Heat Transfer in the Perfused Rabbit Ear at Different Blood Temperatures[1] (35636)

T. NAGASAKA[2] AND L. D. CARLSON

Department of Human Physiology, School of Medicine, University of California, Davis, California 95616

Blood flow and heat loss characteristics of peripheral areas, such as the hand, change with continuous exposure to cold. In man, blood flow and heat loss from the hand in general indicate less vasoconstriction and greater heat loss at temperatures of 1–5° in cold-adapted persons (1). In the rabbit ear, it has been shown that the relation of thermal conductance to blood flow is temperature dependent (2); that the cold exposures alter the response of the ear circulation to norepinephrine (less change in blood flow and ear temperature) (3), although this effect appears only at higher skin or blood temperatures (5); and that the precooling of arterial blood during its flow from the interior to the ear surface in a cold environment is more marked in cold-adapted animals than warm-adapted (4). The investigation described in this paper is concerned with the heat transfer from the rabbit ear when local blood temperature is changed.

Methods. Male New Zealand, California white and Dutch-belted rabbits were used. The rabbits were kept at 3–5° for 8 weeks or more (cold-adapted, CA) and at 25° (warm-adapted, WA). Body weight and food consumption were checked twice a week. Food and water were given *ad libitum.*

The surgical and perfusion procedures in the experimental preparation have been described previously (5). Perfusion pressure was monitored. Blood flow was set to give an approximate blood flow of 20 ml/min·100 ml of tissue. The blood flow was measured with a drop counter.

A Hatfield-Turner disc (6) was fastened with Rezifilm and covered with Hytape on the outer side of the ear, 3–4 cm from the tip, medial to the central artery. The heat flow (W/cm^2) was measured with this thermal gradient device. Care was taken to avoid covering large veins. A YSIC 401 temperature sensor was similarly fixed next to the proximal edge of the disc. The temperature of blood perfusing the ear (T_{ar}) was monitored by a thermistor in a pressure monitoring unit 5 cm from the base of the ear. Venous blood was collected in a 5-ml Plexiglas reservoir in which venous temperature (T_{ve}) was measured.

The ear was perfused with blood at 40, 30, 20, and 10° for approximately 20 min at each temperature. The temperature changes were varied according to a 4 $\times$ 4 Latin square sequence using 8 WA and 8 CA animals. The animal was covered by a Plexiglas box in which temperature was kept at approximately 25° throughout the experiment. The air was changed by a commercial air blower (120 liters/min of fresh air). At the end of some experiments, the ear was excised and weighed. The average weight of the ears was 22 g; the average surface area was 160 cm^2. No edema formation was observed in the perfused ears.

Results. Since the methods used provide for the assessment of heat transfer, each of the relationships was considered and the data are assembled in Table I. The combined heat transfer coefficient, h, of ear to air was calculated in the conventional manner:

$$H = h\ (T_s - T_a),$$

where H = heat loss (W/cm^2); T_s = skin

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[2] Present address: Department of Aviation Physiology, Research Institute of Environmental Medicine, Nagoya University, Furo-Cho, Chikusa-ku, Nagoya, Japan.

TABLE I. Measured Values in the Ear Perfusion Experiments.

T_{ar} (°)	T_a (°)	T_{ve} (°)	T_s (°)	Heat loss (W/cm²)	Flow (ml/min)	n
Warm-adapted rabbits						
36.1	25.3	28.8	28.9	0.0068	25.9	13
SE ±0.2	0.4	0.4	0.4	0.0005	1.5	
29.4	23.8	27.1	26.2	0.0026	24.9	8
SE ±0.6	0.2	0.2	0.2	0.0004	2.3	
20.7	25.3	24.3	23.8	—0.0029	24.8	19
SE ±0.4	0.4	0.6	0.5	0.0005	1.2	
10.5	24.8	19.5	19.2	—0.0095	22.9	10
SE ±0.4	0.6	0.5	0.5	0.0005	1.4	
Cold-adapted rabbits						
37.3	27.7	31.4	31.9	0.0085	29.9	11
SE ±0.5	0.3	0.5	0.6	0.0010	2.0	
29.0	27.2	29.0	27.8	0.0013	28.5	13
SE ±0.4	0.2	0.4	0.3	0.0003	1.8	
20.3	27.4	25.6	24.2	—0.0075	27.2	11
SE ±0.4	0.2	0.4	0.3	0.0009	2.5	
10.8	27.3	20.6	18.9	—0.0150	28.2	12
SE ±0.4	0.2	0.7	0.3	0.0010	2.1	

temperature; T_a = ambient temperature.

The calculated h was not different in the warm-adapted or cold-adapted ears and was independent of perfusion temperature (Table II).

The heat transfer coefficient, h_k, of the ear tissues was calculated from the equation,

$$H = h_k\ (T_{ar} - T_s),$$

where T_{ar} = arterial temperature. There is a larger conductance in the ear of the cold-adapted rabbit than in the warm-adapted. The conductance values in each group were not significantly related to flow. The correlation coefficients were +.04 in cold-adapted animals and +.14 in warm-adapted animals. A similar relation is calculated using the average blood temperature $(T_{ar} + T_{ve})/2$ in place of T_{ar} (Table III). Correlation coefficients

TABLE II. Calculated h and Relation to Perfusion Fluid Temperature (T_{ar}) and Ear Temperature (T_s).[a]

	h (W/[cm² °]) Mean	SE		Corr. coeff.
Cold	0.0018	0.0003	T_{ar}	—0.0368
Warm	0.0019	0.0003	T_{ar}	—0.0287
Cold	0.0018	0.0003	T_s	—0.0412
Warm	0.0019	0.0003	T_s	—0.0690

[a] n = 50.

