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Seasonal Hair Growth in the Adult Domestic Cat (*Felis catus*)

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ABSTRACT. Determination of amino acid requirements by the factorial method requires an estimate of the amount of amino acids required for the replacement of hair. Hair growth rates in a total of 39 adult male and female domestic short-haired cats were determined throughout the year using the mid-side patch technique. The ratio of hair on the mid-side area to total hair on the body was also determined to allow conversion of mid-side hair growth rates to hair growth rates over the entire body. The mid-side hair growth rate showed a sinusoidal pattern throughout the year, similar to that found for day length and daily mean air temperature, with a maximum hair growth rate of 289 μg/cm^2/day in summer and a minimum hair growth rate of 62 μg/cm^2/day in winter. The peak hair growth rate for the female cats was reached earlier than that for the male cats. Sine-functions describing day length, minimum and maximum daily air temperatures and daily hair growth rates are presented. Adult domestic short-haired cats were found to grow 32.7 g of hair per kg body weight per year. Monthly amounts of hair growth per unit of body weight and body surface area are calculated. *Copyright © 1996 Elsevier Science Inc.* comp biochem physiol 116A;1:29–35, 1997.

KEY WORDS. Cat, day length, feline, factorial model, hair growth, requirement, seasonal, total body hair

INTRODUCTION

Protein is the main constituent of animal hair (10,19, 22,23). The amino acids required for the replacement of hair in the adult cat (*Felis catus*), therefore, may make up a significant proportion of the total amino acid requirement for maintenance. To determine dietary amino acid requirements by the factorial method, an estimate of the amino acids required for the replacement of hair is needed.

Hair growth and moulting in the cat have been shown to occur uniformly throughout the pelage in a mosaic pattern (2), unlike in rats and rabbits who replace hair in a wave pattern (18). However, there is seasonal variation with the maximum growth occurring in summer and the minimum hair growth in winter (2,26). The amount of amino acids required for hair growth in the cat should also reflect this seasonal pattern of growth with the highest requirement for amino acids occurring during summer and with a decreased requirement being found during the period of low hair growth rate in winter. There is little quantitative information on hair growth in the adult domestic cat.

The present study was conducted to determine hair growth throughout the year in adult domestic cats of both sexes. Hair growth was determined using the mid-side patch technique, over a total period of 416 days. To relate mid-side patch hair growth rate to hair growth rate over the entire body of the cat, the ratio of the total amount of hair on the body to the amount of hair on the mid-side area was also determined.

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MATERIALS AND METHODS

The two studies reported here were approved by the Massey University Animal Ethics Committee. Fifty-nine (39 males, 20 females) 1–6 y old short-haired domestic cats with an initial body weight range of 2255 to 6693 g (mean ± SEM; 3848 ± 96.8 g) were used.

Study 1

Hair growth in 39 (25 males, 14 females) adult cats from the BestFriend Feline Nutrition Research Unit, Massey University, Palmerston North, New Zealand (longitude 175°38′E, latitude 40°22′S) was determined using the mid-side patch technique. The cats were housed outdoors in large (4.5 × 1.4 × 2.5 m) wire netting cages with the cats being exposed to natural daylight and temperature throughout the study. No artificial lighting was used during the study. The cats were divided into five pens with a distribution of males to females of pen 1, 8:0; pen 2, 5:2 and pens 3–5, 4:4. Throughout the study, the cats were fed to appetite a

