CLINICAL CALORIMETRY

FIFTH PAPER

THE MEASUREMENT OF THE SURFACE AREA OF MAN *

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Recent work on the basal metabolism of infants and adults has revived interest in Rubner's law that heat production in different individuals and species of animals is proportional to the surface area. This law was first definitely formulated by Rubner[1] in 1883, although suggested by Bergman[2] many years before. At the time the experimental work in support of this theory was done no record was kept of body movements and men and animals were allowed to move during the periods of investigation. The average heat production per square meter of body surface was about 1,000 calories per day. In modern work, where the influence of muscular activity is absolutely excluded, the figure is in the neighborhood of 830 calories per square meter per day, as has been shown in Paper 4 of this series. With these new figures it is not unnatural that many investigators have felt that the whole question must be studied anew. Very recently Murlin and Hoobler[3] in New York and Benedict and Talbot[4] in Boston have all concluded that among infants metabolism is more nearly proportional to body weight than to surface area. If this is true for adults, it is a matter of great theoretical and practical importance.

It is obvious that the whole question rests on the accuracy of the determinations of the basal metabolism and of the surface area. The methods of determining the metabolism have been greatly improved, leaving the surface area the doubtful factor. The number of formulas for surface area determination is large, the number of individuals

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1. Rubner: Ueber den Einfluss der Körpergrosse auf Stoff- und Kraftwechsel, Ztschr. f. Biol., 1883, xix, 545.

2. Bergman: Wärmeökonomie der Thiere, Göttingen, 1848, p. 9.

3. Murlin and Hoobler: The Energy Metabolism of Normal and Marasmic Children with Special Reference to the Specific Gravity of the Child's Body, Proc. Soc. Exper. Biol. and Med., 1914, xi, 115.

4. Benedict and Talbot: Studies in the Respiratory Exchange of Infants, Am. Jour. Dis. Child., 1914, viii, 1; The Gaseous Metabolism of Infants, Carnegie Institution of Washington, 1914, Pub. 201.

whose area has been measured is small. In 1879 Meeh[5] finished his painstaking and time-consuming work which has remained the standard ever since. He measured six adults and ten children, using a variety of methods. Some parts of the body were marked out in geometrical patterns, which were then traced on transparent paper. The areas of these were then determined by geometry, or, if the pieces of paper were very irregular, by weighing. Some of the cylindrical parts of the body were wound with strips of millimeter paper like a bandage. Funke[6] in one case covered the skin of a cadaver with adhesive material and pasted over this squares of paper. Fubini and Ronchi[7] measured one man by marking out the anatomical regions of the body and determining the areas geometrically. Bouchard[8] used this same method in measuring a number of adults. He speaks of a plan of clothing the body in tights made of some thin, flexible, inelastic sort of paper, the area of which could be determined by weighing. Apparently, he was not able to find the right material. He mentions the fact that M. Bergonie measured surface area by means of plates of lead, and that M. Roussy used a very ingenious cylinder with a revolution counter which he passed over the whole surface of the body. Bouchard also states that D'Arsonval determined the surface area electrically by clothing the man in silk tights and charging him as one would charge a Leyden jar, calculating the surface by applying a metal plate of known area. Lissauer[9] measured twelve dead babies by covering the skin with colored adhesive material and then applying silk paper and measuring the area of the paper geometrically or with a planimeter.

Meeh[5] as a result of his own measurements, based his formula for determining surface area on the fundamental mathematical law that the surfaces of similar solids are proportional to the ⅔ power of their volumes. Using the body weight to represent volume he determined that the constant 12.312 when multiplied by the cube root of the square of the weight in kilograms gave results which came within 7 per cent. of all his measurements of adults and older children. The constant for infants was 11.9 and for various species of animals still different. Miwa and Stöltzner[10] felt the need of introducing linear measurements

5. Meeh: Oberflächenmessungen des menschlichen Körpers, Ztschr. f. Biol., 1879, xv, 425.

6. Funke: Moleschott's Untersuchungen, z. Naturlehre, 1858, iv, 36.

7. Fubini and Ronchi: Ueber die Perspiration der CO_2 beim Menschen Moleschott's Untersuchungen, z. Naturlehre, 1881, xii.

