*Photogrammetric Determination of Surface Area**

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THE concept of body surface area as a correlate of metabolism and as a basis for parenteral fluid dosage has been severely criticised (Best '54, Oliver *et al.* '58, Royce '58, Durnin '59, Forbes '59), partially on the basis that the methods for calculating surface area are not accurate. Body surface area is most commonly derived from height and weight by the use of nomograms based on the 1916 equations of Du Bois and Du Bois. These were derived from the measurements of only twelve patients, of whom three were malnourished, two had had both legs amputated, one was a 36-year-old male cretin with the physical development of an eight-year-old child, and only three could be said to have approximated normal body build (Du Bois and Du Bois '15, Sawyer *et al.* '16). Twenty-three subsequent investigators have published 37 additional formulae, based on various dimensions of the human subject, for estimating surface area (Oliver *et al.* '58). None of these has been demonstrated to yield an accurate measurement.

The usual method of validating techniques for measuring surface area is by reference to regular geometric objects (Boyd '35). Roussey ('99) determined the accuracy of a surface integrator by measuring a flat cardboard sheet, which was later rolled into a cylinder and then a truncated cone. Others have used twisted metal plates (Bergonie and Sigalas '98, Bordier '01, Berner '54), wooden cylinders (Meeh '79), small rubber balls (Takahira '25), and bowling balls (Sawyer *et al.* '16, Cowgill and Drabkin '27, Boyd and Scammon '27). The results of these validation studies indicate that when surface area is estimated by the various linear methods or height/weight formulae, errors of ± 10 per cent may be expected (Bradfield '27, Boyd '35); when it is calculated from coating methods, surface integration, or triangulation, errors of less than ± 3 per cent result (Boyd '35).

The earliest applications of photogrammetry to area determination were made by Roussey ('07), who found that the surface area of a mannequin as measured from photographic silhouettes was within one 1/100 to one 1,180 of the area as measured by a coating technique, and by Benedict ('16), who determined that results obtained by this method differed by 1.6 per cent from those obtained by use of the Du Bois ('15) linear formula.

Weinbach ('38) presented a method of determining body volume, surface area, and center of gravity from measurements of side and front-view photographs. The underlying assumption is that serial horizontal sections through the body are elliptical, and the areas and perimeters of these ellipses can be calculated by measuring their axes on the photographs. Surface area is estimated by multiplying the perimeters by the distance between ellipses. He made no comparisons with objects of known area, simply presenting the technique without offering any validation. The technique developed by Geoghegan ('53) assumes that the body may be divided into a series of levels, and the area between them may be considered as approximating sections of right cones. Twelve photographs were taken of each subject, and the similarity of the postures to those of the Hindu god Shiva led to the naming of the system "Shivan." Geoghegan compared his results with those obtained from formulae 1 and 2 which he attributed to "Wenbach," formulae 1 and 2 of Boyd, and the equation of Du Bois and Du Bois ('16a). When his data were subjected to statistical analysis by the present writer, it was found that the results obtained by use of the Shivan technique correlate highly with those obtained from the formulae in question ($r = .87$, .86, .96, .99, and .92 respectively).

Recently the use of stereophotogrammetry as a means of measuring surface area has received attention. Berner ('54) employed a profiling technique to calculate the surface areas of eight subjects. He found his results differed by 35 per cent from those obtained by use of Meeh's formula, and by -8 to $+2.5$

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per cent from those obtained by the Du Bois formula. He validated the technique by reference to a metal plate of known area which had been twisted. The area as determined by the photogrammetric method was 1.3 per cent less than the correct measurement. However, it appears that the test plate was bent along one axis only and the error might have been greater had a rounded surface been used. The error for rounded surfaces must be determined if a technique is to be accepted as valid for the measurement of such areas of the human body as the head, shoulders, and buttocks.

Hertzberg *et al.* ('57) presented a contour map of a male subject and suggested a means of surface area calculation based on profiles drawn from this map. They state, " . . . from subsequent work we have found that the measurements of total body volume and the volumes of individual body segments very closely approximate those calculated by the Du Bois formula (Du Bois and Du Bois '16). In addition, we have been able recently to determine the surface area of various body parts with a high degree of accuracy." An evaluation of these statements is difficult: no data are presented, the magnitude of correlation is not stated, and the method of determining the degree of accuracy is not given. Furthermore, the cited Du Bois formula ('16b) is a means of predicting total body surface area from height and weight, and does not purport to measure body volume. However, it is feasible to determine both volume and surface area by photogrammetric techniques (Pierson '57, '59).

From the above review of the literature it appears that three methods have been utilized for areal determination from photographs: (1) direct measurements of photographic silhouettes; (2) measurements taken from photographs and used as factors in a geometric analysis; and (3) horizontal profiling by stereophotogrammetry. Only in the studies of Roussey ('07, '11) and Berner ('54) has the validation been by reference to direct measurements, and, although the latter achieved a perhaps spuriously high correlation with the test object, the correlations with formulae indicate that either the profile method, or the formulae, or both, are unsuitable for accurate estimation of human body surface area. Investigators who have validated their techniques by comparison with formulae which in themselves have an error of ± 10 per cent cannot expect that their validity coefficient can be more accurate than that of the criterion. Furthermore, if the results obtained by photogrammetry closely approximate those obtained by height/weight formulae there is little need for the expensive and time-consuming photogrammetry. In this respect, it may properly be said that photogrammetry validates the formulae. It was the purpose of the present study to determine the limits of accuracy of the stereophotogrammetric method.

