Energy requirements and body surface area of cats and dogs

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Energy requirements, the size of some organs (eg, brain and kidneys), metabolic processes (eg, glomerular filtration rate), and the doses of some drugs (eg, digitalis and chemotherapeutic agents) do not necessarily vary directly with **body weight (BW)**. Some of these factors vary exponentially with BW (eg, $BW^{0.75}$, referred to as metabolic BW) or with **body surface area (BSA)**. Understanding whether energy requirements and other metabolic functions vary with BW, metabolic BW, or BSA is crucial when carefully managing patients that vary in body size (eg, dogs and cats). For example, use of BW or an exponent of BW that is too high will typically underestimate the energy requirements of smaller animals and overestimate energy requirements in larger animals. Overfeeding can be especially life-threatening for malnourished patients and will promote obesity in well-nourished patients. The relationship between size and function may also yield insight into metabolic processes.

The idea that heat loss from a warm-bodied animal should be roughly proportional to BSA was first suggested as early as 1839.[1] To compensate for heat loss, heat production (similar to the situation for BSA) should be relatively greater in smaller animals than in larger ones. Empirical support for this principle was provided for dogs in 1883.[2] In that study, it was reported that the fasting metabolic rate decreased relative to BW as size increased, but it remained comparatively constant relative to BSA (1,000 to 1,200 kcal/m^2 daily [90 to 110 kcal/ft^2 daily]). Subsequently, it was suggested that this principle could be generalized to all species of birds and mammals.[3]

Since that time, few investigators have measured BSA directly in dogs and cats because it is difficult to measure. Dead animals can be skinned and the area of skin measured, but it is difficult to determine how much the skin should be stretched once it has been removed. A paper mold can be made to cover the skin surface, but it is not easy to conform such a mold to the cracks and crannies of an animal's body. Alternatively, the body can be divided into standard geometric shapes (eg, cylinders); the surface area can be calculated for each of the geometric shapes and then combined to obtain a total BSA. All of these measurements are extremely time consuming and likely to be accurate only to within 10% to 20%.[1]

Body surface area may be estimated from BW. The surface area of a consistent geometric shape can be calculated from its volume by use of the following equation (equation 1):

$$SA = k \times V^{2/3}$$

where SA is the surface area, k is a constant, and V is the volume. It was pointed out by 1 investigator[4] that BW could be substituted for volume when density remains constant. Thus, BSA can be estimated from BW by use of the following equation (equation 2):

$$BSA = k \times BW^{2/3}$$

For this and subsequent equations, BSA should be reported as the number of square centimeters and BW should be reported as the number of grams, unless stated otherwise. The number of square centimeters can be converted to the number of square meters by dividing the value by 10,000. The number of grams can be converted to the number of kilograms by dividing the value by 1,000. The number of square inches can be converted to the number of square centimeters by multiplying the value by 6.45, and the number of square inches can be converted to the number of square meters by dividing the value by 1,550. The number of pounds can be converted to the number of grams by multiplying the value by 454, and the number of pounds can be converted to the number of kilograms by dividing by 2.2. These conversions should be performed before the values for BSA (in square centimeters) and BW (in grams) are used to solve the aforementioned equations.

The value of k is smallest for a sphere (4.8) and increases the more a shape diverges from that of a sphere. It was reported[5] that k is between 8 and 12 for many animals, except for bats, in which the surface area is extended as wings, and hedgehogs, which are typically quite

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spherical in shape. Another investigator[1] suggested that a value of 10 for k yields an approximation of BSA in most species when allowance is made for a potential error of 20% in measurement of BSA.

It is not clear what value of k should be used in dogs and cats. Most veterinary textbooks include tables that allow BSA to be estimated from BW. Such tables have been developed on the basis of the aforementioned equation by use of a value of 10 for k. Estimates of BSA obtained in this manner have been recommended for use when calculating the dose of potentially toxic drugs.[6,7] A footnote that typically accompanies BSA tables in textbooks suggests that k should be 10 in cats and 10.1 in dogs, but this recommendation appears to be derived from a study[8] in which BSA was measured in kittens and puppies that were < 4 months old. Furthermore, the author of that study subtracted the weight of intestinal contents from BW, which is impractical for live animals.

Other investigators[9] have questioned the value of k that should be used when calculating the dose of chemotherapeutic drugs for dogs. Most studies on the relationship between BW and BSA were performed many years ago before computers had become widely available. Use of a computerized spreadsheet program[a] and the original data to perform calculations of k and regression of logarithmic transformations of BW and BSA yields results that sometimes differ from those that were originally reported. The objective of the analysis reported here was to reevaluate the relationship between BW and BSA in dogs and cats and then compare this relationship with the relationship between energy requirements and BW.

