THE SURFACE-AREA/BODY-WEIGHT RELATIONSHIP IN MICE*

By N. J. Dawson†

Since Sarrus and Remeaux (see Kleiber 1961, p. 180) first proposed a "surface law", the measured or calculated surface area of animals has been used by many workers as a basis for comparison between individuals and between species in studies of metabolic rate. The history of the surface law has been discussed by Kayser (1951) and by Kleiber (1961). The DuBois standards for determining the surface area of humans have served for many years as a valuable basis for comparison between individuals in physiological and clinical studies of metabolic rate. However, standards similar to the DuBois standards for humans do not exist for other species. The trend in recent work on metabolic rate of animals appears to be to make comparisons on a body-weight basis rather than on a surface-area basis. The work reported in this paper was designed to investigate the usefulness of surface area as a basis for comparison in some studies on metabolic rate of mice.

Methods

(i) *Animals*.—Adult male and female agouti and albino house mice (*Mus musculus*) were used. The animals were kept in an air-conditioned mouse colony at 22°C, with a 14 hr light–10 hr darkness regime; they had *ad libitum* access to water and to rat and mouse cubes (Drug Houses of Australia).

(ii) *Experimental Procedure*.—Each animal was weighed, killed, and immediately skinned. The fresh pelt was gently stretched (the degree of stretching was judged subjectively), placed on stiff paper, and its outline marked in pencil. The pelt outline was cut out, and the area of the cut-out measured using an airflow planimeter‡ (Jenkins 1959). The cut-outs of the ear outlines were similarly measured and the area doubled. The surface area of the tail could not be measured directly, and was calculated on the assumption that the tail was a cone. Each of these areas was then summed. It should be noted that the area of the limbs below the carpus and tarsus could not be measured.

Results

Figure 1 presents the results graphically.

Discussion

Six different techniques for measuring the surface area of animals have been listed by Quiring (1944), who states that the chief drawback of the skinning method is the stretching on removal of the skin. Mitchell (1930) had found that the deviation of the area of the stretched skin from the surface area determined by making a mould

* Manuscript received August 29, 1966.

† Environmental Research and Teaching Unit, Department of Physiology, University of New England, Armidale, N.S.W.

‡ Paton Industries Ltd., Beaumont, South Australia.

of the rat was up to 50%. Results summarized by Brody (1945) show a difference of up to 60% between the values for the surface area of rats of a given body weight when measured by three different workers using the same (collodion membrane) technique; however, the slopes of the three individual regressions, and the spread of points about them, appear to be similar in each case, suggesting that the differences were systematic. Despite these types of drawbacks, the skinning method was used in this work because it was convenient, and because it was a technique likely to be used in a laboratory as a routine check on the applicability of a published regression to a particular group of experimental animals. The need for such a check is suggested by the variation evident in published constants for use in surface-area equations pertaining to mice (Morrison and Meyer 1964).

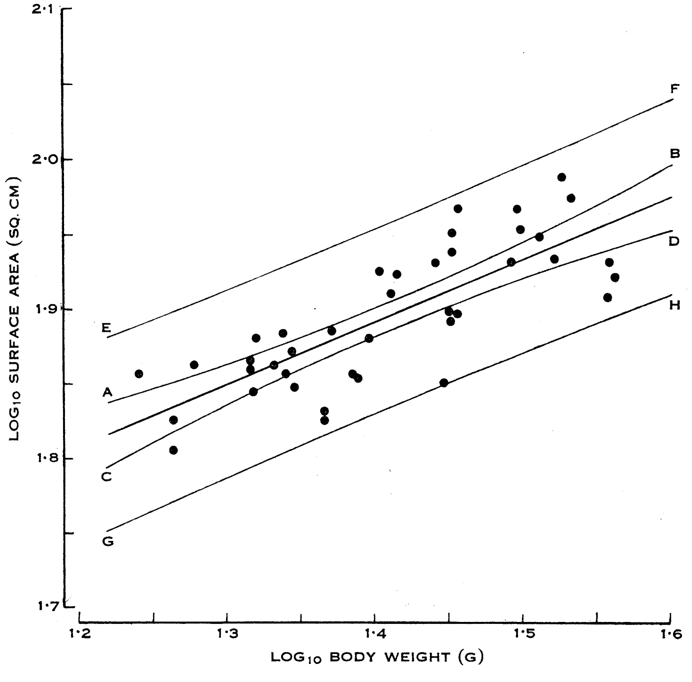

Fig. 1.—Regression of surface area on body weight of 40 mice. The middle line is the regression:

$$\log_{10}(\text{surface area}) = 1\cdot30 + 0\cdot42 \log_{10}(\text{body weight}).$$

The significance of the curves AB, CD, and EF, GH is discussed in the text. The sample correlation coefficient $(r) = 0\cdot78$ $(P < 0\cdot001)$; t for the sample regression coefficient $(b) = 7\cdot77$ $(P < 0\cdot001)$.