Material and Methods

A contour map of one-half of a spheroid was constructed by means of standard topographic photogrammetric procedures. Details of the construction have been reported previously (Pierson '59). The spheroid was then separated into eight segments. These were cut to lie flat, and their areas were measured with a LASICO Model 1100 CP rolling planimeter. Five readings of each segment were taken. The average deviation for each reading was .35 cm.^{2}, and the mean of the five readings was used to compute the total surface area of each segment. The figure thus derived was compared with those obtained through geometry, profiling, and a technique devised by the author which was suggested by the slope analysis studies of Hanson-Lowe ('35) and Debenham ('37). The contour lengths were measured with a Cutiecut map measurer to the nearest quarter-inch. These were considered as the circumferences of circles with a common center. Average slope length between each two contours was calculated by the Pythagorean theorem, with the contour interval taken as the *height* and the difference in radii of the assumed circles as the *base*. The surface area between each set of contours was then calculated by the formula $A=(h\cdot a)+h(b-a)$ where a = circumference of the upper contour, b = circumference of the lower contour and h = average slope length. The formula for the area of a right sphere was used to calculate the area of the "top" of the spheroid. The mean of five readings for each of the following was used in the various computations: diameter of the spheroid, diameter of the map, diameter of the area encompassed by each contour, and length of each contour. In addition, profiles were constructed at quarter-inch intervals and their perimeters measured.

Results

As measured with the planimeter, the surface area of the test object was 267.28 in^2. However, since the contour map protrays only half of the test object, 133.65 in^2 was used for comparative purposes. The results of

TABLE I

MEASUREMENT AND CALCULATION OF DIAMETER AND SURFACE AREA OF A TEST SPHEROID

Method	*Diameter (In inches)*	*Surface Area (In square inches)*	*Error (Per cent)*
Geometry			
(1) Caliper measurement of diameter	9.44	140.02	04.56
(2) Map measurement of diameter	9.41	139.01	03.87
(3) Diameter calculated from zero contour perimeter	9.39	138.54	03.54
Photogrammetry			
(1) Profiling		115.66	13.34
(2) Perimeter of contour multiplied by distance between contours		138.87	03.77
(3) Slope analysis		134.46	00.61
Planimetry		133.64	Criterion

the measurements and calculations are presented as Table I.

DISCUSSION

The geometric techniques cited in Table I are roughly comparable to those of Weidenfeld ('02), Roussey ('07, '11), and Geoghegan ('53) respectively. The profiling technique was that suggested by Hertzberg *et al.* ('57) and was similiar to the one employed by Berner (54). The results of the second photogrammetric technique may be compared to those of Roussey ('11) and Weinbach ('38). Slope analysis was the technique developed for the present study.

With the exception of the profiling technique, photogrammetric analyses of surface area have assumed that the human body can be segmented into smooth geometric figures. However, there are few areas of the body for which this assumption is valid; humans, especially those with a high degree of endomorphy, have wrinkles, protuberances, and hollows. The profiling technique results in an accurate portrayal of the object from a "side view" but the "end view" is a series of steps, each as wide as the distance between profiles. While this is of little consequence for objects with a curvature perpendicular to the axis of the profiles, the results of the present study indicate that profiling is not an accurate technique for determining the surface area of objects whose curvature is parallel to the profile axis, as is characteristic of the human body. The inherent error in the technique developed for the present study lies in the assumption that the slope between contours is a plane surface. It cannot be assumed that the human body has as many protuberances as hollows and that the errors will therefore cancel each other. However, the use of supplemental contours on areas of slight gradient can minimize these errors.

SUMMARY

The common method of validating formulae for human surface area has been by reference to geometric objects of known surface area. The formula method is accurate to only ± 10 per cent, yet present photogrammetric techniques have used these formulae as validation criteria. In the present study, an object of known surface area was subjected to analyses by several geometric and photogrammetric techniques for surface area determination. The surface area as calculated by these techniques varied from the criterion measurement by 03.5 to 13.3 per cent. A technique was presented which resulted in measurements differing from the criterion by 00.6 per cent.

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*Diapositives for Today's Photogrammetry**

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(*Abstract is on following page*)

BECAUSE diapositive requirements vary with altitude, terrain, and type of stereoplotter, discussion in this paper will be limited first, to projection-type stereoplotters, and second, to low-altitude, large-scale photography.

As changes are made from medium to low-altitude photography, the photogrammetrist is faced with several problems which previously were of only minor concern. These are:

1. An increase in the brightness ratio of the photographic situation. This tends to produce unusually contrasty negatives.
2. Contour intervals sufficiently small to be affected by normal ground cover.
3. Compilation scales large enough to require that several contours be placed within a single shadow or highlight area.
4. An increase in the number of contours concealed by "hidden ground."

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