Geometric method for measuring body surface area: A height-weight formula validated in infants, children, and adults

Estimates of body surface area were made based on measurement of 81 subjects, ranging from premature infants to adults. SA was calculated geometrically for each subject from 34 body measurements, and the values obtained compared with those based on previously published formulas and graphs. The most widely used formula, that of Du Bois and Du Bois, increasingly underestimated SA as values fell below 0.7 m²; the disparity was greatest in the newborn infant (7.96%). Closer agreement was obtained with the equations and nomograms of Body, Brody, Faber and Melcher, and Sendroy and Cecchini, although minor deviations were noted in some age ranges. The formula $SA\ (m^2) = weight\ (kg)^{0.5378} \times height\ (cm)^{0.3964} \times 0.024265$*, derived from the measured data by multiple regression analysis, gave a good fit for all values of SA from less than 0.2 m² to greater than 2.0 m² (r = 0.998). This formula was used to construct nomograms for estimation of SA in infants, children, and adults from height (length) and weight.*

George B. Haycock, M.B., B.Chir., M.R.C.P., George J. Schwartz, M.D.,* and David H. Wisotsky, M.D., *Bronx, N. Y.*

ESTIMATES of body surface area are widely used in physiology and clinical medicine to normalize measures of biologic function with respect to variations in body size and conformation. For example, results of metabolic and renal function tests are conventionally expressed per unit SA, and fluid and drug requirements are frequently calculated in the same manner. The formula of Du Bois and Du Bois[1] is in widespread use in computing estimates of SA from height and weight, usually by means of the nomograms derived from it by other workers.[2-5] Although the Du Bois formula was meticulously validated by its originators for adults,[1, 6] using a laborious but very accurate method for the direct measurement of SA, only one child was included in the study group, a severely undernourished girl who weighed only 6.27 kg at 21 months of age. Aware of this deficiency, Boyd[7] re-examined the problem and devised a more complicated formula which has received considerable exposure in the form of a nomogram published by Hill[5] and reproduced in a major textbook of pediatrics.[8] Other, generally less well known, equations and graphs have been put forward by other workers.[10, 11] These formulas do not yield identical estimates of SA from the same H/W measurements, the divergence of values being quite large in some instances[7, 11]; arguments offered by various authors to establish their respective superiority appear inconclusive. We made further measurements of SA by a method

Abbreviations used	
SA:	surface area
H:	height
W:	weight
BMHC:	Bronx Municipal Hospital Center
AECOM:	Albert Einstein College of Medicine

From the Department of Pediatrics, Albert Einstein College of Medicine, and Bronx Municipal Hospital Center.

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Table I. Measurements taken for calculation of body surface area and volume

Body part	*Length*	*Circumference*	*Analogue**
Head	–	Occipitofrontal	1
Neck	Angle of mandible–sternomanubrial joint	Midpoint	2
Trunk	Sternomanubrial joint–intertrochanteric line	Mean of nipple, umbilical, and intertrochanteric	3
Upper arm	Acromion–olecranon	Midpoint	2
Lower arm	Olecranon–tip of 4th metacarpal	Midpoint	2
Index finger	Tip of 2nd metacarpal–fingertip	Middle phalanx	3
Thigh	Greater trochanter–head of fibula	Midpoint	2
Lower leg	Head of fibula–lateral malleolus	Mean of calf and ankle	2
Foot	Calcaneum–tip of 4th toe	Midpoint	3

*Each section of the body was taken to correspond to one of the following geometric analogues for the purpose of surface area calculation: (1) a sphere minus the cross-sectional area of the neck; (2) a cylinder of which only the curved surface is interpreted as contributing to body surface area, both ends being in contact with adjacent segments; and (3) a cylinder of which the curved surface and the area of one end are incorporated. Some of the measurements, particularly of circumference, may appear arbitrary; however, preliminary trials indicated that they agree well with more elaborate methods involving multiple measures of each component. The area of one index finger, multiplied by ten, agrees closely with the sum of ten individual finger and thumb measurements. Measurements were taken with a nonelastic tape measure with the subject erect or supine, knees, and elbows straight.

described in the text, in order to add to the existing stock of data, and analyzed the relationship of measured SA to H and W, the resulting formula and nomogram being compared with earlier ones.

