

METABOLIC RATE AND THERMAL INSULATION IN ALBINO AND HAIRLESS MICE

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SUMMARY

1. Rates of oxygen consumption of albino and hairless mice were measured in a metabolism chamber during periods of approximately 5 or 24 hr. Rectal temperature was measured before and after each period. The chamber temperatures used were 22, 30 and 32° C for both albino and hairless, and in addition 34 and 36° C for the hairless mice.

2. The mean age and body weight of the albino mice were 102 days and 34.6 g; the corresponding values for the hairless mice were 87 days and 32.8 g.

3. The mean minimum rates of oxygen consumption (ml./kg.min) were 31.0 for the albino and 38.8 for the hairless mouse; the corresponding estimated critical temperatures were in the ranges 30–32° C for the albino mouse and 32–34° C for the hairless mouse.

4. The mean values for core-ambient thermal insulation (° C.m².hr/kcal) were 0.418 and 0.328 for the albino mouse, and 0.275 and 0.221 for the hairless mouse, at 22 and 30° C respectively in each case.

INTRODUCTION

The hair coat of a mammal is usually that part of the animal's thermal insulation which is quantitatively the most important, and which consequently has the greatest effect on the total thermal conductance and thereby on the animal's heat loss in the cold. This is clearly the case in the sheep, in which variations in the length of the coat are accompanied by marked variations in insulation (Blaxter, Graham & Wainman, 1959; Joyce & Blaxter, 1964). The various species of arctic mammals which are well adapted to prolonged and intense cold have very well developed coats, which permit body temperature to be maintained with relatively low rates of heat production, as in the arctic fox (Scholander, Hock, Walters & Irving, 1950). Some other species show marked resistance to cold partly

on account of their large body size, as in cattle and the mature pig (Barnett & Mount, 1967; Mount, 1968).

As the size of the animal decreases, however, it tends to lose heat more readily. In addition to this tendency, a given thickness of thermal insulation would be expected to produce a smaller increase in over-all insulation on an object of small mean diameter compared with one of larger diameter; this is a well recognized phenomenon (Dilla, Day & Siple, 1949; Burton & Edholm, 1955). It is therefore of interest to determine the insulation offered by the coat in a small mammal such as the mouse, and to compare it with the insulation measured *in vitro*. This problem has now been investigated in normally haired albino mice and in hairless mice over a range of rectal-ambient temperature gradient.

METHODS

Animals. The mice used in this study were normally haired albino (referred to subsequently simply as albino) derived initially from the Institute's breeding stock, and hairless, derived in the following manner. Some hairless mice were first obtained in 1964, and at first showed poor reproductive performance. Crossing with albino mice produced vigorous hybrids (all albino), and the consequent mating of hybrid animals produced a proportion of vigorous hairless animals. This was possible since hairlessness is inherited as a simple Mendelian recessive character (Hošek, Chlumecký & Mišustová, 1965; Poppleton, 1963). The albino and hairless animals used in the present experiments were therefore inter-related. The animals were kept in transparent plastic boxes with sawdust and cotton wool bedding, in a room at 22–23° C, with water and a commercial pelleted feed given *ad libitum*.

Metabolic rate. Metabolic rate was measured as the rate of oxygen consumption in a closed system. The mouse was housed in a circular glass vessel 160 mm in diameter and 90 mm in height, fitted with a wire mesh floor (mesh size 12 mm). This container was covered by a wire mesh lid which itself supported centrally a glass dish (of diameter 90 mm) containing soda asbestos (Carbosorb, 3–6 mesh, British Drug Houses Ltd.) for the absorption of carbon dioxide and water vapour. A small fan, driven at approximately 300 rev/min by a 6 V motor, was mounted above the dish of absorber so that, although the air in the chamber was mixed, forced convection currents did not impinge on the animal. The circular chamber, of capacity 4.5 l., was made of brass; a Perspex lid held the motor and fan, and was fitted with a rim which made a gas-tight fit in liquid paraffin in an annular trough around the top of the chamber.