8. Bouchard, Ch.: Traité de Pathologie générale, Paris, 1900, iii[1], 200, 384.

9. Lissauer, W.: Ueber Oberflächenmessungen an Säuglingen und ihre Bedeutung für den Nahrungsbedarf, Jahrb. f. Kinderh., 1902, lviii, 392.

10. Miwa and Stöltzner: Bestimmung der Körperoberfläche des Menschen, Ztschr. f. Biol., 1898, xxxvi, 314.

and chose the height (L) and the circumference of the chest (U) at the level of the nipples in men and just above the breasts in women, retaining the weight (G) as a factor. Using Meeh's measurements they determined by means of the following formula,

$$\text{Surface} = \frac{K\ UGL}{\sqrt[6]{G^4L^4U^2}} \text{ using an average constant (K) of 4.5335.}$$

This formula, which might have been simplified to $\text{Surface} = K\sqrt[3]{U^2GL}$ has never been much used, although its originators have shown that it comes closer to Meeh's cases than Meeh's own formula. Lissauer from the measurement of babies, almost all of whom were atrophic, retained the principles of Meeh's formula, but found that the constant 10.3 gave better results than the constant 11.9. This indicated that Meeh's figure was about 16 per cent. too high. The formula of Miwa and Stöltzner, according to Lissauer, gave no better results than that of Meeh. Howland and Dana,[11] using the measurements of Meeh and Lissauer, have devised a simple formula in which the surface area (y) of the child equals the weight in grams (x) multiplied by a constant 0.483 (m) plus 730 (b). This is expressed in the terms $y = mx + b$.

Bouchard found a consistent plus error in Meeh's formula as given in Table 1. In his own formula, which requires twenty-five pages of tables for its application, he uses the body weight, the height and the diagonal circumference of the abdomen from the hollow of the back to a point somewhere above the umbilicus according to the degree of obesity. Bouchard states that a measuring tape passed around the abdomen and moved back and forth will of itself find the right circumference, which he calls the "tour de taille." Bouchard's formula has been very little used, as it seems to be difficult to understand and apply.

Recently Dreyer, Ray and Walker[12] have made many measurements of birds and small mammals and have found that the surface area, blood volume, cross sections of the aorta and trachea are all nearly proportional to the ⅔ power of the weight. The formula which applies to all these measurements is $S = k\,W^n$, in which S is the surface, blood volume, etc.; k is a constant which varies with the species; W is the weight, and n is approximately 0.70-0.72 instead of 0.666 which would be the ⅔ power. Benedict and Talbot[4] have suggested that the active mass of protoplasmic tissue develops normally on this ratio. They are convinced that metabolism is determined, not by the body

11. Howland and Dana: A Formula for the Determination of the Surface Area of Infants, Am. Jour. Dis. Child., 1913, vi, 33.

12. Dreyer and Ray: Phil. Trans., 1909-10, cci, Series B, p. 133. Dreyer, Ray and Walker: The Size of the Aorta in Warm-Blooded Animals and its Relationship to Body Weight and to Surface Area, Expressed in a Formula, Proc. Roy. Soc., 1912-1913, lxxxvi, Series B, pp. 39 and 56.

surface, but by the active mass of protoplasmic tissue. If both are assumed proportional to the same thing, it will be a difficult matter to prove which is the more important factor.