variety of commercially available canned cat foods of proven nutritional quality (1). Water was available at all times. Minimum and maximum daily air temperatures at the cage level were recorded throughout the study. At the start of the hair growth measurement, each cat was weighed and restrained by applying plastic clips to the nape of the neck (29). A small patch (3 × 4 cm) of skin was shaved using electric clippers with a 1.9-cm wide clipper blade (Oster, Professional Products, McMinnville, TN, U.S.A.) at the left lateral chest side between the 4th and 7th intercostal space and 5 to 10 cm ventral to the spine of the cat. At the designated collection time, the restrained cat was held in a normal standing position and the hairs, shaved off the patch with a single stroke of the clipper blade, were collected manually in a plastic container. Care was taken to collect all the hairs shaved off the patch. Any hairs remaining on the clipper blade were carefully washed into the plastic container using 20 ml of a 50% (v/v) water–methanol solution. The length of the shaved patch was measured accurately using a ruler and the entire patch shaved again to the skin. The hair containing water–methanol solution was filtered through a preweighed sintered glass crucible and the retained hairs were washed using methanol and water, whereafter the crucible was dried until constant weight. The cats housed in pens 1, 2 and 3 were shaved at 4-week intervals over a 364-day period while the cats housed in pens 4 and 5 were shaved at consecutive intervals of 31 and 39 days, respectively, over a 381-day period. The 416-day study was started on February 21, 1994, with the start of the first hair growth measurement for the cats in the five pens spread over the first 4 weeks. The hair growth rate (mg/cm^2/day), calculated by dividing the hair growth (mg/cm^2) during each period by the number of days in the respective period, was taken to be the rate of hair growth for the median of the period.

To determine if there was an effect of repeated shaving of the left mid-side patch on hair growth rate, the hair growth rate on the left as well as on the right side of every cat was determined over a 4-week period at the end of the study using the above described procedure.

Study 2

The following study was conducted to obtain information on the relationship between the total amount of body hair and the amount of hair on the mid-side area of cats. Twenty (14 male, 6 female) adult cats that had been put down by an Animal Shelter Group, using carbon dioxide as the method of euthanasia, were made available for this study. The animals had been killed at different times of the year and their nutritional history was unknown. After death the cats were weighed, and the skin was removed and spread flesh-side upwards on a plastic sheet. A small patch (5 × 5 cm) was dissected from the skin at the position where the hair growth measurement was made in study 1. The flesh-side of the skin and the patch were then treated with approximately 2.3 ml/dm^2 of a depilatory solution (1.0 M NaOH and 2.0 M $Na_2S{\cdot}9H_2O$) and the skin was stored at 4°C at a relative humidity of 100% for 16 hr. On removal from the chiller, the skin was placed with the hair-side up and the hair was plucked off manually. The hair was then washed for 5 hr in a detergent–water solution using a laboratory stirrer. After washing, the hairs were strained through a wire sieve (1.5 mm) and the detergent was removed by rinsing with excess water and the hairs were dried until constant weight. The hair on the 25 cm^2 mid-side patch was collected in a beaker, washed for 5 hr in a detergent–water solution using a magnetic stirrer and was then filtered onto a preweighed glass sintered crucible. The detergent was removed using excess water and the crucible was dried until constant weight. The amount of hair (g) per cat was calculated on a body weight basis and a surface area (cm^2) basis using the equation of Greaves (11). The amount of hair (mg/cm^2) on the mid-side patch was calculated by dividing the amount of hair on the patch (mg) by the area of the patch (25 cm^2).

Data Analysis

Ryder (26) showed that hair growth in cats throughout the year occurs in a sinusoidal pattern and therefore the following sine-function was fitted to the daily hair growth (mg/cm^2/day) data for each cat, using the SAS non-linear regression procedure and the Marquardt method (27).

$$Y = \mathbf{a} + \mathbf{b} * \sin(\mathbf{c} * (X - \mathbf{d}))$$

where:

Y = dependent variable
X = time in days
a = horizontal shift
b = half amplitude
c = frequency
d = phase start

The parameter **c** was set to 0.0172 (2π/365.25 days) when fitting the sine-function. The estimates of the parameters **a**, **b** and **d** were subjected to analysis of variance (GLM procedure) (27) with gender, shaving interval and the interaction of gender and shaving interval as variables. There was no effect of gender, shaving interval or the interaction between gender and shaving interval on the estimates of **a** and **b** and the data were thus pooled across sexes and shaving intervals when fitting the sine-functions. There was an effect of gender on the estimates for **d** and separate functions were fitted to the daily hair growth data for the male and female cats with the parameters **a** and **b** set to 175.5 and 113.9, respectively. The sine-function was also fitted to the body weight data for every cat throughout the study with the values for the parameters **a**, **b** and **d** being subjected to analysis of variance (GLM procedure) (27) with gender as