Two chambers of this type were set up in a temperature-controlled room held at 22, 30, 32, 34 or 36 (± 0.2)° C. The temperature difference between the chamber and room fell within the variation in room temperature. A tube from each chamber led to a spirometer filled with oxygen. The counter-weights of both spirometers were fitted with pens which recorded continuously the volume of each spirometer on a chart moving at 12.2 mm/hr. Rates of oxygen consumption, estimated from the slopes of the spirometer traces, were reduced to s.t.p. following corrections for any changes in barometric pressure and spirometer temperature during the periods of measurement.

The periods of measurement employed were either approximately 5 hr (mean length 4.5 hr) or 24 hr. For the 24 hr periods, but not for the shorter periods, the mouse was supplied with food and water. One hour was allowed for habituation prior to each 5 hr period, and overnight for habituation before a 24 hr period. Twenty-four hr periods were restricted to 22 and 30° C environmental temperatures in order to avoid the hyperthermia which might have occurred at the higher temperatures. Body weight and rectal temperature were recorded before and after each period of measurement; rectal temperature was determined by a thermistor probe inserted 1–2 cm deep to the anus. Male mice were used throughout the study in order to avoid any possible variation in metabolic rate associated with the oestrous cycle.

On each occasion, an albino mouse was introduced into one chamber and a hairless mouse into the other; the use of each chamber was alternated between the two breeds in an attempt to eliminate effects due to possible differences between the two chambers.

RESULTS

Results were obtained from experiments involving 29 albino mice of mean body weight 34.6 ± 0.5 g, and 36 hairless mice of mean body weight 32.8 ± 0.5 g (means and s.e.). The mean ages were 102 days (range 52–192) for the albino mice, and 87 days (range 44–172) for the hairless.

Metabolic rate. The mean values for oxygen consumption from 5 hr observations on a total of twenty-six albino and thirty-three hairless mice are given with their s.e. in Fig. 1. At 22 and 30° C the oxygen consumption rates of hairless mice were clearly greater than those of albino mice ($P < 0.001$).

The results from successive 24 hr observations on three mice of each breed at 22 and 30° C are given in Table 1. The animals were arranged in pairs, each pair comprising one albino and one hairless mouse, and measurements were made simultaneously on the members of each pair. The sequence of chamber temperatures for each pair was as follows: first pair 22–30–30; second and third pairs, 30–30–22–22. The differences between the 24 hourly metabolic rates of albino and hairless mice were significant at both 22 ($P < 0.001$) and 30° C ($P < 0.001$). The 24 hr results were similar to those from the 5 hr experiments for hairless mice at 22 and 30° C, and for albino mice at 22° C; in the case of albino mice at 30° C, however, the 24 hr value was higher than the 5 hr value ($P < 0.05$).

The lowest 5 hourly rate of oxygen consumption by albino mice occurred at 30° C; at 32° C there was a rise. In the hairless mice, the lowest observed rates were at 32 and 34° C, with a tendency towards a higher value at 36° C.

Rectal temperature. The rectal temperatures in connexion with the 24 hr experiments are given in Table 1, and Table 2 gives the mean values for rectal temperature at the beginning and end of the 5 hr periods in the metabolic chamber. The mean rectal temperature during both the 5 hr

and 24 hr periods were estimated as the means of the initial and final values for each individual mouse.

Thermal conductance. The total thermal conductance was calculated for each mouse as the ratio of the mean rate of heat production to the difference between the mean rectal and environmental temperatures. The values at the several environmental temperatures used are summarized in Fig. 2;

