freshly killed animal blood was washed from the ear vessels by NaCl solution (0·9 g/100 ml. water), injected through cannulae inserted into the carotid arteries (under water, to avoid air embolism). The vessels were fixed in the dilated state with 10 % formalin injected under a pressure of 100–200 mm Hg for ½–1 hr and then washed out with water. The vessels were then filled with Indian ink or stained with haematoxylin injected under pressure (Grant, 1929–31). The ear was separated into its various layers and these were dehydrated and mounted. The nerve supply to the vessels was displayed by Gomori's (1952) modification of Koelle & Friedenwald's thiocholine technique (butyryl thiocholine), using the procedure described for the rabbit's ear by Grant & Thompson (1962). In one instance, a whole rat ear was cut in serial sections and stained with haematoxylin and eosin.

RESULTS

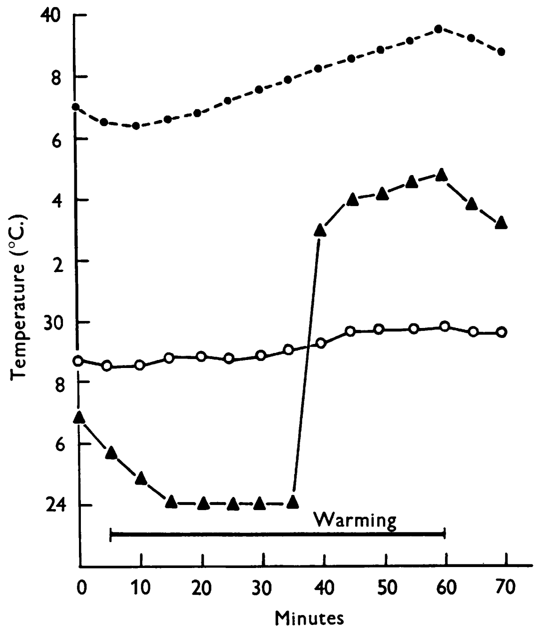
Except where it is otherwise stated, the results are derived from experiments on at least six animals to determine each point. The results were consistent. The rounded, thin ear of the rat measures usually about 17 mm from side to side and 10 mm from base to margin. At room temperatures about 21° C, and with a thermal junction attached to the medial aspect,



Text-fig. 1. Albino rat. Temperature chart of colon (●), medial aspect of right ear (△) and lateral aspect of left ear (○) in relation to body warming. Room temp. 21° C.

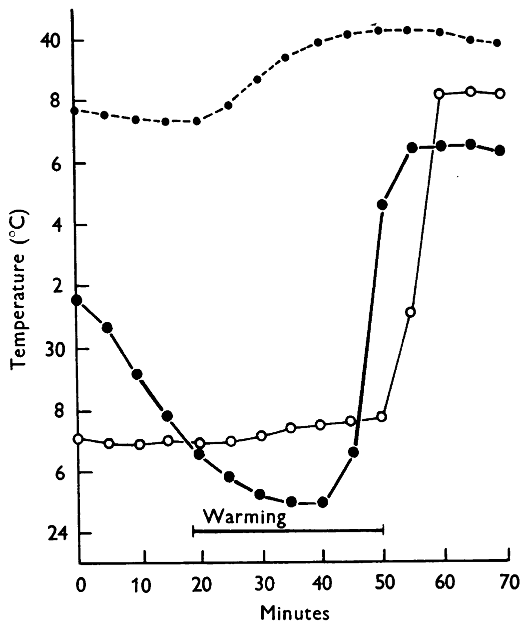
ear temperature lies between 24 and 30° C; colon temperature is usually between 37 and 38° C. When the rat is cooled and then warmed so that colon temperature falls to 36 and rises to over 40° C, ear temperature changes but little, falling and rising slightly, though to a less extent than that of the colon. Since it seemed possible that the thermal junction on the dorsum of the ear might compress the vessels and so prevent a large rise of temperature, in two instances a junction was applied also to the lateral aspect of the other ear. The temperatures showed no material difference (Text-fig. 1).