SUBJECTS AND METHODS

The individuals studied consisted of: (1) infants in the newborn nurseries and Neonatal Intensive Care Unit of the Bronx Municipal Hospital Center, (2) infants and children in the pediatric wards and clinics of the hospital of the Albert Einstein College of Medicine and BMHC, (3) children undergoing renal function studies in the Pediatric Renal Function Study Unit of the AECOM, and (4) members of the medical and secretarial staffs of the above hospitals. All subjects were of grossly normal bodily structure, but the sample included individuals of widely varying physique, ranging from very thin to obese. Black, Hispanic, and white children were included.

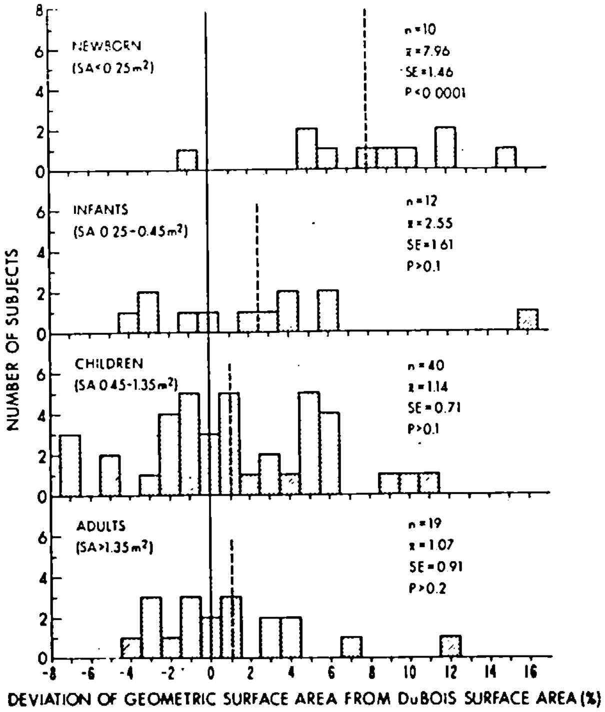

Fig. 1. Distribution of individual deviations of geometrically determined surface area from Du Bois surface area, shown as a histogram for each of four subgroups of the sample, expressed as (SA [geometric] – SA [Du Bois])/SA (Du Bois) × 100. Vertical interrupted lines represent the mean deviation for each group.

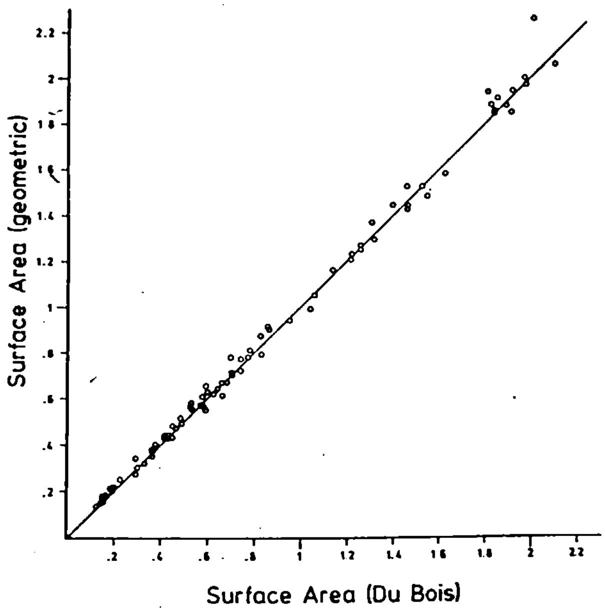

Fig. 2. Correlation of surface area calculated by the geometric method with that predicted by the formula based on the data presented: $SA = weight\ (kg)^{0.5378} \times height\ (cm)^{0.3964} \times 0.024265$. The line of identity is drawn; it is visually indistinguishable from the calculated regression line. $y = 1.006x - 0.0028$; $r = 0.998$; $n = 81$.