In Figure 1, the curves AB and CD delineate the 95% confidence belt for the regression line; that is, there is 95% confidence that the population mean of surface area for given body weight in the range covered by the sample lies within these limits. The curves EF and GH delineate the 95% confidence belt for an individual future observation; that is, there is 95% confidence that for a given body weight in the range covered by the sample, the corresponding surface area lies within these limits (see Snedecor 1956). It should be noted that the above curves delineate the respective confidence belts only if surface area bears a linear relationship to body weight.

The present results demonstrate two types of variability that arise in surface-area work. First, in the equation $S = kW^{a}$ (where S = surface area; W = body weight; and k and a are constants), new values for k and a have been found, such that $S = 20 \cdot 0 \times W^{0 \cdot 42}$. These values are peculiar to this particular set of animals. Second, the spread of points about the regression line is quite wide; the uncertainty introduced into a prediction of surface area from a given body weight as a consequence of such a spread is indicated by the distance apart of the curves EF and GH. The accuracy—or inaccuracy—of the estimate of surface area for a given body weight does not appear to have been one of the major objections yet raised to the use of surface area as a basis for comparison of metabolic rate between animals within a species (cf. Kleiber 1961), but Kleiber (1965) has cited this as an objection. From Figure 1 the surface area of a mouse weighing 25·7 g is estimated to be 78·6 cm^2, with a range (95% confidence limits) of 68·2–90·4 cm^2. Body weight can be measured to $\pm 0 \cdot 1$ g, or with an error of 0·4%; but surface area can be estimated with 95% confidence to be within the range quoted above, that is, with an error of 13·2% (lower limit) to 14·8% (upper limit). It is concluded that at least for this set of experimental conditions the spread of observations about the regression line is too great to allow this calculated relationship to be used for prediction, with very great accuracy, of surface area from a given body weight. This criticism of the use of surface area is made more cogent by the findings of Galvão (1947, 1950) on the lack of relationship between metabolic rate and surface area in dogs and fat men of the tropical zone. Statistical considerations relating to comparison of parameters on a body-weight basis have been discussed by Héroux and Gridgeman (1958), Kleiber (1961), and Angervall and Carlström (1963).

This work was carried out while the author held Junior and Senior Postgraduate Studentships from the Australian Cattle and Beef Research Committee. The author wishes to thank that Committee for its support; the Department of Agronomy, University of New England, for the use of its airflow planimeter; Dr. E. J. Burr for statistical advice; and Mr. M. E. D. Webster for helpful comment.

References

Angervall, L., and Carlström, E. (1963).—Theoretical criteria for the use of relative organ weights and similar ratios in biology. *J. Theor. Biol.* **4**, 254–9.

Brody, S. (1945).—"Bioenergetics and Growth." p. 361. (Reinhold Publishing Corporation: New York.)

Galvão, P. E. (1947).—Heat production in relation to body weight and body surface. Inapplicability of the surface law on dogs of the tropical zone. *Am. J. Physiol.* **148**, 478–89.

Galvão, P. E. (1950).—Human heat production in relation to body weight and body surface. III. Inapplicability of surface law on fat men of the tropical zone. IV. General interpretation of climatic influence on metabolism. *J. Appl. Physiol.* **3**, 21–8.

HÉROUX, O., and GRIDGEMAN, N. T. (1958).—The effect of cold acclimation on the size of organs and tissues of the rat, with special reference to modes of expression of results. *Can. J. Biochem. Physiol.* **36**, 209–16.

JENKINS, H. V. (1959).—An airflow planimeter for measuring the area of detached leaves. *Plant Physiol.* **34**, 532–6.

KAYSER, C. (1951).—La loi des surfaces. *Rev. Sci.* **89**, 267–78.

KLEIBER, M. (1961).—"The Fire of Life." pp. 177–216. (John Wiley and Sons: New York.)

KLEIBER, M. (1965).—In "Energy Metabolism". pp. 427–32. (Ed. K. L. Blaxter.) (Academic Press, Inc.: London.)

MITCHELL, H. H. (1930).—The significance of surface area determinations. *J. Nutr.* **2**, 437–42.

MORRISON, P., and MEYER, M. P. (1964).—In "Biology Data Book". p. 121. (Eds. P. L. Altman and D. S. Dittmer.) (Federation of American Societies for Experimental Biology: Washington.)

QUIRING, D. P. (1944).—In "Medical Physics". Vol. 1. pp. 1490–4. (Ed. O. Glasser.) (Year Book Publishers: Chicago.)

SNEDECOR, G. W. (1956).—"Statistical Methods." pp. 135–40. (Iowa State University Press: Ames.)