At normal rectal temperatures the ground tone of the transilluminated ear is pale. Three main veins are visible to the naked eye. The arteries, close to the veins, are so narrow as to be barely seen. Body warming provokes no obvious change in the general colour of the ear or in the calibre of the vessels; if anything, the vessels contract slightly (Pl. 1). The vessels clearly dilate, however, when the ear itself is warmed, rubbed between the fingers or pricked with a needle. Microscopic examination (4 rats) reveals no dilatation but possibly a slight narrowing in response to body warming; a needle prick promptly provokes a general dilatation which subsides after 2–3 min. Cervical sympathectomy (3 rats) does not raise ear temperature or dilate the vessels.



Text-fig. 2. Albino rat. Temperature chart of colon (●), tail near tip (▲), and medial aspect of ear (○) in relation to body warming. Room temp. 23·5° C.

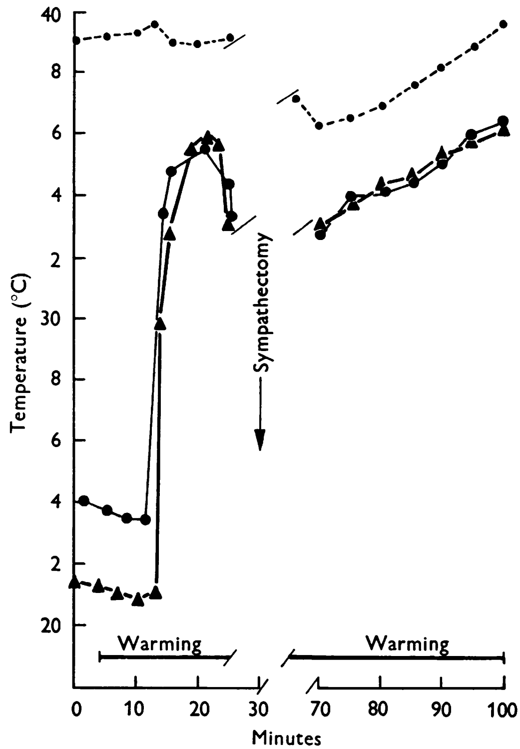
This absence of dilatation in response to body warming and sympathetic nerve section contrasts strongly with the dilatation provoked in the tail and feet. The tail of the unheated rat is cold to the touch, its temperature is that of the room and but little blood issues from the cut tip. During body warming, and usually when colon temperature is about 39° C, tail temperature rises rapidly, surpasses that of the ear and comes to lie only 3–4° C below that of the colon (Text-fig. 2). As Text-fig. 4 illustrates, the rapid peripheral vasodilatation often provokes a transient fall of colon temperature and this in turn is followed by a fall of tail temperature. When the tail warms, it becomes slightly flushed, the large veins are visible beneath the skin and blood flows freely from the cut tip. The temperatures of the fore and hind feet behave in the same way as that of the tail; the veins on the dorsum of the feet become dilated. Bilateral abdominal sympathectomy raises tail and hind foot temperatures to the same degree as does body warming, but the temperatures of these parts do not fall steeply when the rat is cooled; they remain parallel to and 3–4° C below colon temperature even when this is below normal (Text-fig. 4).



Text-fig. 3. Guinea-pig. Temperature chart of colon (●), forefoot (●) and medial aspect of ear (○) in relation to body warming. Room temp. 20·3° C.

The guinea-pig ear, like that of the rat, is thin but is larger, measuring about 30 mm from side to side and 20 mm from base to margin. Its vessels behave like those of the rabbit's ear. They obviously dilate when the body is warmed (Pl. 2) and ear temperature rises from a little above room temperature to near that of the colon (Text-fig. 3). Cervical sympathectomy (3 animals) dilates the vessels and raises ear temperature, as does body warming.

The arterio-venous anastomoses present in the guinea-pig ear (Daniel & Prichard, 1956) are displayed by the injection methods and cholinesterase staining now used, but I have failed to discover any arterio-venous anastomoses in the rat's ear. No arterio-venous anastomoses were seen in the transilluminated ear examined microscopically during life; none was found in the cleared injected preparations or in the serial sections. Cholinesterase staining reveals a perivascular network, denser over the arteries than over the veins. The arterial branches, however, do not show the localized condensations of this network which indicate the site of arterio-venous anastomoses in the rabbit's (Grant & Thompson, 1963) and guinea pig's ears. Sweat glands are absent.