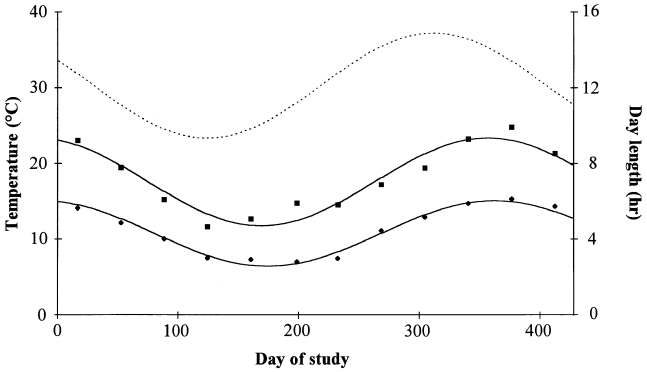

FIG. 1. Day length at long. 175°38′E, lat. 40°22′S (– – –), average minimum (◆) and maximum (■) monthly temperatures and the sine-functions fitted to the day length (– – –) and minimum and maximum daily temperature (—) data.

a variable. There was no effect of gender on the estimates of **b** and **d** and the data were thus pooled across sexes. There was an effect of gender on the estimates of **a** and separate functions were obtained for the male and female cats with the parameters **b** and **d** being set to 35 and 299, respectively. The sine-function was also fitted to day length data (time between sun rise and sun set) at longitude 175°38′E, latitude 40°22′S (20,21), and the minimum and maximum daily air temperatures occurring during the study. A paired *t*-test was used to determine the level of significance for differences between the hair growth rates (mg/cm^2/day) on the left and right mid-side patches of the cats during the 4-week period at the end of the study.

Student's *t*-test was used to determine the effect of gender on the total amount of hair on the body per unit of body weight and surface area, and amount of hair on the mid-side area of the cats in study 2.

RESULTS

The cats used in study 1 remained healthy throughout the experimental period. There was no significant difference ($P = 0.13$) in hair growth rate between the left or right mid-side patches of the cats. A mean (±SEM) hair growth rate of 0.28 (±0.01) mg/cm^2/day was found for the left mid-side while a value of 0.27 (±0.01) mg/cm^2/day was obtained for the right mid-side.

The day length, average minimum and maximum monthly air temperatures during the study and the fitted sine-functions are shown in Figure 1. Day length showed a sinusoidal pattern with the shortest and longest days at 120 and 303 days after the start of the study, respectively. The minimum and maximum daily air temperatures showed a similar sinusoidal pattern, but out of phase with day length, with the coldest and warmest day being at around days 167 and 350, respectively.

The average daily hair growth rate expressed per unit of body surface area for the male and female cats as measured using the mid-side patch technique throughout the 416-day study and the sine-functions fitted to the male and female hair growth rate data are shown in Figure 2. There was a distinct sinusoidal pattern in the hair growth rate data with maximum and minimum daily hair growth rates occurring at approximately 20 and 200 days, respectively. A coefficient of variation between cats of 17% was found for the estimates of **a** for the sine-function fitted to the daily hair growth rate data, while a coefficient of variation of 31% was found for the estimates of **b**. The estimates of **d** had a coefficient of variation of 23% for the male cats and a coefficient of variation of 25% for the female cats. There was no significant effect ($P > 0.05$) of gender, shaving interval or the interaction between gender and shaving interval on the estimates of **a** and **b**. Furthermore, there was no effect ($P > 0.05$) of shaving interval or the interaction between