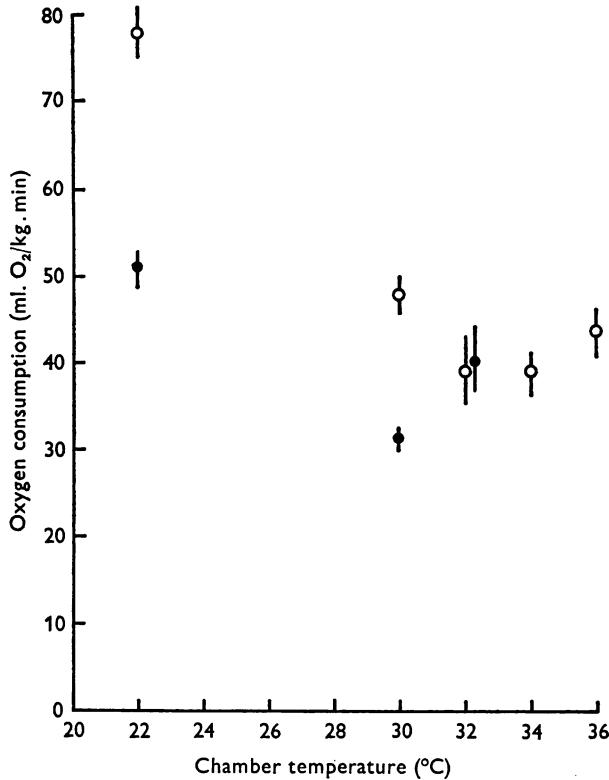


Fig. 1. Rates of oxygen consumption (ml./kg.min: means and s.e.) of albino and hairless mice, during periods of approximately 5 hr at several environmental temperatures.

from this diagram it can be seen that a marked increase in conductance takes place between 30 and 32° C in the albino mice, and between 32 and 34° C in the hairless mice.

Thermal insulation. In order to calculate the thermal insulation it is necessary to estimate the rate of non-evaporative heat transfer from the organism to the environment, as distinct from the total heat transfer. The total heat transfer can be obtained from the oxygen consumption by assuming a calorific value for oxygen of 4.8 kcal/l., corresponding to a

TABLE 1. Rates of oxygen consumption and thermal conductances from successive observations of 24 hr duration on three pairs of mice, each pair comprising one albino and one hairless on which measurements were made simultaneously

Chamber temperature (° C)	...	22					30				
		Body wt. (g)	O ₂ consumption (ml./kg. min)	Rectal temperature (° C)	Thermal conductance (kcal/° C m ² hr)		Body wt. (g)	O ₂ consumption (ml./kg. min)	Rectal temperature (° C)	Thermal conductance (kcal/° C m ² hr)	
				Initial	Final			Initial	Final		
1st pair	Albino	31.1	59.8	37.6	37.6	3.57	31.1	44.4	38.0	37.9	4.98
	Hairless	31.0	77.4	35.9	36.1	5.15	31.0	39.7	37.9	36.6	4.93
2nd pair	Albino	33.0	56.4	36.2	37.4	3.47	30.5	54.4	36.6	36.6	7.35
	Hairless	33.4	53.6	37.4	38.2	3.14	30.6	47.1	36.6	37.1	6.13
		30.7	86.3	38.8	38.7	4.59	32.8	36.6	38.6	37.4	4.42
		30.6	76.5	38.7	36.5	4.41	33.2	39.2	37.4	38.2	4.55
3rd pair	Albino	36.4	50.8	37.2	37.4	3.24	31.4	40.8	37.5	37.7	5.24
	Hairless	36.4	49.7	37.4	37.7	3.07	31.1	48.6	37.7	36.8	5.88
		35.3	76.5	37.7	37.5	4.72	36.7	34.9	37.4	36.8	4.39
		34.4	73.3	37.5	35.0	4.83	36.1	29.4	36.8	37.6	3.76
							33.8	50.9	38.1	37.8	5.59
							34.8	46.6	37.8	37.4	5.62

respiratory quotient between 0.8 and 0.9 (Mount, 1959). When the heat lost by evaporation is subtracted, the non-evaporative heat transfer is left.