Text-fig. 4. Albino rat. Temperature chart of colon (●), left hind foot (●) and tail near tip (▲) in relation to body warming before and after bilateral abdominal sympathectomy. After operation the rat was not warmed until colon temperature had fallen to about 36° C. Room temp. 20–21° C.

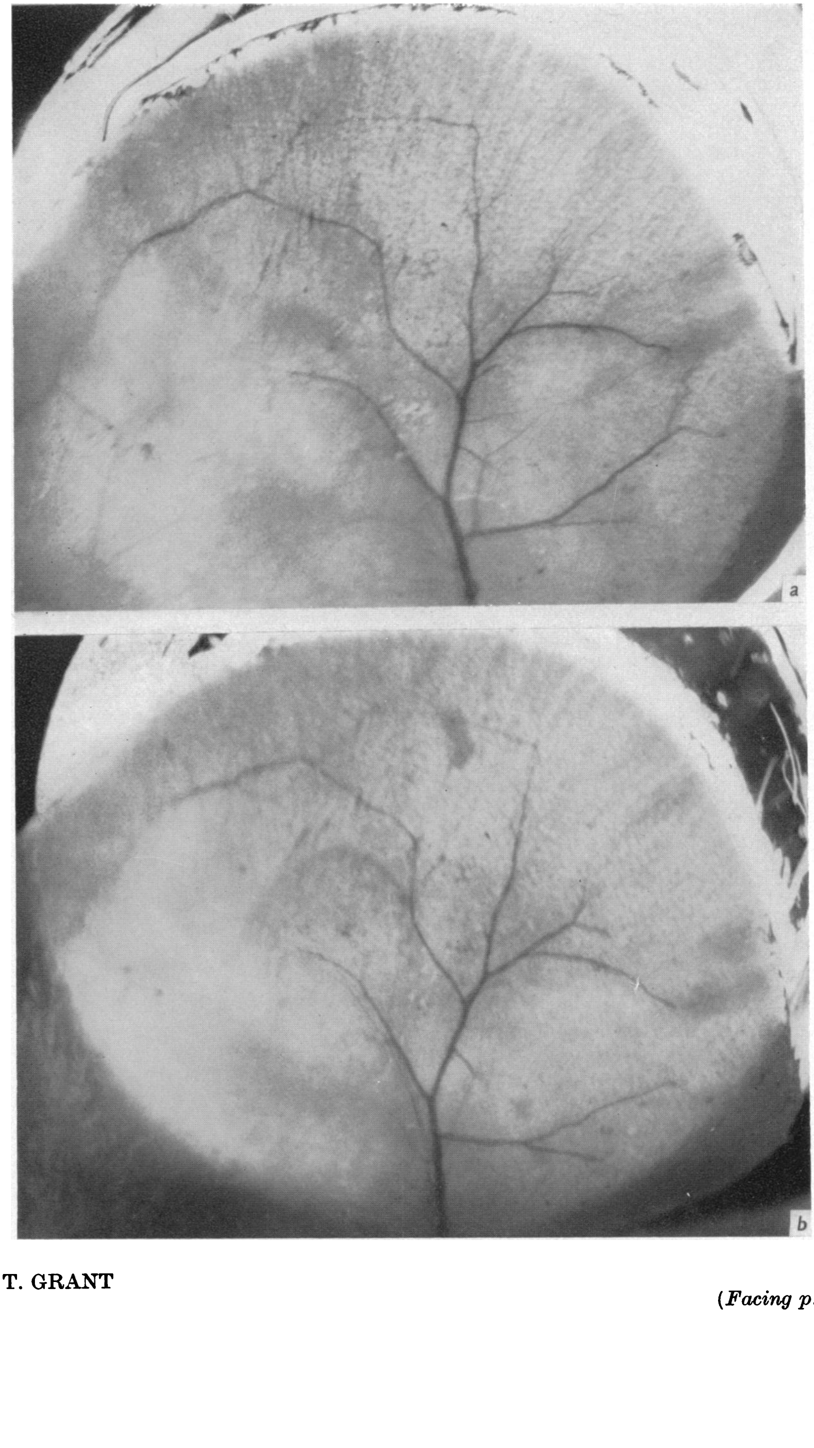
DISCUSSION

These findings show that the rat's ear is apparently different from those of the rabbit and guinea-pig in both its vascular anatomy and its vasomotor control.

Numerous arterio-venous anastomoses are known to be present in the ear of man (Prichard & Daniel, 1956) and a number of animals (Daniel & Prichard, 1956) and not reported absent in any. I have found no reference to them for the rat's ear, but Professor Daniel tells me that, though he and his colleagues spent much time looking for arterio-venous anastomoses in the rat's ear, they were unable to find one. This agrees with my own experience and it therefore seems fair to conclude that arterio-venous anastomoses are either absent or so few as to be easily overlooked.

It is known from previous work, chiefly in man (Fox, Goldsmith & Kidd, 1962), that peripheral vasodilatation in response to body warming is brought about in two ways, inhibition of constrictor tone and stimulation of vasodilator nerves. There is evidence to show that the vasodilator nerves act not directly on the vessels but through sweat-gland activity; it is suggested that this type of vasomotor control is found only where sweat glands are present (Fox & Hilton, 1958). Whether or not this is true for other animals is unknown. Sweat glands are absent from the rat's ear and thus the absence here of active vasodilatation on body warming is in