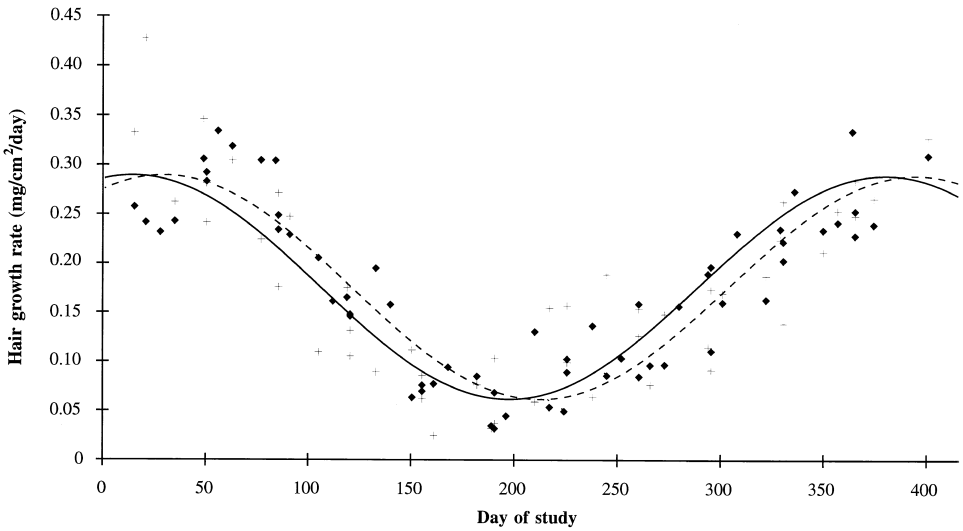

FIG. 2. Daily hair growth rate as measured on the mid-side area in adult domestic short-haired cats of both sexes (◆ = male, average of 8, 5 or 4 animals, + = female, average of 4 or 2 animals) and the sine-functions fitted to the data (– – – = male, — = female).

TABLE 1. Parameters (a, b, d), coefficient of determination (R^2), minima and maxima of the sine-functions[a] fitted to day length (long. 174°38′E, lat. 40°22′S), minimum and maximum daily air temperature, and mid-side hair growth rate data for adult male and female short-haired cats

	Parameter					
	a	**b**	**d**	**R^2**	**Min.**	**Max.**
					(Days)	(Days)
Day length (hr)	12.11	2.77	211	1.00	120	303
Temperature (°C)						
min.	10.73	4.32	260	0.96	169	352
max.	17.57	5.80	255	0.96	164	346
Hair growth (μg/cm^2/day)						
male	175.5	113.9	304	0.91	212	30
female	175.5	113.9	289	0.86	197	15

[a]$f(x) = \mathbf{a} + \mathbf{b} * \sin(0.0172 * (x - \mathbf{d}))$ where **a** = horizontal shift, **b** = half amplitude and **d** = phase shift of the sine.

gender and shaving interval on the estimates of **d**. There was, however, an effect ($P < 0.05$) of gender on the estimates of **d**. Maximum and minimum daily hair growth rates, as estimated using the sine-function fitted to the hair growth rate data, of 289 and 62 μg/cm^2 day, respectively, were found. The maximum and minimum hair growth rates for the female cats were reached on days 15 and 197, respectively, while the maximum and minimum hair growth rates for the male cats were reached on days 30 and 212, respectively. Table 1 shows the parameters for the sine-function fitted to day length, minimum and maximum daily air temperatures and the daily hair growth rates for the mid-side patch of the male and female cats. There was an effect ($P < 0.05$) of gender on the estimates of **a** for the sine-function fitted to the body weight data but no effect ($P > 0.05$) of gender was found for the estimates of **b** and **d**. The male cats were significantly heavier than the female cats with a mean body weight of 4.35 kg for the males and 3.17 kg for the female cats.