Evaporative loss was not measured in the present experiments. Newburgh & Johnston (1942), however, in reviewing evaporative loss from man and animals, collected information indicating a mean value of 21 %

TABLE 2. Mean values of rectal temperature of albino and hairless mice before (initial) and after (final) periods of measurement of oxygen consumption of 5 hr approximate mean duration

	Chamber temperature (° C)	No. of mice	Rectal temperature (° C)	
			Initial	Final
Albino	22	10	38.9	37.0
	30	7	38.3	37.0
	32	9	39.0	37.1
Hairless	22	10	38.8	36.9
	30	7	38.2	37.2
	32	5	38.7	37.3
	34	6	38.5	37.9
	36	5	38.9	39.8
Mean standard errors:			± 0.31	± 0.27

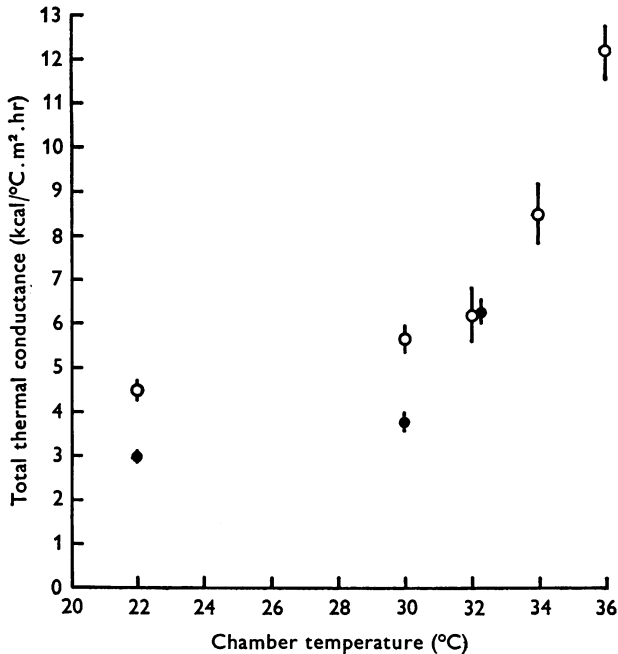


Fig. 2. Total thermal conductance (kcal/°C.m².hr: means and s.e.) of albino and hairless mice, during periods of approximately 5 hr at several environmental temperatures.

for the proportion of heat lost by vaporization from the rat and mouse at 23–31° C environmental temperature.

Tennent (1946) obtained values for water loss from rats at 23–25° C from which, on the assumption that the animals' metabolic rates were given by Kleiber's (1961) inter-specific standard metabolism (kcal/day) of $70 W^{\frac{3}{4}}$, where W = body weight in kg, it can be calculated that 18% of heat loss was by vaporization. Water loss occurs both from the respiratory tract and from the skin surface, and the presence or absence of hair may therefore be expected to have little effect at temperatures below

TABLE 3. Mean values for thermal insulation ($^{\circ}$ C m² hr/kcal) of *A*, excised pelts of A2G and C57BL mice (Barnett, 1959) and *B*, whole mice (present results)

Excised pelt	Smoothed	Ruffled	Shaved	Differences	
				Smoothed-shaved	Ruffled-shaved
<i>A</i> Mice raised 21° C at -3° C	0.129	—	0.074	0.055	—
	0.134	0.167	0.067	0.067	0.100
<i>B</i> Whole mouse	Albino		Hairless	Albino-hairless	
	22° C	0.418	0.275	0.143	
	30° C	0.328	0.221	0.107	

thermal neutrality. On these grounds, it may therefore be reasonable to conclude that at 22 and 30° C, the subcritical temperatures used in the present work, vaporization accounted for approximately 20% of the total heat loss. Values for heat loss and thermal insulation, calculated on this basis, are given in Table 3, together with results on excised pelts from Barnett (1959). Surface area in m² was calculated from the formula $0.1 W^{\frac{3}{4}}$, where W = body weight in kg. The constant used, 0.1, was intermediate between the 0.091 of Benedict (1938) and the 0.114 used by Hošek *et al.* (1965).