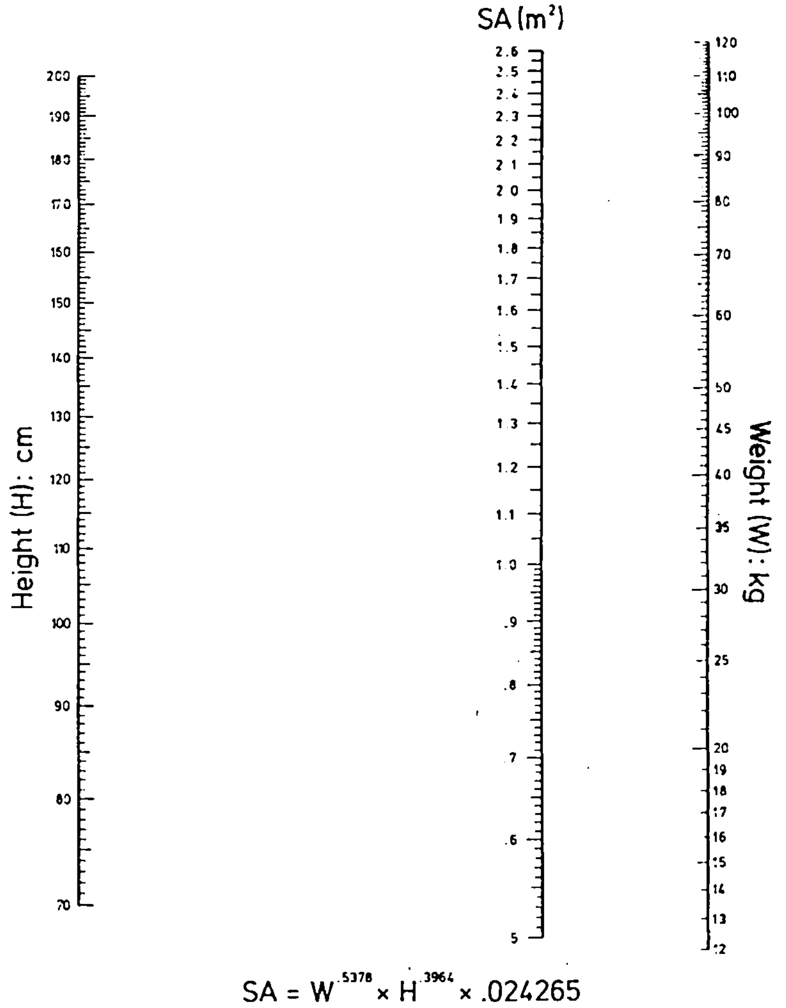

Fig. 3. Nomogram representing the relationship between height, weight, and surface area in children and adults. To use the nomogram, a ruler is aligned with the height and weight on the two lateral axes. The point at which the center line is intersected gives the corresponding value for surface area.

Surface area was calculated by means of a geometric method, in which the body and limbs were schemetically reduced to a set of cylinders, the head being represented by a sphere. The length and circumference of each component were measured, and the SA and volume calculated. These moieties were added to give an estimate of total body SA and volume; the area of overlapping portions of adjacent cylinders was subtracted. For tapering or nonuniform "cylinders," the mean of specified circumferential measurements was used. Calculations were performed using an Olivetti Programma 101 desktop computer. Details of the measuring scheme are described in Table I.