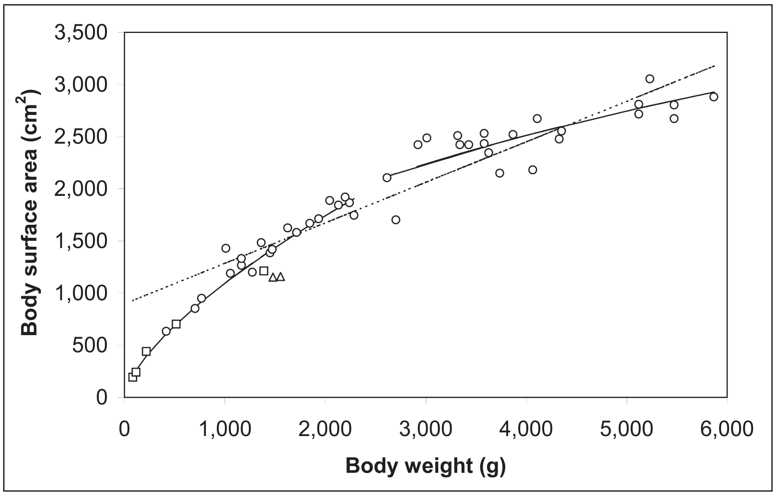

Figure 1—Relationship between body surface area (BSA) and body weight (BW) in cats. Each symbol represents data from a specific report (open triangles[10], open squares[8], and open circles[12]). Notice the regression line (dotted line) for all the data reported for reference 12 differs from the regression lines (solid lines) obtained from data for reference 12 that had been divided into 2 sets (cats that weighed > 2.5 kg [5.5 lb] or cats that weighed ≤ 2.5 kg). To convert the number of square inches to the number of square centimeters, multiply the value by 6.45. To convert the number of pounds to the number of grams, multiply the value by 454. (Adapted from Vaughan JA, Adams T. Surface area of the cat. *J Appl Physiol* 1967;22:956–958. Reprinted with permission.)

BSA and BW in cats—We are aware of only 4 studies[8,10-12] in which both BSA and BW were measured in cats (**Appendix 1**). One investigator[10] measured BSA in 2 cats, but the values for BW reported suggested that the cats were growing kittens. Another investigator[8] measured BSA in 6 kittens that ranged from 0 to 103 days of age. Although that investigator chose to deduct the weight of the intestinal contents, it is possible to obtain the total BW of the kittens by adding the weight of intestinal contents provided in the original data. Thus, regression of the logarithm of BSA against the logarithm of BW (including intestinal contents) yields a BSA of 7.6 cm^2/g of BW$^{0.71}$ (R^2, 1.0). In another study,[11] investigators regressed BW$^{0.67}$ against BSA for 19 adult cats and determined that BSA was 8.7 cm^2/g of BW$^{0.67}$ (R^2, 0.5). Unfortunately, it is not possible to reanalyze the data from that study because individual data points were not reported.

The fourth study[12] was much larger and involved measurement of BSA in 42 cats. Those investigators chose to report a linear relationship between BW and BSA; however, we believe that visually their data describes a curve (**Figure 1**). Individual data points were not reported in that study, but it is possible to extract individual data points from the graph by use of computer graphics. After scanning the graph into a computer, log-log regression of all 42 data points yielded a regression line that did not fit the data well. Nevertheless, the BW of these cats varied between 0.4 and 5.8 kg (0.88 and 12.76 lb), which suggests that some of the cats must have been growing kittens. We assumed that cats ≤ 2.5 kg (≤ 5.5 lb) of BW were growing kittens and cats > 2.5 kg of BW were adults; thus, we divided the data into 2 data sets (ie, growing kittens and adult cats). Regression of the divided data set revealed that the BSA of growing kittens is 10.7 cm^2/g of BW$^{0.67}$ (R^2, 0.97) and the BSA of adult cats is 91.3 cm^2/g of BW$^{0.4}$ (R^2, 0.58). This can be converted such that the BSA for growing kittens is 0.110 m^2/kg of BW$^{0.67}$ and the BSA of adult cats is 0.143 m^2/kg of BW$^{0.4}$. Curves for these 2 data sets visually appeared to fit the data well, although there was much more variation among the adult cats. This wider variation among adult cats is similar to that reported in another study[11] and probably reflects greater variation in body fat among adult cats, compared with variation in body fat among juveniles. The curve for growing cats also fits well with the data from another study.[8] Thus, BSA appears to fit with the principle described by equation 2[4] for growing kittens but not for adult cats.