DISCUSSION

The mean minimum rates of oxygen consumption which were obtained in these experiments were 31.0 ml./kg. min at 30° C for the albino mice, and 38.8 ml./kg. min at 32 and 34° C for the hairless mice. The mice of the two types were similar in size, and the magnitude of the difference between their minimum rates suggests that, in the feeding animal at least, the hairless mouse has a higher thermoneutral metabolic rate than the albino mouse. The critical temperature (the environmental temperature below which there is an increase in the metabolic rate of the homoiothermic animal) for the albino mouse can be expected to lie in the interval 30–32° C (Herrington, 1940; Willmott, 1968), and the present results are in

accordance with that expectation, although the temperature intervals were not small enough to allow a precise statement. Similarly, the best estimate of the critical temperature for the hairless mouse is 33° C, close to the 34° C which is suggested by the results of Benedict & Fox (1933, quoted by Kleiber, 1961), although the latter did not include values in the zone of hyperthermic rise in metabolism.

The appearance of the rise in oxygen consumption which is associated with an increasing environmental temperature, and the accompanying tendency to hyperthermia, occur at 32° C for the albino mice and at 36° C for the hairless mice. The associated sharp increases in total thermal conductance take place at 32° C for the albino mice and at 34° C for the hairless mice (see Fig. 2).

The 5-hr values for oxygen consumption by the hairless mouse at 22, 30 and 32° C fall on the same line (see Fig. 1) suggesting that the increased metabolic rate required at 22° C is not beyond the animal's capability to sustain it. The initial and final levels of rectal temperature also support this view; the mean fall in rectal temperature is similar in both albino and hairless mice (see Table 2).

On these grounds the choice of 22 and 30° C for the comparison of thermal conductance and pelt insulation between the two strains is justified, since neither the albino nor the hairless mouse was exposed to conditions which led either to hypothermia or to hyperthermia.

Thermal conductance

Under the conditions of these experiments the total thermal conductance of hairless mice was approximately 45 % greater than that of albino mice. This is equivalent to the statement that the coefficient for total heat transfer was 45 % higher in hairless mice, since the calculated conductance included evaporative heat loss as well as sensible heat loss. At higher temperatures the coefficients were approximately equal (see Fig. 2), an effect which can be attributed to increased evaporative heat loss in both strains. At 22 and 30° C, however, heat transfer was primarily sensible, that is it was dependent on temperature gradients rather than on the evaporation of water, and consequently the difference in thermal conductance between the two strains was chiefly due to differences in the radiation, convection and conduction of heat. Of these three channels of heat exchange, variation in conduction may be expected to have played the least part in contributing to differences between the two strains since in all measurements the animals were placed on a wire mesh and were not therefore in contact with a continuous solid surface. In the case of radiation and convection, however, the insulation of a hair coat would tend to lead to reduction in heat transfer by both channels.

Hošek *et al.* (1965) measured oxygen consumption during periods of 1 hr duration in haired and hairless mice of varying ages at the one environmental temperature of 23° C. At 14 weeks of age their haired mice consumed oxygen at approximately 65 ml./kg. min, and the hairless mice at about 90 ml./kg. min, the mean weights of the animals being 28.6 and 29.6 g. Their metabolic rates were somewhat higher than the present results, but the albino/hairless ratio of total thermal conductance of 0.72 was close to the values of 0.66 and 0.67 found in the present experiments at 22 and 30° C respectively. In this connexion a comparison can be made with the results of experiments carried out by Baldwin (1968) in which he used the method of operant conditioning to determine the frequency with which haired and hairless mice switched on radiant heaters when the animals were exposed to an air temperature of 0° C. The mean haired/hairless ratio of frequency of switching, estimated from Baldwin's Fig. 2, was 0.65, closely similar to the ratios of the thermal conductances at rather higher environmental temperatures.

