A FORMULA FOR THE DETERMINATION OF THE SURFACE AREA OF INFANTS

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Certain physiological functions are directly dependent on the surface area of the body. The heat elimination, as first shown by Rubner, and the excretion of carbon dioxid and the consumption of oxygen are *pari passu* proportional to the extent of the body surface. The study of the heat production of infants by Rubner and Heubner and Niemann, and of the infants' respiratory exchange by Schlossman, allows one to compare the different infants under the varying conditions of experimentation. They have been studied while fasting and while taking diets of different compositions. Some of the children have been well, some moderately and some poorly nourished. Great care has been used and much labor has been expended in making the different forms of apparatus and the experiments accurate in all details. The metabolism of the children has been compared on the basis of their surface area. It is evident, therefore, that the determination of the surface area should be very exact, for it obviously would be useless to determine the heat elimination painstakingly and with an error of only 1 or 2 per cent., and then use a formula for the surface area which may give an error of 15 per cent. or more. And yet, as will be seen later, this has been the case.

For the determination of the surface area various formulas have been proposed. Meeh[1] was the first to construct a formula for this purpose. He was anxious to obtain one applicable for all ages. His observations include the measurements of only three infants and these were all well nourished. The basis for Meeh's formula was the determination by Molischott that the volume of bodies of similar composition and form varies in the ratio of the cube root of their weight, and their surface areas in the ratio of the square root of their volume. He saw that the difference between the figures obtained from a formula, surface area = $\sqrt[3]{\text{Weight (in grams)}^2}$ and those from actual measurement would allow him to fix on a constant with which his results could be multiplied and thus surface areas calculated with reasonable accuracy. This constant was 12.3. But while the results for adults with the formula are satisfactory, they are not so for infants, as Meeh himself recognized would probably be the case; and he suggested that a smaller constant should be employed for infants. For this reason Rubner and Heubner used 11.9

1. Meeh: Ztschr. f. Biologie, 1879, xv, 425.

instead of 12.3, and with this the calculated surface areas of Meeh's three children were nearly the same as those actually measured. But when either of these constants is used to calculate the surface area of infants of different degrees of nutrition, the errors in certain instances may be extreme.

More recently Lissauer[2] has pointed out that either of these constants is too large for any but well-nourished children, and sometimes even for these. On the basis of twelve measurements of his own, almost all on poorly-nourished children, he has proposed 10.3 as a constant. While it is true that Meeh's formula with the constant 11.9, which has been used by Rubner and Heubner, Schlossmann and Niemann, is generally accurate for well-nourished children—but not always, as an error of 15 per cent. in one instance shows—it is very inaccurate for poorly-nourished children; and yet it has been used to calculate the surface area of all those infants with whom these authors have experimented, well-nourished and poorly-nourished alike. It is apparent that a formula is required that will have accuracy and elasticity so that it may be applicable to infants of all degrees of nutrition. Simplicity of calculation is also to be desired.

To this end we have constructed a formula of the $y = mx + b$ form, using the data supplied by Meeh and Lissauer. We have employed the weight as the only variable in the formula, as it is apparent from a study of the figures given by Meeh and Lissauer that the length and the circumference of the chest bear no necessary relationship to the extent of surface. It is not, therefore, imperative to introduce them into a formula as Miwa and Stoeltzner[3] have done, with resultant complexity and no assurance of greater accuracy.

The weight and surface area were first plotted on a chart similar to the one shown in the illustration, and a curve drawn which appeared to represent in the best way the conditions. This curve, by its distance from the axes OX and OY, represents an average of the observed data, so that when drawn to the proper scale, the point on the curve or line representing any known weight of child may be marked on the chart and the corresponding area read off directly. Thus, if we have an infant weighing 7,000 grams, and we desire to know his surface area, we find where the 7,000 gram line intersects the curve. Carrying this point horizontally to the left we find that it intersects the OY axis at a point corresponding to 4,100 square centimeters. The small circles on the chart are indicative of the fourteen observations given in the tables. The curve was drawn as nearly as possible to all these points, so that the average distance from any point would be as small as possible.

2. Lissauer: Jahrb. f. Kinderh., 1903, lviii, 392.
3. Miwa and Stoeltzner: Ztschr. f. Biologie, 1898, xxxvi, 314.

In the formula y = mx + b, which is the algebraic representation of this form of curve, x and y represent the abscissas and ordinates of the curve, b represents the distance along the Y axis from the origin to where the curve intersects the Y axis, and m represents the tangent of the angle that the curve makes with the x axis.

In this formula,
y = surface area of child in square centimeters
x = weight of child in grams
m = 0.483
b = 730

Having these last three quantities, it becomes possible to obtain the y or surface area by simple computation; b was read directly from the chart, and m was obtained by dividing 5,560—730 by 10,000.