Energy consumption and BW in cats—Only 3 studies[13,14,b] have measured energy intake in a sufficient number of cats with a wide range of BWs to enable regression of energy intake against BW. All those studies have reported a much lower exponent for BW than would be expected from the classical allometric relationships expressed in equation 2.[4] Investigators in the first study[13] reported that adult cats with BW ranging from 2.5 to 6.5 kg (5.5 to 14.3 lb) consumed 136 kcal of **digestible energy (DE)**/kg of BW$^{0.404}$ daily. Investigators in the second study[14] reported that adult cats with BW ranging from 2.6

to 8.1 kg (5.7 to 17.8 lb) consumed 150 kcal of **metabolizable energy (ME)**/kg of $BW^{0.4}$ daily, and in the third study,[b] it was reported that adult cats with a BW ranging from 2.3 to 9.1 kg (5.1 to 20.0 lb) consumed 130 kcal of ME/kg of $BW^{0.4}$ daily.

The reason for such a low exponent has not been clearly explained. However, comparison of the relationship between energy requirements and BW with the relationship between BSA and BW in adult cats derived earlier suggests that the energy requirements of adult cats may be related to BSA. Thus, data for ME intake provided by 1 group of investigators[14] suggest that the ME requirement of adult cats is 1,048 kcal/m^2 daily. This value is remarkably similar to that reported for **basal metabolic rate (BMR)** in dogs.[2] Values reported for DE[13] and ME[b] provided by other investigators suggest slightly lower values for the energy relative to BSA (940 kcal DE/m^2 or 846 kcal ME/m^2, assuming 90% retention of energy and 909 kcal of ME/m^2, respectively). These lower values are similar to the values calculated for BMR in dogs and humans[15] and for resting metabolic rate in puppies and adult dogs.[16]

A new aid for estimating BSA from BW in cats— It is easier to use BSA to estimate energy requirements when BSA is calculated for a range of BWs in advance (**Table 1**). The estimate of BSA obtained in this manner is almost 20% lower in heavy cats than has been suggested by traditional calculations. However, it is essential to carefully monitor patients when an estimate of BSA derived from BW is used for clinical management because measured BSA in 1 study[12] differed from predicted values in a few cats by > 10% and in 1 cat by as much as 30%.

BSA and BW in dogs—We are aware of only a few studies[2,5,8,10,15,17,18] in which both BSA and BW were measured in dogs (**Appendix 2**), and BSA was measured in enough dogs to enable regression of the logarithm of BSA against the logarithm of BW in only 4 of those studies.[2,8,15,17] Regression of data from the 8 dogs described in the first of these 4 studies[2] suggests that BSA is 9.9 cm^2/g of $BW^{0.68}$ (R^2, 0.99). In the second study,[8] BSA was measured in 6 puppies that ranged from 0 to 100 days of age; regression of BSA against BW (including intestinal contents) for those puppies suggests that BSA is 7.6 cm^2/g of $BW^{0.71}$ (R^2, 0.99). Another investigator[17] measured BSA and BW (excluding intestinal contents) in 10 adult dogs and 2 puppies; however, 2 adult dogs and 1 puppy were in poor health. Regression of data from the 8 healthy adults suggests that BSA is 5.1 cm^2/g of $BW^{0.74}$ (R^2, 0.99). Other investigators[9,15] have quoted a lower exponential value ($BW^{0.71}$) for the regression of data from that study[17]; however, for some unexplained reason, they used data from only 7 of the 10 adult dogs. In the fourth study,[15] BSA was measured in 7 dogs but included a nutritional status factor (BW^3/length, with length defined as the distance from the tip of the nose to the anus) in their calculations to improve the goodness of fit. Regression of data for that study[15] without this nutritional factor reveals that BSA is 11.7 cm^2/g of $BW^{0.66}$ (R^2, 0.98). Thus, results of some but not all studies suggest a higher exponential value than the value suggested by Meeh ($BW^{0.67}$).[4]

Regression of data for all dogs described in several studies[2,5,8,10,15,17,18] reveals that BSA is 8.3 cm^2/g of $BW^{0.69}$ (R^2, 0.99), which converts to 0.10 m^2/kg of $BW^{0.69}$. Regression of data from only adult dogs in those studies reveals that BSA is 9.11 cm^2/g of $BW^{0.68}$ (R^2, 0.97), which converts to 0.109 m^2/kg of $BW^{0.68}$. Visual comparison of the regression line for adult dogs with the data reported in those studies reveals that the regression line fits the data well, except that some larger dogs have an actual BSA that is 20% to 30% greater than predicted (**Figure 2**). The range of varia-

Table 1—Conversion of body weight (BW) to body surface area (BSA) for cats.