The depilation of the skin by the procedure described in the present study allowed easy removal of most (>99%) hair. There was no effect ($P > 0.05$) of gender on the total amount of hair on the body per unit of body weight and per unit of surface area, or the amount of hair on the mid-side area. The data were, therefore, pooled across sexes. Table 2 shows the mean, standard error and coefficient of variation for body weight, total amount of hair on the body and the amount of hair on the mid-side area for the 20 cats. There was approximately 20 g of hair per kg of body weight on the body of the cats although there was a large variation (CV 23%) between animals. The amount of hair collected from the mid-side area had a high variability (CV 26%) with an average amount of 39.7 mg of hair per cm^2 surface area. The ratio of hair on the whole body to hair on the mid-side area was less variable with a coefficient of variation between animals of 12% when the total amount of hair on the body was expressed on a body weight basis (ratio 1) and a value of 11% when the total amount of hair on the body was expressed relative to surface area (ratio 2).

DISCUSSION

No difference was found for hair growth rates on the left and right mid-side areas over the 4-week period at the end of study 1, indicating that there was no effect of the repeated clipping on hair growth rate. Observations made in sheep have shown that there is no effect of clipping per se on the growth rate of wool as measured on mid-side patches (4,7,8). In humans, Saitoh *et al.* (28) measured growth of chest hairs using a sensitive capillary tube method and also found no effect of shaving on hair growth rates. However, a reduction in wool growth has been observed in sheep when the temperature of the clipped area was lowered (5). In the present study, there may have been an effect of the reduced insulation of the mid-side patch on the hair growth rate due to the clipping. This effect, however, is expected to be minor as the clipped area was small (3 × 4 cm) and was partially covered by the surrounding hairs throughout the experiment. Also there was no influence of the interval (frequency) of clipping on the mid-side patch hair growth rate in the present study. This is in accordance with observations made in sheep where the frequency of clipping a

TABLE 2. Mean, standard error (SEM) and coefficient of variation (CV) for body weight (BW), total body hair and hair on the mid-side patch of adult domestic short-haired cats

	Mean (n = 20)	**SEM**	**CV (%)**
Body weight (g)	3819	135	15.8
Total body hair			
(g/kg BW)	19.9	1.0	22.6
(mg/cm^2 SA[a])	23.7	1.2	22.3
Patch hair (mg/cm^2 SA)	39.7	2.3	26.3
Ratio 1 (cm^2 SA/g BW)[b]	0.51	0.01	12.3
Ratio 2[c]	0.61	0.02	11.0

[a]Calculated using surface area (SA) = $14.15 * BW^{0.657}$ from Greaves (11).
[b]Total body hair (mg/g BW)/patch hair (mg/cm^2 SA).
[c]Total body hair (mg/cm^2 SA)/patch hair (mg/cm^2 SA).

patch of skin has been found to have no effect on wool growth (4,7).

The body weight of the cats throughout the study showed no obvious sinusoidal pattern. A half-amplitude (parameter **b**) of the sine-function fitted to the body weight data of 35 g was found indicating that the average variation in body weight throughout the year was small. This was also observed by Ryder (26) who reported a slight tendency for an increased body weight of cats during summer and a decrease during winter.

The daily hair growth rate on the mid-side patch of cats as measured over the experimental period (Fig. 2) showed a distinct sinusoidal pattern similar to the pattern for day length. Hair growth rates in many animals including cattle (*Bos taurus*), ferrets (*Mustela furo*), dogs (*Canis familiaris*) and sheep (*Ovis aires*), have been shown to be regulated by photoperiod (13,23,25,30). Although no measurements have been made in cats, Baker (2) implied that the increased photoperiod is a stimulus for the replacement of hair in cats and the present data are in line with this hypothesis. The minimum and maximum daily temperatures also showed a sinusoidal pattern out of phase with the day length and, although unlikely, it cannot be excluded that temperature may regulate hair growth in cats.