The validity of the method was tested in three ways. (1) The geometric SA values for our adult subjects were compared with those predicted by the Du Bois H/W formula. Infants and young children, having less subtle molding of limbs and torso, resemble more closely than adults a model composed of cylinders and a sphere; the geometric method would therefore be expected to give at least as accurate an estimate of SA as in adults, and probably better. (2) Body weight was divided by computed volume to give an estimate of mean body density, which was compared with published values for density obtained by Archimedes' principle. (3) The geometric estimate of SA for infants was compared with that obtained by Faber and Melcher[12] using the linear method of Sawyer and associates,[13] which has been shown to give excellent agreement with Du Bois' laborious mold methods.[6]

RESULTS

Measured values of SA were compared with those obtained using the Du Bois and Boyd formulas by the

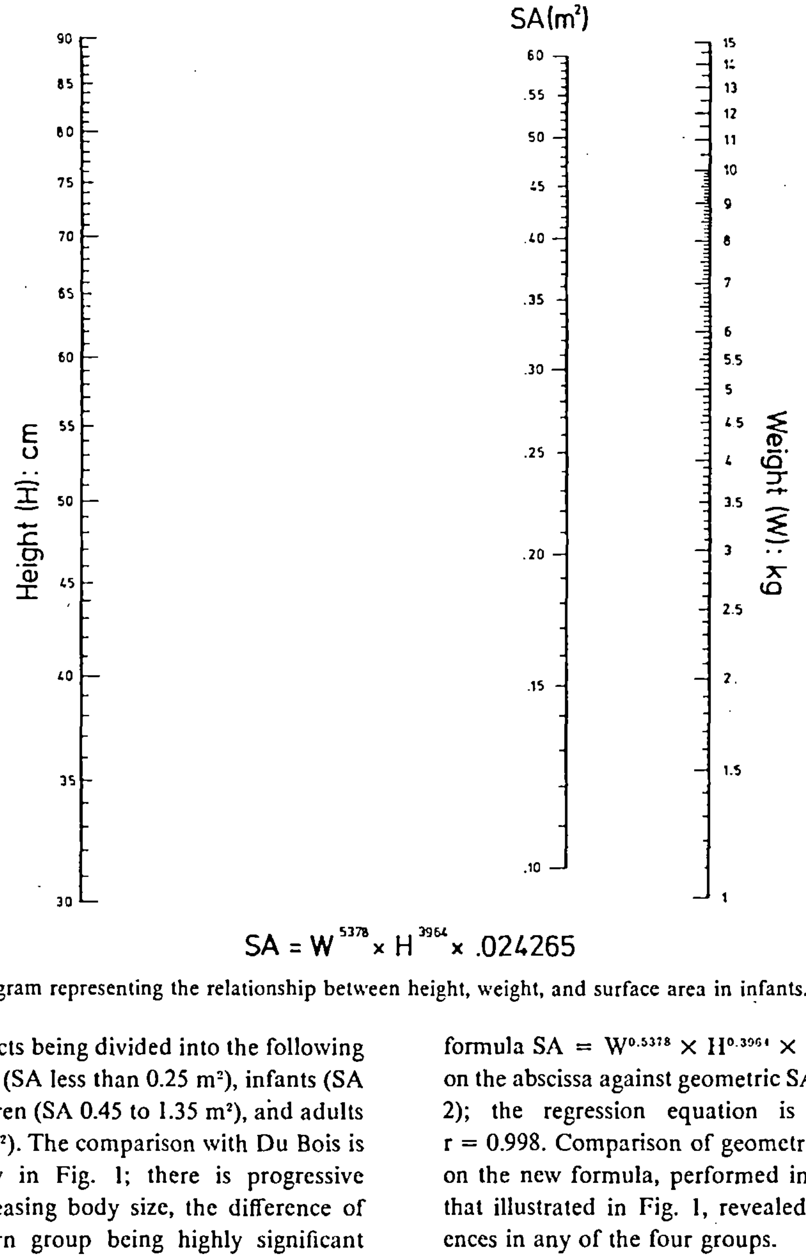

Fig. 4. Nomogram representing the relationship between height, weight, and surface area in infants. Use as Fig. 3.

paired t test, the subjects being divided into the following four groups: neonates (SA less than 0.25 m^2), infants (SA 0.25 to 0.45 m^2), children (SA 0.45 to 1.35 m^2), and adults (SA more than 1.35 m^2). The comparison with Du Bois is illustrated graphically in Fig. 1; there is progressive divergence with decreasing body size, the difference of 7.96% in the newborn group being highly significant ($P < 0.001$, 2-tailed test). The Boyd formula gave better agreement, and the differences of 1.5% in the children and 5.77% in the infants, though statistically significant, are probably too small to be of practical importance.