BW (kg)	BSA* (m^2)
0.5	0.07
1.0	0.11
1.5	0.14
2.0	0.17
2.5	0.20
3.0	0.22
4.0	0.25
5.0	0.27
6.0	0.29
7.0	0.31
8.0	0.33

*Value for BSA is 0.110 m^2/kg of $BW^{0.67}$ for cats that weighed ≤ 2.5 kg (≤ 5.5 lb) and 0.143 m^2/kg of $BW^{0.40}$ for cats that weighed > 2.5 kg.

To convert the number of pounds to the number of kilograms, divide the value by 2.2. To convert the number of square inches to the number of square meters, divide the value by 1,550.

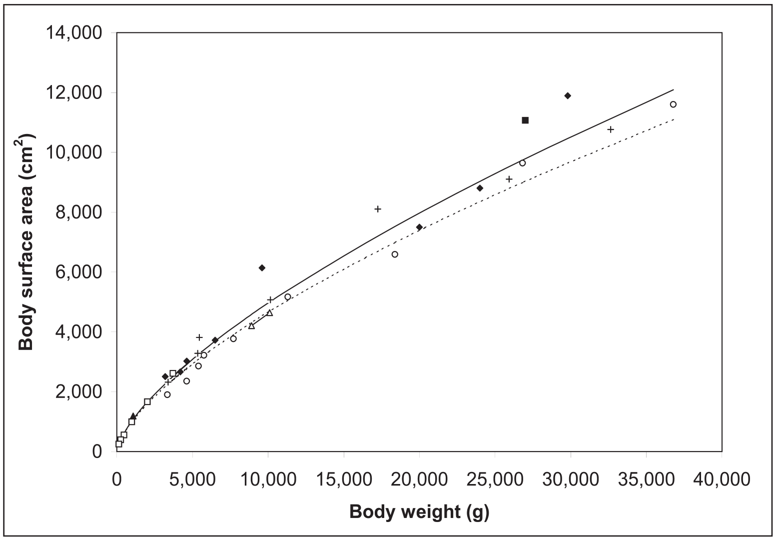

Figure 2—Relationship between BSA and BW in dogs. Each symbol represents data from a specific report (open triangles[10], solid diamonds[2], solid squares[5], open squares[8], open circles[17], crosses[15], solid triangles[18]). Notice the regression line for data obtained from all adult dogs (solid line), compared with the regression line (dotted line) for the following traditional equation[4]: BSA = 10 cm^2/kg of $BW^{0.67}$. *See* Figure 1 for remainder of key.

Table 2—Conversion of BW to BSA for dogs.

BW (kg)	BSA* (m^2)
2	0.18
5	0.31
10	0.49
15	0.64
20	0.78
25	0.91
30	1.03
40	1.24
50	1.44
60	1.63
70	1.81
80	1.98

*Value for BSA is 0.105 m^2/kg of $BW^{0.67}$.
See Table 1 for remainder of key.

tion is greater in older and larger dogs, probably because nutritional status varies more in adult dogs. This variation can be reduced by including a nutritional factor.[15]

The regression value of $BW^{0.68}$ for adult dogs is extremely close to the value ($BW^{0.67}$) reported elsewhere.[4] When a value of $BW^{0.67}$ is used, the mean value of k for all the dogs in those aforementioned studies is 10.5 (range, 8.5 to 13.6). Use of a value of 10 for k, as is recommended in most textbooks, in the calculations will underestimate BSA (as measured in those studies[2,5,8,10,15,17,18]) by a mean of 5%. Therefore, it would be more accurate to use a value of 10.5 for k when calculating BSA from BW in dogs. However, it would be premature to choose a value of $BW^{0.68}$ or higher, rather than that of $BW^{0.67}$. There appear to have been no measurements of BSA in extremely large dogs (ie, BW > 37 kg [81 lb]). Results for such extremely large dogs could greatly influence the exponent, especially because their shape varies considerably among breeds.