The sine-function fitted to the day length data explained more than 99.9% of the variation in the data. Baker (2) showed that hair growth in adult cats follows a sinusoidal pattern throughout the year and, therefore, a sine-function was fitted to the daily hair growth rate data of the cats in the present study. The sine-function fitted to the daily mid-side hair growth rate explained 91% of the variation in the data for male cats and 86% of the variation in the data for female cats. Nagorcka (23) found slightly lower coefficients of determination (0.77 and 0.78, respectively) when fitting a sine-function to wool growth data from Ferguson *et al.* (9) and Hart *et al.* (12). The sinusoidal hair growth pattern in cats was also observed by Baker (2) who measured hair follicle inactivity in different cats killed during the year in the northern hemisphere. Maximum follicle inactivity was observed during February and March, which corresponds to maximum daily hair growth rates found in the present study. Ryder (26) measured the follicle inactivity of primary and secondary hairs for two male cats and one female cat for a 19-month period, in the southern hemisphere, and found the same sinusoidal pattern in follicle inactivity as the sinusoidal pattern in daily hair growth rates found in the present study. The minimum follicle inactivity (40%) of the primary and secondary hairs was found in mid-summer while the maximum follicle inactivity (85%) was found in winter (26). These percentages agree closely with the estimates for minimum and maximum hair growth rates on the mid-side area found in the present study. Assuming that 40% of the follicles were inactive during the period relating to the highest daily hair growth rate (289 μg/cm^2/day, Table 1) in the present study, an estimate of the minimum daily hair growth rate (85% of the follicles inactive) of 72 μg/cm^2 would be obtained. This estimate is similar to the minimum daily hair growth rate of 62 μg/cm^2 (Table 2) found here.

There was no difference in the average daily hair growth rate (parameter **a**) and the half amplitude of the variation in the daily hair growth rate (parameter **b**) between the male and female cats. Baker (2) measured daily growth of hair length for a male and two female cats during an 11-month period and concluded that the average daily hair growth rates over the 11-month period were not different for the two sexes. The relatively small coefficient of variation found for parameter **a** (17%) in comparison to parameter **b** (31%) in the present study, indicates that the average daily hair growth rate between cats is similar but that there is a large variation in the amplitude of the daily hair growth rate. A significant difference in the timing of the hair growth (parameter **d**) was found between the male and female cats in the present study. Ryder's (26) data shows that the maximum follicle inactivity of the female cat is reached earlier than that of the adult male cats which is consistent with the results found in the present study. Reproductive hormones have been shown to have an effect on the timing of hair growth in the rat (*Rattus rattus*) and guinea-pig (*Cavia porcellus*). Johnson (17) and Jackson and Ebling (16) showed that oestradiol delays the initiation of hair growth in the female of these species. Johnson (17) also showed that testosterone had no effect on the initiation of hair growth in the male rat. As all the cats in study 1 were castrated, it is possible that the reduced levels of body oestrogen in the female cats may have resulted in hair growth being initiated earlier in comparison to the hair growth of the male cats, which were unaffected by the reduced levels of body testosterone.

The mid-side patch technique has been used to measure wool growth in sheep (4,6,7) and hair growth in dogs (22). In sheep, it has been shown that the wool growth rate on the mid-side area is close to the average wool growth rate over the entire body (6). Wool production can, therefore, be estimated by using the mid-side patch hair growth rate and an estimate of the total wool-bearing skin surface (6). Another method to estimate wool production in sheep was used by Hawker *et al.* (15) and Hawker and Crosbie (14), who partitioned the fleece weight of sheep according to the relative weights of wool clipped from the mid-side patch at different times. No measurement of the relationship between the hair growth rate on the mid-side area and the hair growth rate on other areas of the body has been made in cats and it is unknown whether the mid-side hair growth rate is representative of the hair growth rate over the entire body. Furthermore, as cats loose significant amounts of hair throughout the year, the latter method used by Hawker *et al.* (15) and Hawker and Crosbie (14) cannot be used. In the present study and in order to convert the mid-side patch hair growth rate to hair growth rate over the entire body,

TABLE 3. Monthly hair growth rate[a] per unit body weight (BW) and surface area (SA) for adult male and female domestic short-haired cats (long. 174°38′E, lat. 40°22′S)