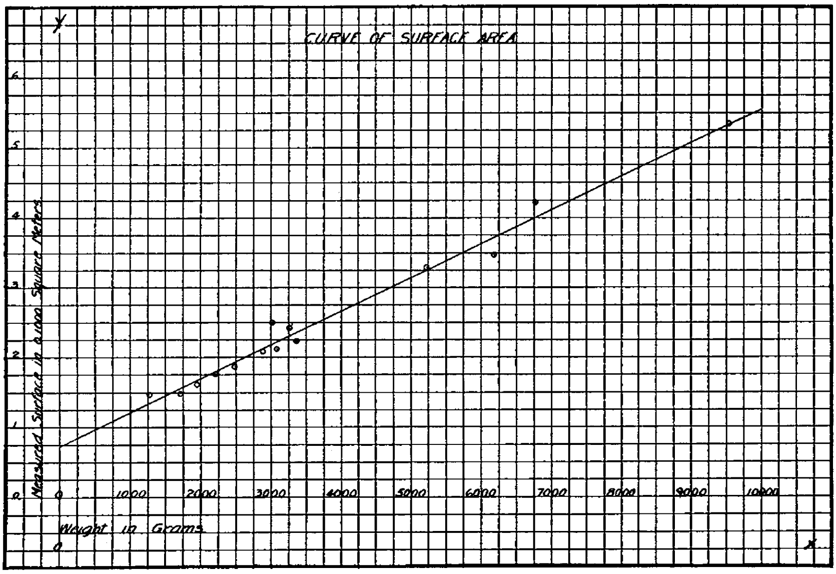

Chart showing weight and surface area determined as explained in the text.

This formula has the following advantages as compared with those of Lissauer and Meeh:

1. Accuracy.
2. Applicability to all conditions of nutrition.
3. Simplicity.
4. Elasticity.

1. The only accurate measurements of infants have been made by Meeh and Lissauer. They employed different but painstaking methods, and there is no reason to question the reliability of their results. They used, however, different types of children. Meeh was anxious to obtain

a formula accurate for all ages of normal individuals; Lissauer, on the other hand, measured with one exception only poorly-nourished and emaciated infants.

Meeh used millimeter paper laid on marked portions of the body and also accurately weighed paper for determining such areas as those of the nails. The extremities, fingers and toes were wound with circular strips. Lissauer measured cadavers by putting a colored adhesive material on the skin, pressing paper against the surfaces, and measuring exactly the stained portions after they had been removed. For infants between the ages of 6 and 435 days, there are available fifteen sets of observations obtained by these experimenters. One of these sets seems to be so decidedly abnormal that it should not be considered in the construction

No.	Surface sq. cm.	Weight gm.	$12.3\sqrt[3]{Wt.^2}$	Error % +	Error % −	$11.9\sqrt[3]{Wt.^2}$	Error % +	Error % −	$10.3\sqrt[3]{Wt.^2}$	Error % +	Error % −	y=mx+b	Error % +	Error % −
1	1462	1280	1450		0.8	1403		4.0	1215		16.9	1348		7.78
2	1482	1730	1773	19.2		1715	15.7		1485	0		1566	5.66	
3	1610	1960	1926	19.6		1864	15.8		1613	0		1677	4.16	
4	1768	2220	2081	17.7		2013	13.8		1742		1.5	1803	1.98	
5	1866	2500	2266	21.4		2192	17.4		1897	1.7		1940	3.97	
6	2092	2900	2501	19.6		2420	15.7		2095	0		2132	1.91	
7	2116	3100	2615	23.6		2530	19.6		2190	3.5		2229	5.34	
8	2230	3370	2764	24.0		2675	20.0		2315	3.8		2360	5.62	
9	2420	3270	2710	12.0		2622	8.3		2269		6.2	2311		4.51
10	2505	3020	2575	2.8		2490		0.6	2150	14.1		2190		12.55
11	3292	5230	3706	12.6		3586	8.9		3103		5.7	3260		0.97
12	3470	6180	4142	19.3		4007	15.5		3469	0		3715	7.07	
13	4222	6766	4310	2.1		4260	0.9		3685		12.7	4005		5.15
14	5345	9514	5530	3.5		5350	0		4630	13.4		5330		0.28
Total	35860		40349	12.4		39127	9.0		33858		5.7	35866		0

Table showing surface area of infants obtained by different formulas as compared with results obtained by actual measurement.

of a formula that is intended to express the results obtained in general form. The other fourteen are herewith tabulated in a comparative table showing the relative accuracy of the various formulas, namely, Meeh's, Rubner and Heubner's, Lissauer's and the one herein proposed. It will be observed that the gross error for the fourteen cases compares as follows:

	Per cent.
Meeh	12.4
Rubner and Heubner	9.
Lissauer	5.7
Y = mx + b	0.

whereas the individual calculations show less departure from and greater consistency with the observed facts by means of the new formula than with any of the others.

2. The tables also demonstrate that the formula $y = mx + b$ gives trustworthy results for all classes of children, the well- and the poorly-nourished, while the other formulas that have been proposed are not accurate in this respect. Thus Meeh's, and Rubner and Heubner's are fairly satisfactory for well-nourished children, but are very bad for the poorly-nourished; while almost the exact opposite may be said of Lissauer's.

3. By the other formulas it is necessary to take the cube root of the square of the weight of the child, multiplying this by an arbitrary constant, in order to obtain the desired area. In contrast with this, a simple multiplication and one addition are all that is required. A still simpler method of computing is by direct readings from a readily constructed chart, such as the one herewith presented, abscissas representing the weight in grams, and ordinates the desired areas in square centimeters.

4. This formula is constructed from the data at present available and can readily be applied to any future observations that may be made. No elaborate acquaintance with mathematics is necessary for this purpose. Future data may be plotted on this chart, and if it seems desirable to establish another curve to fit the then existing facts, the same can be done at sight and the new constant computed at a moment's notice. It should be mentioned in this connection that many more precise measurements on infants are needed in order satisfactorily to determine the average line. It is expected that with further observations, it will be necessary to alter this line somewhat, but the method of constructing the formula will still be the same and at the present time the formula is the most exact of those that have been proposed.

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