keeping with this hypothesis. Vasodilatation through constrictor inhibition, however, is also absent, as are arterio-venous anastomoses, and this leads to the suggestion that perhaps, in general, vasomotor control by variations in constrictor tone is limited to areas containing many arterio-venous anastomoses. These relatively wide channels are known to be present in the human hand and foot, ear, nose and probably also the lip (see Clara, 1956), and these are all areas in which vasodilatation is brought about mainly by inhibition of constrictor tone (Fox *et al.* 1962). Arterio-venous anastomoses are present in the corresponding areas and in the tail of other animals (see Clara, 1956), but knowledge of their vasomotor control is scanty. Inhibition of constrictor tone is responsible for dilatation on body warming in the ear of the rabbit and guinea-pig, in the rat's tail and foot and in the cat's pad and dog's paw (Folkow, 1955). It is clear, however, that many more observations are required before the suggestion can be accepted that a close connexion exists between this mode of vasodilatation and the presence of numerous arterio-venous anastomoses. The tail of the musk rat (*Ondathra zibethica*), according to Johansen (1962), may be an example of active vasodilatation in response to body warming in an appendage without sweat glands but probably with arterio-venous anastomoses. Johansen does not mention the latter, but the great increase in blood flow caused by body warming strongly suggests their presence in large numbers. His evidence for active vasodilatation depends on the injection of a local anaesthetic into the base of the tail. It would be important to know the effect of sympathectomy.