Month	Hair growth rate			
	Male		Female	
	(g/kg BW/Month)[b]	(mg/cm^2 SA/Month)[c]	(g/kg BW/Month)[b]	(mg/cm^2 SA/Month)[c]
January	3.54	4.21	3.93	4.67
February	3.86	4.59	4.05	4.82
March	4.55	5.41	4.54	5.40
April	4.26	5.07	4.03	4.80
May	3.82	4.55	3.42	4.07
June	2.86	3.41	2.42	2.88
July	2.05	2.43	1.66	1.97
August	1.32	1.57	1.11	1.32
September	0.97	1.15	0.99	1.17
October	1.16	1.38	1.40	1.67
November	1.70	2.02	2.09	2.48
December	2.62	3.12	3.07	3.66

[a]Calculated using integrated function F(x) = a*x − (**b**/0.0172)*cos(0.0172*(x-**d**)) and estimates of **a**, **b**, and **d** (Table 1).
[b]Calculated using ratio 1 (Table 2).
[c]Calculated using ratio 2 (Table 2).

the assumption was made that hair growth rate per unit of hair weight on the mid-side patch is representative of the hair growth rate per unit of hair weight over the entire body (*i.e.* the turnover of hair over the entire body of the cat is similar). Evidence to support this assumption is given by Baker (2) who states that hair replacement occurs uniformly throughout the pelage in adult cats. This indicates that the turnover of hair is similar on any area of the cats body, otherwise uniform hair replacement could not occur. Therefore, to convert hair growth rate on the mid-side patch to hair growth rate over the entire body, in the present study, the ratio of the amount of total body hair (in mg/g body weight and mg/cm^2 surface area) to the amount of hair on the mid-side area (mg/cm^2) was determined. Ratio 1 (Table 2) can be used to convert mid-side patch hair growth rates to hair growth rates over the entire body expressed on a body weight basis while ratio 2 (Table 2) can be used to convert mid-side patch hair growth rates to hair growth rates over the entire body expressed on a surface area basis. The amount of hair grown by domestic short-haired cats over a period of time can now be estimated by integrating the sine-function over a designated period and multiplying this value by the body weight of the cat and ratio 1 (Table 2) or the surface area of the cat and ratio 2 (Table 2). Relationships between the surface area and the body weight of cats have been published by Greaves (11) and Bartorelli and Gerola (3). The monthly hair growth in adult male and female domestic short-haired cats at longitude 175°38′E and latitude 40°22′S calculated using the above described method is shown in Table 3.

The calculated turnover of hair on the mid-side area for cats in the present study was 226 days. This, however, may not be an entirely accurate estimate as the amount of hair found on the mid-side area (39.7 mg/cm^2) may not have been the average amount of hair present on the mid-side area throughout the year because 8 cats used in study 2 were obtained in summer and 11 cats were obtained in early autumn. Moulting starts in October (2,26) and the cats in study 2 would have had a relatively "light" coat at the time of measurement as compared to winter. However, this should not affect the ratio of the amount of hair on the entire body to the amount of hair on the mid-side area (ratio 1 and 2), as this may be expected to be constant throughout the year.

Mundt and Stafforst (22) measured hair growth in various breeds of another carnivore, the dog (*Canis familiaris*), and reported yearly amounts of hair growth of 60–186 g per kg body weight, depending on the breed of dog. In the present study, a yearly amount of hair growth of 32.7 g per kg body weight was found for adult short-haired cats which is about half of the lowest values of hair growth reported by Mundt and Stafforst (22) for dogs. The total amount of body hair of cats on a body weight basis, however, is comparable to that of dogs with a high weight of body hair. Mundt and Stafforst (22) found an average amount of body hair of 20.5 g per kg body weight for hairy breeds of dog (pekinese, collie, pomeranian, German shepherd dog), which is comparable to the 19.9 g of hair per kg body weight found in the present study for cats.

The present study provides estimates of hair growth in adult male and female short-haired domestic cats. These can be used in the determination of the nitrogen and amino acid requirements of the adult domestic cat by the factorial method.

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