Thermal insulation

Barnett (1959) made measurements *in vitro* of the thermal insulation of mouse skin, both with the coat intact and with the skin shaved, using the technique of Scholander *et al.* (1950). The determinations were made on two mouse pelts simultaneously, spread flat, covering the two sides of a hot-plate, with a guard-ring to minimize lateral loss of heat. The differences which he found between unshaved and shaved skin in A2G and C57BL mice were similar to the difference found in the present experiments between intact albino and hairless mice (Table 3), suggesting that the two lines of evidence are mutually corroborative with regard to the insulative value of mouse fur. There are, however, at least two reasons why such a conclusion should not be accepted unconditionally: the first is concerned with the level of activity in the animal; the second is concerned with the decreased efficiency of insulation of material covering a body of small radius of curvature.

Activity

Increased bodily activity in a cool environment leads to an increased loss of sensible heat which is associated with three factors: increased forced convection due to the passage of the animal or its parts through the air, an increased mean effective body area for radiant and convective heat loss associated with the mean configuration in activity as compared with the resting posture, and the tendency towards peripheral vasodilatation which is connected with the increased metabolism of activity. The hairless mice used in the present study gave the impression that they were more active

than the albinos. In order to pursue this further, four members of this Institute who were unaware of the objectives of the present investigation were invited, each alone and on two occasions, to observe two hairless and two albino mice, each in a separate box, and to comment on the one strain relative to the other. The unanimously presented observation was that the hairless mice were more active than the albino, thereby confirming the original impression.

Another reason for suspecting increased activity of the hairless mice during the period of the experiment is suggested by the 5-hr and 24-hr values for oxygen consumption rate at 30° C. In the case of the albino mouse, the 5-hr rate (measured during daylight hours) was significantly less than the 24-hr rate, an effect which is in accordance with observations previously made on the 24-hourly pattern of variation of metabolic rate in the albino mouse, which demonstrated increased nocturnal metabolism for the range of environmental temperatures used here (Mount & Willmott, 1967). In the case of the hairless mice, however, there was no significant difference between the 5-hr and 24-hr rates, suggesting that the activity of hairless mice in the hours of daylight was closer to the mean level of activity throughout the 24 hr. Only a short habituation period of one hour was used before the 5-hr experiments, and it is probable that the excitement associated with change of environment was still exercising some influence on the metabolic rate. Although both albino and hairless mice were treated similarly, the effects of disturbance may have lasted longer in the case of the hairless animals.

If the hairless mice were indeed more active than the albinos, they would have less 'air' insulation (Joyce, Blaxter & Park, 1966) or 'ambient' insulation (Hey & Katz, 1970) than a quieter animal. The terms 'air' and 'ambient' have been applied to the insulation in respect of radiant and convective heat transfer between an animal's surface (either surface of the coat or of bare skin) and the surroundings. The air-ambient insulation is additive to the insulation of the coat, since the two insulations are effectively in series. The difference observed between the insulations of albinos and hairless mice could therefore be greater than the difference due only to the presence or absence of the coat, provided that the effect is large enough to counteract the minor effect associated with small radius (see below). In so far as the coats of Barnett's (1959) A2G and C57BL mice were comparable with those of the albino mice used in the present experiment, reference to Table 3 shows that this expectation is borne out.

Insulation and radius of curvature

The difference between albino and hairless mice would, however, be expected to be smaller than that predicted from measurements on coat

insulation on a plane surface by an amount dependent on the decreased insulative efficiency of fur on a part of small radius of curvature. Van Dilla *et al.* (1949) have calculated that for a given thickness, x , of an insulating material on a part of radius r , the actual insulation is the insulation determined in the plane condition multiplied by the factor $\{r/(r+x)\}$ for a sphere, and by $r/x \ln \{1+(x/r)\}$ for a cylinder. The mice used in the present study were of radius approximately 15 mm, with a hair coat of about 1.5 mm in depth. The insulation of the coat can therefore be calculated to lie between 91% (for a sphere) and 95% (for a cylinder) of that in the plane situation. This effect would decrease the difference in insulation between albino and hairless mice. It is, however, a small effect, and consequently any major variation cannot be attributed to it. This conclusion is supported by the estimates of the difference in insulation associated with the presence and absence of coat in these experiments.

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