A new aid for estimating BSA from BW in dogs— It is easier to use BSA when BSA is calculated for a range of BWs in advance **(Table 2)**. Similar to the situation for cats, it is essential to carefully monitor patients when an estimate of BSA derived from BW is used for clinical management of dogs because the difference between predicted and estimated values of BSA in dogs can be as high as 30%. Use of values for BSA derived in this manner should be considered especially circumspect for dogs that weigh > 40 kg (88 lb) because those BSA values have been extrapolated from data for dogs that weigh much less.

Energy consumption and BW in dogs—In only a few studies[19-23] have investigators reported measurement of BMR in adult dogs **(Appendix 3)**. Of these, only 2 studies[19,22] have reported measurement of BMR in dogs with a wide range of BWs. An exponential value of $BW^{0.67}$ for the relationship between BMR and BW was cited in the first study, but in the second study,[22] an exponentential value of $BW^{0.88}$ was reported. The exponential value for the relationship between BMR and BW is $BW^{0.85}$ for all dogs described in the aforementioned studies,[19-23] but this value is heavily influenced by data for the 31 dogs from a single study,[22] which comprised a large portion of the data set and encompassed a wide range of BWs.

The interspecies exponential value for the relationship between minimal metabolism and BW has often been reported to be higher than $BW^{0.67}$.[24-28] Interspecies exponential values of $BW^{0.73}$ and $BW^{0.74}$, respectively, were reported in 2 early studies[24,25] of mammals, including dogs and cats. It was suggested that a slightly higher exponential value ($BW^{0.75}$) should be used to facilitate calculation.[26] It was suggested in a more recent report[27] that included a large data set of 248 species that BMR was related to BW with a slightly lower exponential value ($BW^{0.70}$); however, the exponential value was higher ($BW^{0.74}$) for 18 species of carnivores. In another recent report,[28] the interspecies exponential value among 43 species of carnivores was slightly lower ($BW^{0.71}$). Regression of data from that report[28] yields a higher interspecies exponential value of $BW^{0.84}$ for 6 species of wild canids that ranged from 1 to 10 kg (2.2 to 22.0 lb) of BW and a higher exponential value of $BW^{0.78}$ for 7 species of wild felids that ranged from 4 to 138 kg (8.8 to 303.6 lb) of BW.

Differences between exponential values for dogs and cats—It is unclear why the exponential value is higher than $BW^{0.67}$ for the relationship between BW and BMR in dogs and several other mammalian species but not in cats. Similarly, it is not known why the exponential value for BMR and BW is higher than that between BSA and BW in dogs but not in cats. It has been suggested that the interspecies exponential value was high ($BW^{0.87}$) for animals such as dogs that weigh > 3.2 kg (> 7.0 lb).[29] However, most adult cats also weigh > 3.2 kg, yet they have a low exponential value. It has been argued that animals do not remain geometrically similar as they increase in size[30]; instead, they are composed of columns that become thicker as size increases in an effort to counteract a tendency to bend. Use of that assumption predicts that BSA varies as $BW^{0.625}$, whereas the power output of muscles and therefore metabolic rate varies as $BW^{0.75}$. These exponential values are somewhat similar to those derived from empirical data in dogs but bear no relation to the exponential values derived from empirical data in cats.

Dietary habits, climate, and activity, as well as BW, help to explain variation in metabolic rate among carnivores.[28] Thus, carnivores that eat mostly fruit and invertebrates tend to have lower metabolic rates than carnivores that eat mostly vertebrates, cold-adapted animals have higher metabolic rates than warm-adapted and desert-living animals, and arboreal species have lower metabolic rates than terrestrial species. However, none of these differences in lifestyle greatly affect the exponential values. Body temperature and gravitational forces may also affect metabolic rate but are similar in dogs and cats.[1]

The effect of ambient temperature on BMR may provide an explanation for some of the differences between dogs and cats. It has been suggested that the exponential value generated by data in 1 study[18] of dogs was closer to a value of 1 than has been reported elsewhere because surface area is less important in the warm climate of Sao Paulo, Brazil, where that study was conducted. Dogs evolved from wolves that live in cold environments, whereas cats are adapted to warm environments. The thermoneutral zone of adult dogs is between 20° to 25°C (68° to 77°F) and 30° to 35°C (86° to 95°F) for most adult dogs, whereas unacclimatized adult cats have a comparatively narrow thermoneutral zone that appears to be higher than 30° to 35°C.[23,31,32] Therefore, heat loss from the body surface is likely to have a greater influence on BMR in cats than dogs at room temperature because dogs are within their thermoneutral zone at room temperature, whereas cats are not.