As shown in Paper 4 of this series, the metabolism of the normal and pathological subjects studied in the Sage respiration calorimeter in Bellevue Hospital has been expressed in terms of calories per square meter per hour. The work had progressed but a short distance when it was obvious that no formula based on weight could give the surface area of all the patients with any great degree of accuracy. Among the patients studied were men emaciated from typhoid fever and hyperthyroidism, men of normal shape and men with acromegaluy, hypophysial dystrophy and cretinism. Eventually, it is hoped every conceivable shape will be studied. A formula such as Meeh's is accurate only for objects of different size, *but of similar shape.*

TABLE 1.—Determination of Error in Meeh's Formula as Applied to Measured Individuals

Subject	Observer	Weight, Kg.	Surface Area as Measured, Sq. Cm.	Constant for Meeh's Formula, Area Divided by Wt.⅔	Error in Meeh's Formula	Age, Yrs.	Height, Cm.	Body Form
Benny L.	D.B. and D.B.	24.2	8,473	10.13	+21	36	110.3	Cretin. Short and fat.
Hagenlocher	Meeh................	28.30	11,883	12.80	— 4	13.1	137.5	Medium strong.
Very thin woman	Bouchard...........	31.8	12,737	12.69	— 3	...	....	Very thin.
Korner	Meeh................	35.38	14,988	13.17	— 7	15.7	152	Muscular.
Schneck	Meeh................	50.00	17,415	12.96	— 5	36	158	Very thin.
Adult man	Fobini and Ronchi	50.00	16,067	11.84	+ 4	...	....	?
Nagel	Meeh................	51.75	18,158	12.96	— 5	45	160	Somewhat thin.
Fr. Brotbeck ...	Meeh................	55.75	19,206	13.16	— 6	17.7	169	Very strong and muscular.
Naser	Meeh................	59.50	18,695	12.27	+ 0	...	170	Somewhat thin, but well proportioned.
Normal man	Bouchard...........	61.6	18,930	12.13	+ 2	...	....	Normal man.
Fr. Haug	Meeh................	62.25	19,204	12.01	+ 2	26.2	162	Strong.
Morris S.	D.B. and D.B.	64.0	16,720	10.45	+17	21	164.3	Short and rather stout.
R. H. H.	D.B. and D.B.	64.08	18,375	11.49	+ 7	22	178	Tall and thin.
Forstbauer	Meeh................	65.50	20,172	12.48	— 1	66	172	Still very strong.
E. F. D. B.	D.B. and D.B.	74.05	19,000	10.55	+14	32	179.2	Tall, average build.
Normal woman..	Bouchard...........	76.5	19,484	10.81	+14	...	....	Normal woman.
Kehrer	Meeh................	78.25	22,435	12.26	+ 0	36	171	Corpulent.
Large man	Bouchard...........	88.6	21,925	11.03	+12	...	....	Large strong man.
Mrs. McK.	D.B. and D.B.	93.0	18,592	9.06	+36	...	149.7	Very short and very fat.
Very fat man...	Bouchard...........	140.0	24,966	9.26	+33	...	....	Very fat man.

The obvious method for determining surface area is to multiply the length by the average width. An attempt has been made to measure a characteristic length and an average or characteristic circumference of each part of the body and determine the area of the part by multiplying the two and correcting by a constant factor. The sum of the parts will then give the total surface area of the body. When the proper measurements have been selected and the constants for each part determined, it is evident that the method can be applied to individuals of varying shape no matter what disproportion may exist between the different parts of the body.

Fig. 16.—The cretin, Benny L., with mold of his surface area.

INDIVIDUALS MEASURED

The five individuals whose surface area was measured differed from each other in bodily form to a marked degree. All of them had served as the subjects of observations in which the basal metabolism was determined. Benny L. was a cretin 36 years old with the general mental and physical development of a boy of 8. As his photograph (Fig. 16) shows, he was short and stocky, with prominent abdomen, short thick extremities and rather small head. Morris S., 21 years old, was measured three months after he was discharged from the hospital, where he had been confined three and one-half months with a severe attack of typhoid fever. He had recovered even more than his usual weight in the hospital and during the subsequent stay in the country. At the time he was measured he was of well rounded figure, almost stout. He was short and of small frame, with small hands and feet. R. H. H., a chemist, 22 years old, was tall and thin, with long, slim bones, sinewy muscles and very little subcutaneous fat. E. F. D. B., 32 years old, was tall, but of average build. Mrs. McK. was a very short and very fat woman whose metabolism had been studied in great detail by Dr. David