The absence from the rat's ear of vasodilatation in response to body warming is not due to lack of nerve supply. The vessels can dilate in response to a sensory stimulus. Moreover, the perivascular network revealed by cholinesterase staining is in all probability sympathetic in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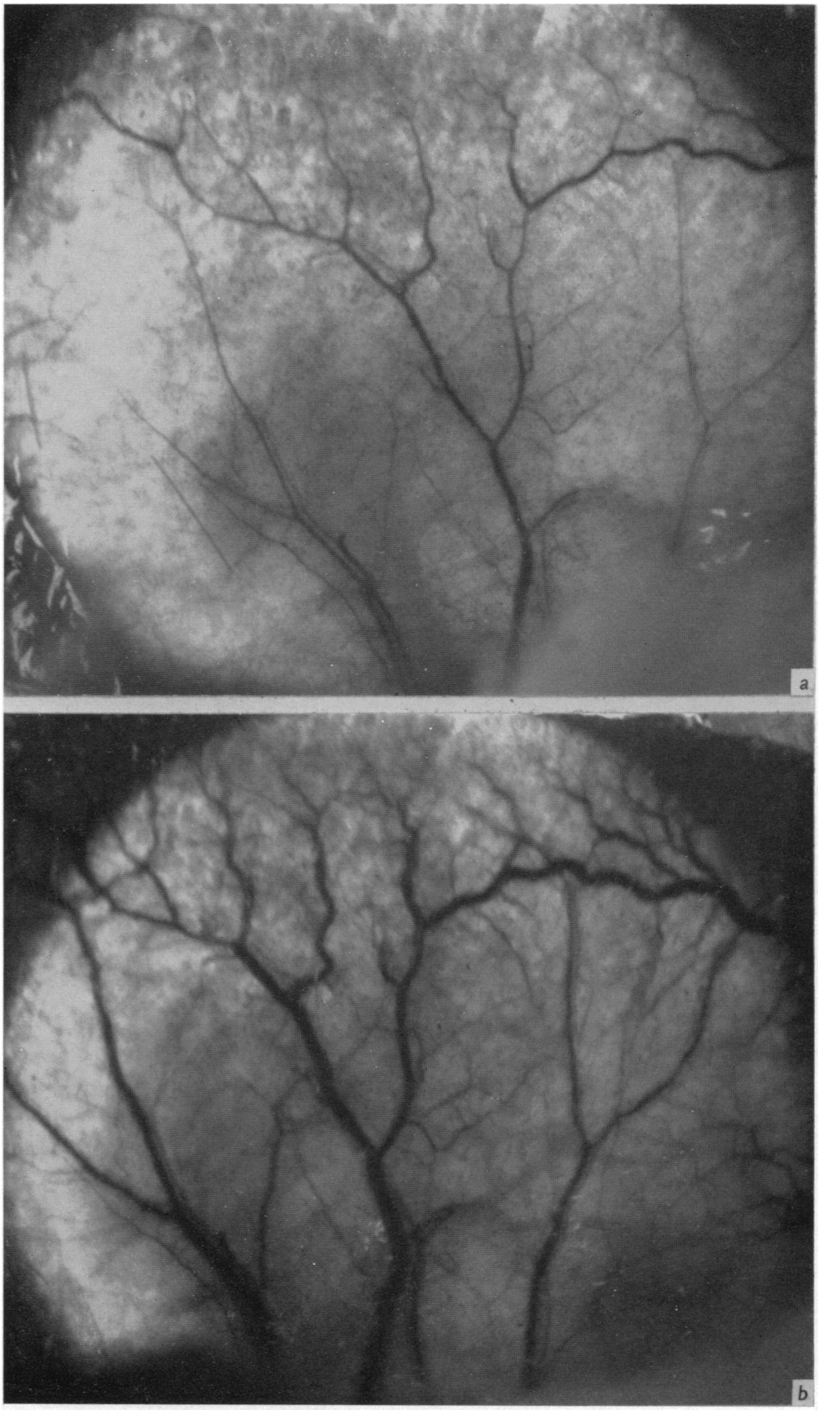

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origin, though this has not been established for this particular region. It seems likely that the central connexions of the vascular nerves differ from those in man, the rabbit and the guinea-pig.

SUMMARY

1. The vessels of the rat's ear do not dilate in response to body warming or to sympathetic nerve section.

2. Arterio-venous anastomoses are absent from the rat's ear.

3. These and other observations suggest that vasodilatation through inhibition of vasoconstrictor tone in response to body warming may be limited to areas containing numerous arterio-venous anastomoses.

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EXPLANATION OF PLATES

Plate 1

Photograph (×12·5) of vessels on medial aspect of ear. (*a*) unwarmed albino rat, colon temperature 36–37° C, tail cold; (*b*) warmed rat, colon temperature 40–41° C, tail warm.

Plate 2

Photograph (×12·5) of vessels on medial aspect ear (*a*) unwarmed guinea-pig, colon temperature 37° C; (*b*) warmed guinea-pig, colon temperature 40–41° C.