Effect of obesity on exponents—Degree of obesity may also affect the exponential values. Energy requirements, BSA, and BW were compared in laboratory cats.[12-14,b] It is possible that heavy adult cats in those studies were more obese rather than being larger in size. The exponential value may be lower ($BW^{0.4}$) in obese cats and higher ($BW^{0.67}$) in nonobese cats of large breeds (eg, Maine Coon), which are larger but whose shape and density are similar to those of smaller nonobese cats and kittens.

Conclusions—The exponent for the relationship between BSA and BW is $BW^{0.67}$ in kittens that weigh ≤ 2.5 kg, $BW^{0.4}$ in cats that weigh > 2.5 kg, and approximately $BW^{0.67}$ in dogs and puppies. The exponent for the relationship between daily energy intake and BW is $BW^{0.4}$ (ie, the same as that between BSA and BW) in adult cats that weigh > 2.5 kg, whereas the exponent for the relationship between BMR and BW is > $BW^{0.67}$ (ie, greater than that between BSA and BW) in dogs. It is possible that BSA has less influence on energy requirements in dogs than in cats at room temperature because dogs are within their thermoneutral zone at room temperature, whereas cats are not. Therefore, it is important to account for ambient temperature and the thermoneutral zone of dogs and cats when assessing the effects of BW and BSA on BMR.

[a]Quattro Pro 10, Corel Corp, Ottawa, ON, Canada.
[b]Edtstadtler-Pietsch G. *Untersuchungen zum Energiebedarf von Katzen*. Doctoral dissertation, Veterinary Faculty, Ludwig-Maximilians-University, Munich, Germany, 2003.

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Appendices continued on next page.

Appendix 1

Values reported in cats for body weight (BW), body surface area (BSA), and the Meeh constant (k).

Method	No. of cats	BW (g)	BSA (cm^2)	k (cm^2/g of $BW^{2/3}$)	Reference
Triangulation*	2	1,479 and 1,555	1,154 and 1,159	8.9 and 8.6	10
Skinned†	6	84–1,495	190–1,482	9.2–11.3	8
Skinned	19	2,503 ± 1,060‡	NR	8.7§	11
Adhesive tape cover†	42	418–5,868	633–3,055	8.5–14.2	12

*Values reported are for each cat. †Values reported are the range. ‡Value reported is mean ± 2 SD. §Value reported is the slope of the regression line.

NR = Not reported.

To convert the number of pounds to the number of grams, multiply the value by 454. To convert the number of square inches to the number of square centimeters, multiply the value by 6.45.

Appendix 2

Values reported in dogs for BW, BSA, and k.

Method	No. of dogs	BW (g)	BSA (cm^2)	k ($cm^2/g^{2/3}$)	Reference
Adult dogs					
Triangulation*	2	8,900 and 10,100	4,209 and 4,643	9.8 and 9.9	10
Skinned†	8	3,200–29,800	2,506–11,890	10.1–13.6	2
Paper Mold	1	27,000	11,070	12.3	5
Skinned†	8	3,340–36,780	1,900–11,600	8.5–10.7	17
Paper mold†	7	3,390–32,640	2,320–10,763	10.3–12.3	15
Skinned	1	1,080	1,186	11.2	18
Puppies					
Skinned†	6	132–3,708	251–2,613	9.1–10.9	8
Skinned	1	4,615	2,352	8.5	17

See Appendix 1 for key.

Appendix 3

Values reported in dogs for the regression* of basal metabolic rate (BMR) against BW.

Sex	BW (kg)†	No. of dogs	a	b	R^2	Reference
M	5–26	8	109	0.67	0.93	19
M and F	10–15	7	84	0.68	0.73	19
M and F	12–17	4	77	0.78	0.41	19
F	9–16	11	109	0.57	0.69	19
M	9–27	6	133	0.51	0.94	19
M and F	10–18	13	91	0.72	0.55	20
M and F‡	20–27	11	83	0.74	0.87	21
M	3–28	31	51	0.88	0.95	22
F	8–10	3	446	–0.07	0.07	23
All	**3–28**	**94**	**57**	**0.85**	**0.91**	

*Regression analysis was conducted by use of the following equation: $BMR = a \times BW^b$, where the value for BMR is reported in kilocalories per day, a is a constant, and b is the exponent for BW; values for BW must be converted to kilograms before the equation is solved. †Values reported represent the range. ‡Represents results for Bull Terriers.

M = Male. F = Female.