TABLE 2.—Measurements Used in Formula

Index Letter of Part Measured	Benny L.	Morris S.	R. H. H.	E. F. D. B.	Mrs. McK.
A................	57.5	63.9	65.0	67.0	58.0
B................	50.2	54.1	56.6	57.8	56.6
F................	37.2	56.7	65.0	67.3	55.0
G................	20.2	29.5	27.5	32.5	33.0
H................	18.7	24.6	26.0	27.5	27.0
I................	12.8	16.7	16.3	16.2	16.5
J................	13.6	20.0	21.5	20.2	17.0
K................	15.2	20.4	20.5	20.5	17.5
L................	36.6	55.0	55.0	51.5	56.0
M................	62.0	76.2	72.5	77.0	111.0
N................	63.5	87.2	85.8	96.0	100.0
O................	26.4	41.7	47.0	46.3	40.0
P................	35.5	55.5	54.0	59.0	60.0
Q................	61.0	96.0	93.2	96.5	117.0
R................	29.3	41.7	47.0	49.4	36.8
S................	23.7	35.7	33.8	37.0	41.0
T................	17.7	24.8	26.2	28.3	21.5
U................	16.8	22.5	22.2	23.5	19.3
V................	15.7	21.2	21.2	23.5	22.0

Edsall and Dr. James H. Means in Boston. We are greatly indebted to Dr. Means for taking the measurements of this subject and for taking the mold of the surface and sending it to us to be measured.

MEASUREMENTS OF THE BODY

The individual to be measured was undressed, weighed and placed on a flat table with a vertical foot-board about 30 cm. high. All the measurements were made with the subject flat on his back with his feet against the foot-board. A steel tape was used for all the linear measurements and a cloth tape for the circumferences. The measurements actually used are given in Table 2; those not used are given in Table 3 in case other investigators wish to apply different formulas.

THE MOLD OF THE BODY

The method of determining the surface area finally adopted consisted in making a thin mold of the body, cutting this up in pieces which would lie flat, printing the patterns of these pieces on photographic paper (Fig. 17) and finding the area of the printed patterns by cutting them out and weighing them. The subject was dressed in a tight-fitting suit of thin union underwear, which covered the body, arms and legs. Socks were put on the feet, thin cotton gloves on the hands, while over the head and neck was slipped a section of the leg of a knitted undersuit held in place by means of bandages. On this groundwork strips of paper were pasted until a flexible inelastic mold of the

TABLE 3.—Measurements Not Used in Formula

Index Number of Part Measured	Benny L.	Morris S.	R. H. H.	E. F. D. B.	Mrs. McK.
I............	24.2 kg.	64.0 kg.	64.08	74.49	93.0
II............	110.5 cm.	164.3 cm.	178.0	179.2	149.7
III............	88.3	135.5	148.0	147.2	125.0
IV............	81.1	124.6	136.5	135.5	.....
V............	83.6	124.4	139.0	141.2	125.4
VI............	76.5	115.2	130.0	125.5	107.0
VII............	55.7	83.4	94.0	95.7	76.8
VIII............	46.2	72.3	84.5	85.5	60.2
IX............	65.1	83.5	80.7	84.5	92.0
X............	40.0	60.2	81.5	67.5	55.5
XI............	29.6	43.6	48.0	49.0	40.0
XII............	8.2	11.3	.....	11.7	15.8
XIII............	17.0	24.5	27.0	28.0	21.0
XIV............	21.2	33.1	38.5	38.5	32.0
XV............	18.6	27.5	25.3	30.0	30.5
XVI............	17.8	26.0	25.0	29.0	30.0
XVII............	35.5	50.3	48.0	56.5	56.0
XVIII............	23.2	34.7	32.7	37.5	39.0
XIX............	22.6	31.0	31.5	33.5	30.6
XX............	43.2	52.0	48.0	52.5	35.5
XXI............	28.5	38.0	36.0	37.0	34.2
XXII............	74.5	108.0	99.0	107.0	106.0