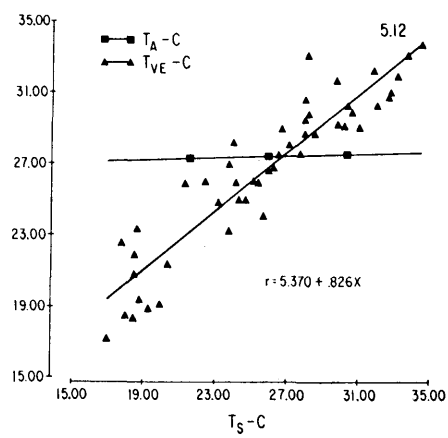

FIG. 1. Relation of venous temperature (T_{ve}) to ear skin temperature (T_s) in cold-adapted rabbits at air temperature of about 27° (T_a): (▲) T_{ve}; (■) T_a. The linear equation is given at the right lower quadrant and the number in the upper right-hand corner is the percentage variability remaining unaccounted for by the regression line. The slope is not significantly different from 1.0; that is, $T_{ve} = T_s$.

TABLE III. Ear Tissue Conductance (W/[cm² °]) of Warm- and Cold-Adapted Rabbits.[c]

	$h_k = (H/[T_{ar} - T_s])$		$h_k^* = (H/[(T_{ar} + T_{ve})/2] - T_s)$	
	Mean	SE	Mean	SE
Cold	0.0017[a]	0.0002	0.0124[b]	0.0062
Warm	0.00094[a]	0.00005	0.00216[b]	0.0001

[a] Cold > warm, $p < .01$; [b] $p < .05$.
[c] $n = 50$.

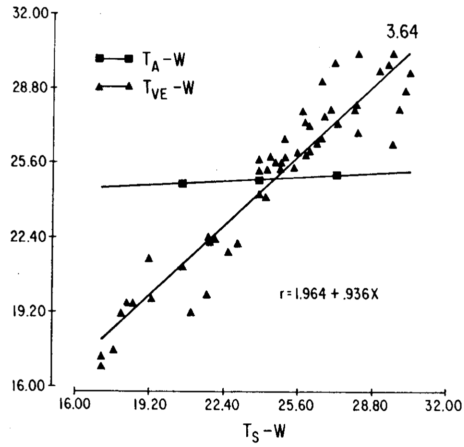

FIG. 2. Relation of venous temperature (T_{ve}) to ear skin temperature (T_s) is warm-adapted rabbits at air temperature of about 25° (T_a). Symbols and numbers have same meaning as in Fig. 1. The slope of the regression line is not significantly different from 1.0.

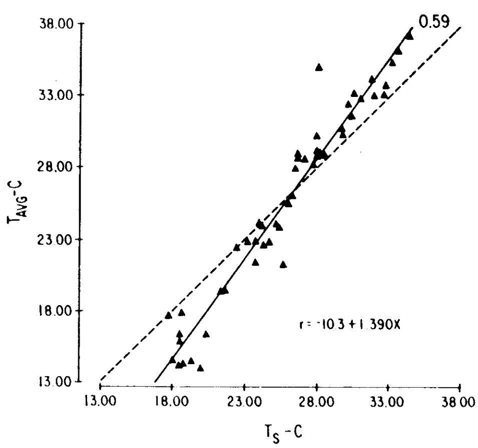

FIG. 3. The relation of mean blood temperature (T_{av}) to ear skin temperature in cold-adapted rabbits: (- - -) the line of corresponding temperature.

were −0.13 and +0.28, respectively.

The linear relation of T_{ve} to T_s is shown in Figs. 1 and 2 and a similar relation for the average blood temperatures (Figs. 3 and 4).

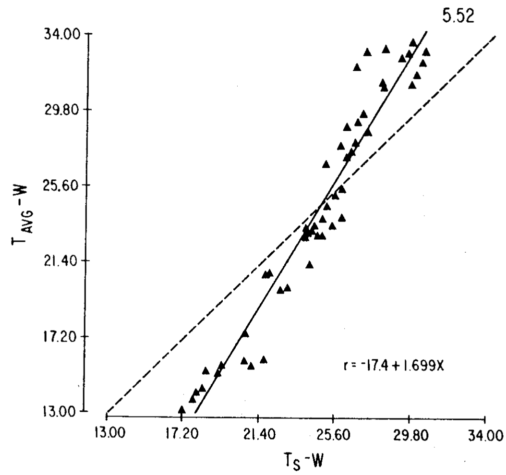

FIG. 4. The relation of mean blood temperature (T_{av}) to ear skin temperature in warm-adapted rabbits: (- - -) the line of corresponding temperature.

The difference from correspondence lines shows the gradient for heat flow. The position of the arterial and venous temperature sensors introduced a systematic error which was not quantitated. Since T_{ve} was not statistically different from T_s, the error introduced does not qualify our results.

Discussion. The increased tissue conductance in the cold-adapted animal occurred at blood flows that were not significantly different in these experiments, although there was a lower vascular resistance (5). Cooling of arterial blood by means of heat exchanging with venous blood, as suggested by Honda (4), was not demonstrated in the ear and must occur elsewhere in the vascular bed.

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