The relationship between H and W, on the one hand, and SA on the other, was therefore solved for our data by multiple regression analysis.[14] H and W were taken as the independent variables, SA as the dependent; the relationship was analyzed in the form SA = x log W + y log H + log z (equivalent to $SA = W^x \times H^y \times z$). The least squares best fit for this equation yielded the follwing values for the three coefficients: x = 0.5378, y = 0.3964, z = 0.024265. Extimates of SA based on the resulting formula $SA = W^{0.5378} \times H^{0.3964} \times 0.024265$ were plotted on the abscissa against geometric SA on the ordinate (Fig. 2); the regression equation is $y = 1.006x - 0.0028$; $r = 0.998$. Comparison of geometric SA with that based on the new formula, performed in the same manner as that illustrated in Fig. 1, revealed no significant differences in any of the four groups.

The mean body density, calculated as described above, was 0.999 ± 0.016 (SE) for the newborn infants and 1.059 ± 0.008 for all other subjects.

DISCUSSION

Many measurable processes, particularly those involving interchanges of matter and energy with the environment, take place across surfaces which might be expected to vary as a function of the square of body length. Such interchanges include absorption of nutrients from the gut, radiative energy loss from the body surface, pulmonary gas exchange, and glomerular filtration. SA, which bears the same relationship to H and W as these surfaces (being itself one of them), might be expected on theoretical grounds to be correlated with functions of this general class. Despite alternative suggestions,[15-17] practical experience suggests that this is so, and SA is widely used in both clinical and experimental physiology as a standard of reference. The "surface law" has been well documented for heat production and metabolic rate; the historical evidence is reviewed by Brody.[10]

It is therefore desirable that any method of estimating SA should be shown to be accurate. This requirement has been rigorously fulfilled for the Du Bois formula with respect to adults, but not for infants and small children. Our results support the conclusions of Faber and Melcher,[12] Boyd,[7] and others[10, 11] that the Du Bois formula underestimates SA in small infants by about 8%.

Two other proposed solutions to this problem merit further discussion. Sendroy and Cecchini[11] constructed a chart using a partly graphic and partly mathematical method. This rectangular nomogram gives values close to those obtained from our formula, but the form of the nomogram makes it more difficult to use than that presented here, in that alignment in two dimensions is necessary. An additional limitation of this method is that it cannot be expressed in algebraic form, which makes it unsuitable for such applications as the computerized processing of laboratory data. Brody, in his comprehensive book *Bioenergetics and Growth*,[10] presents a formula almost identical with ours—SA $(cm^2) = 240 \times H (cm)^{0.4} \times W (gm)^{0.53}$—which was arrived at by a process of trial and error. A nomogram is presented but this also suffers from the disadvantage of being rectangular in form, although the provision of a grid makes it easier to use than that of Sendroy and Cecchini.

The density of the human body ranges from 0.98 to 1.13[18]; infants tend to occupy the lower part of this range,[19] whereas older children and adults are denser.[20] The mean values calculated from our measurements (0.999 for neonates, 1.059 for older children and adults) are therefore in accord with those obtained by more direct methods, which lends credence to the validity of our technique.

The results we have obtained are in fairly close agreement with those of Boyd,[7] Brody,[10] Faber and Melcher,[12] and Sendroy and Cecchini[11]; since several different methods of measurements were used in these studies, the overall concordance is evidence against the existence of a systematic methodologic artifact. The Du Bois formula, on the other hand, is inaccurate when applied to infants and young children, and should not be used in this age group. The nomograms (Figs. 3 and 4) based on our data, and derived from the formula SA $(m^2) = W (kg)^{0.5378} \times H (cm)^{0.3964} \times 0.024265$, are suitable for routine use.

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