body was completed. The material used was strong manila paper, about 1½ inches broad, gummed on one side. It is manufactured in large rolls and is used by stores as a substitute for string in doing up small packages and also by some tailors in making models of their customers. For our purposes it was wound in small rolls and placed in a small brass holder which moistened the gummed side as it was applied to the cloth covering the body. It could be applied so quickly that very little

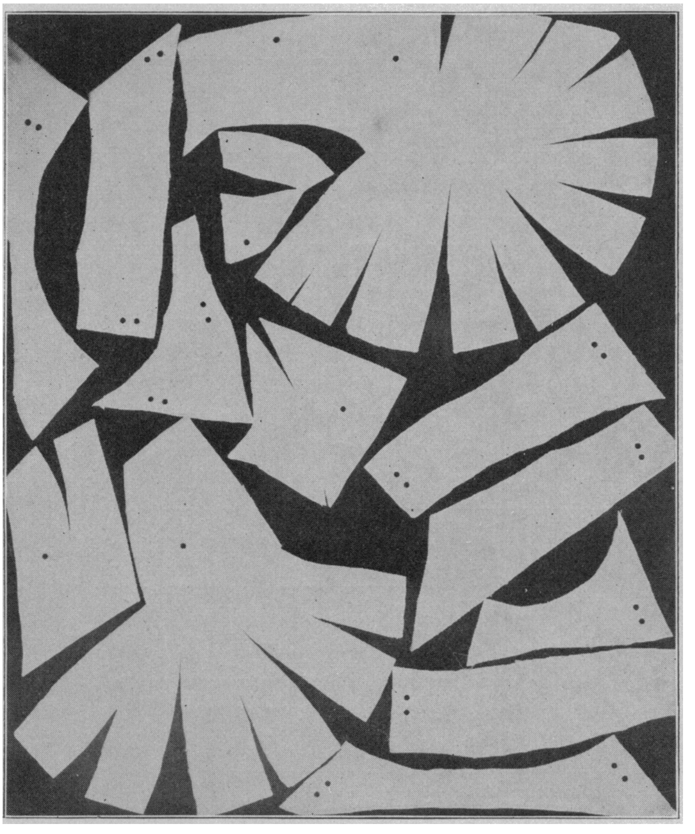

Fig. 17.—Reduced photograph of the patterns printed from the mold of the head and neck of one of the subjects measured. The patterns of the head marked with one punch were cut out and weighed separately from the pieces of the neck marked with two punches. The dark areas were also weighed as control.

time was required to cover the body. The head presented no difficulty until the nose was reached. This region was the last to which the paper was applied and a couple of holes were left for the person to breathe through. The mold of the face was then quickly opened by means of curved bandage scissors. In most cases only one arm and one leg were measured.

TABLE 4.—Comparison of Areas of Parts of Body as Actually Measured and as Calculated from Formulas

Part of Body	Benny L.			Morris S.			R. H. H.			E. F. D. B.			Mrs. McK.		
	Area as Measured, Sq. Cm.	Area as Calculated from Formula, Sq. Cm.	Error in Formula, Per Cent.	Area as Measured, Sq. Cm.	Area ac Calculated from Formula, Sq. Cm.	Error in Formula, Per Cent.	Area as Measured, Sq. Cm.	Area as Calculated from Formula, Sq. Cm.	Error in Formula, Per Cent.	Area as Measured, Sq. Cm.	Area as Calculated from Formula, Sq. Cm.	Error in Formula, Per Cent.	Area as Measured, Sq. Cm.	Area as Calculated from Formula, Sq. Cm.	Error in Formula, Per Cent.
Head.......	900	888	— 1	1,030	1,064	+3	1,173	1,132	—4	1,154	1,192	+4	1,090	1,010	— 7
Arms.......	1,092	1,074	— 2	2,314	2,236	—3	2,524	2,535	+0	2,776	2,865	+3	2,298	2,351	+ 2
Hands......	596	458	—23*	900	905	+1	968	977	+1	876	918	+5	678	660	— 3
Trunk......	3,060	3,229	+ 6	6,304	6,318	+0	6,444	6,121	—5	6,572	6,264	—5	7,746	8,308	+ 7
Thighs......	1,284	1,294	+ 1	3,022	3,207	+6	3,712	3,512	—5	3,820	3,655	—4	3,500	3,594	+ 3
Legs.......	930	973	+ 5	2,000	2,085	+4	2,396	2,225	—7	2,472	2,560	+4	2,156	2,113	— 2
Feet........	611	596	— 3	1,150	1,123	—3	1,158	1,178	+2	1,330	1,378	+4	1,124	920	—18
Total.......	8,473	8,512	+ 0.5	16,720	16,938	+1.3	18,375	17,680	—3.8	19,000	18,832	+0.9	18,592	18,956	+ 2.0

* Benny L. had chronic ulcers on his hands, and the measurement was made with difficulty. The hands of six other individuals were measured and calculated by the formula. The percentage of errors of the calculations in these cases were: —4.0, —1.8, +2.5, —1.8, +2.0 and —2.7.

The hands could not be covered satisfactorily with paper, and hard paraffin was used instead. This was melted and applied to the glove with a brush, soaking well into the meshes of the cotton. The melted paraffin was not too warm for the hands, but was uncomfortable for parts of the body which were not so accustomed to heat. Starch was tried in some instances, but dried too slowly; plaster-of-Paris was too stiff.

Certain portions of the skin were not measured by this mold. The area back of the ears was determined by tracing the back of the ears on a piece of cardboard and correcting by careful measurements. The skin between the toes was measured by tracing. The penis and scrotum were measured and the area determined geometrically. This left unmeasured only very small portions of the face and ears since the mold did not fit closely into the eye-sockets and the concavities of the ear. This error could not have amounted to more than 10 to 20 square centimeters in a total of fifteen thousand.

While the mold was still on the subject the landmarks of the body were located through the paper and the different anatomical regions marked off by drawing the borders on the paper. The mold was then removed with bandage scissors or small probe pointed scissors and the inside of the cloth covered with a thin layer of melted paraffin which, when it hardened, left a material much easier to work with than the cloth and paper alone, since this would not lie flat. Next the mold was cut at the borders of the various regions of the body and each of these regions cut into pieces which would lie flat. These pieces were then marked with a punch for identification and transferred to a large photographic printing frame. After printing in the sun and without developing or fixing, patterns of the pieces of the mold were cut out and weighed to the tenth of a milligram and the blank parts of the sheet weighed as a control. Before this printing each sheet of photographic paper was carefully measured and weighed and the area of each gram of paper determined. By weighing the patterns of each region together it was a simple matter to find the area of that region. A copy of the print made from the mold of the head and neck of one of the subjects is given in Figure 17 showing the method of cutting the paraffined mold so that it would lie flat.

ACCURACY OF METHOD

The accuracy of the procedure was tested in several ways. The bottom of a porcelain evaporating dish was measured twice with a difference of 0.1 per cent. between the two measurements. The surface of the hand of D.D.B. was measured three times, the glove being covered once with starch and on the two other occasions with paraffin.

The square centimeters of surface area as determined on the three occasions were 555.5, 556.0 and 555.5. The right and left sides of the whole body of Benny L. measured separately, agreed within 0.5 per cent.

MEASUREMENTS

The body was divided into the larger regions used by Meeh. An effort was made to select the measurements which represented the length and average breadth of the part. The head region included the ears and the trunk included the neck, the breasts in the female, and the penis and scrotum in the male.

DETERMINATION OF NEW FORMULA

Having measured the surface areas of the different parts of the body and the linear measurements of these parts, the formula to determine the surface area of each part was calculated as follows: the various measurements of length were multiplied by various sums of the measurements representing the width; the resulting figure was divided by the surface area as actually measured. The factors resulting from this calculation in each of the five individuals were compared to determine the percentage variation. That particular combination of length and breadth measurements which showed the smallest variation was chosen and the reciprocal of the average factor for this combination taken as a constant. Fortunately the best results were always obtained by using measurements which were simple. The factors include the multiplication by two necessary to give the area of the right and left arm, hand, etc.

MEASUREMENTS USED IN FORMULA (TABLE 2).

HEAD: AB 0.308.
- A—Around vertex and chin.
- B—Around occiput and forehead, just above eyebrows.

ARMS: F(G + H + 1) 0.558.
- F—Outer end of clavicle to lower border of radius.
- G—Circumference at level of upper border of axilla.
- H—Largest circumference of forearm.
- I—Smallest circumference of wrist.

HANDS: JK 2.22.
- J—Lower posterior border of radius to tip of second finger.
- K—Circumference of open hand.

TRUNK: L(M + N) 0.703.
- L—Suprasternal notch to upper border of pubes.
- M—Circumference of abdomen at level of umbilicus.
- N—Circumference of thorax at level of nipples in the male, and just above breasts in the female.

THIGHS: O(P + Q) 0.508.
- O—Superior border of the great trochanter to the lower border of the patella.
- P—Circumference of thigh just below the level of the perineum.
- Q—Circumference of hips and buttocks at level of trochanters.

LEGS: *RS* 1.40.

R—From sole of foot to lower border of patella.

S—Circumference at level of lower border of patella.

FEET: T(U + V) 1.04.

T—Length of Foot.

U—Circumference of foot at base of little toe.

V—Smallest circumference of ankle.

MEASUREMENTS NOT USED IN FORMULA (TABLE 3)

I—Weight.

II—Height.

III—Sole of foot to suprasternal notch.

IV—Sole of foot to level of nipples.

V—Sole of foot to upper border of axilla.

VI—Sole of foot to tip of ensiform process.

VII—Sole of foot to superior border of great trochanter.

VIII—Sole of foot to perineum.

IX—Circumference of body at level of tip of ensiform.

X—Tip of second finger to upper border of axilla.

XI—Tip of second finger to tip of olecranon process.

XII—Tip of second finger to metacarpo-phalangeal joint.

XIII—Tip of olecranon to lower border of radius.

XIV—Tip of olecranon to outer end of clavicle.

XV—Circumference of arm at the insertion of the deltoid.

XVI—Circumference of arm at belly of biceps.

XVII—Circumference of thigh half way between anterior superior spine of the ilium and the lower border of the patella.

XVIII—Largest circumference of calf.

XIX—Circumference of foot around heel.

XX—From back of neck around superior maxilla just below ears and nose.

XXI—Around neck just below larynx.

XXII—Around shoulders at level of heads of humeri.

BORDERS OF REGIONS OF BODY:

Head: Lower margin of the mandible to its posterior border, thence to tip of the mastoid process and in a straight line to the external occipital protuberance.

Arm: From the acromion process anteriorly and posteriorly to the upper border of the axilla.

Hand: Line at right angles to long axis of forearm drawn at level of tip of ulna.

Thigh: From the perineal point going posteriorly in the natal fold to the upper border of the great trochanter, thence medially in a straight line to the perineal point.

Leg: Line at level of lower border of patella.

Foot: Line at level of tip of lateral malleolus.

DISCUSSION OF RESULTS

Table 1 shows that the constant employed by Meeh has not been confirmed by subsequent observers. It gives results which are too high in every case except one very thin woman. Lissauer found Meeh's figure for infants 16 per cent. too high. Bouchard in four of his five cases found it from 2 to 33 per cent. too high, while in our five cases we have found it from 7 to 36 per cent. too high. The majority of Meeh's subjects seem to have been thin, and the error of the formula is very great in fat individuals. One can perhaps obtain fairly accurate results in using Meeh's formula if one retains the factor of 12.3 for thin subjects, 11 to 12 for people of average build, 10 to 11 for the moderately stout and 9 to 10 for the very fat. Possibly at some later date a more accurate factor can be determined by the relationship of weight to height, retaining Meeh's fundamental principle of the ⅔ power of the weight.

Miwa and Stöltzner's formula gives results only slightly better than Meeh's. The errors in calculated areas of our five subjects using their formula are as follows: Benny L. + 18 per cent., Morris S. + 17 per cent., R. H. H. + 8 per cent., E. F. D.B. + 18.5 per cent., Mrs. McK. + 26.5 per cent. If the constant of 3.84 were used instead of 4.5335 the results would be much better for this series.

The series of five individuals measured by us is perhaps too small to determine factors which will remain unaltered by subsequent research, but it is doubtful if the changes will be of significance. The range of body shape among our subjects was, however, very great, and the error of the factors comparatively small. The principle of the method has been demonstrated to be sound. Unfortunately, it involves the taking of nineteen measurements, a matter of perhaps fifteen minutes time. Subsequent investigation may reduce the number, but it is difficult to see how one can avoid measuring each part of the body if one wishes to obtain accurate results on people whose shapes do not correspond closely to the average.

In any discussion as to whether metabolism is proportional to body weight or to surface area it is essential to apply a method of measuring the surface which does not depend entirely on weight. The key to the question may perhaps be found in those individuals whose surface area is not proportional to the ⅔ power of their weight, multiplied by a constant determined by measurements of average individuals.

SUMMARY AND CONCLUSIONS

The discussion of the relationship of metabolism to surface area has been based almost entirely on Meeh's formula as determined in 1879. Subsequent observers have found a consistent plus error in this formula amounting to as much as 36 per cent. in the case of very fat individuals.

The surface area of the various parts of the body can be determined as follows: A mold of the surface is made by pasting paper over tight-fitting underwear. The area of the mold is then determined by cutting it in pieces, printing a pattern on photographic paper, cutting out the pieces of the pattern and weighing them.

To determine the area of each part of the body by linear measurements alone a formula has been devised on the principle of length times the average breadth times a constant. The sum of these parts gives the total surface area of the body.

Five individuals of widely varying shapes have been measured and the surface area as calculated from the formulas compared with the surface area as actually measured. In the five cases the average error was 1.7 per cent.

In discussing the question as to whether the basal metabolism is proportional to surface area or to weight it is preferable to determine the surface area by a formula which is not of necessity a function of the weight.

Note.—Since this article was submitted for publication the formula has been tested on a tall and exceedingly thin boy, 18 years old. This patient, Gerald S., came to the hospital much emaciated from diabetes and was kept for eleven days practically without food, receiving only whisky. The mold of the body was taken on Dec. 1, 1914, shortly after his fast. At this time he weighed 45.25 kg. His surface area according to Meeh's formula was 1.563 square meters. The mold was kindly measured for us by Miss Margaret Sawyer who obtained the following figures:

	Actual Area as Measured sq. cm.	Area as Calculated from Formula sq. cm.	Error in Formula Per Cent.
Head	950	978	+ 3
Arms	2,052	2,047	— 0
Hands	847	875	— 0
Thighs	3,002	2,677	—11
Trunk	5,003	4,158	—17
Legs	1,876	2,144	+14
Feet	1,042	1,055	+ 1
Totals	14,801	13,934	— 5.8