THE DETERMINATION OF BODY SURFACE AREA*

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Surface area of the human body is a measure that is used extensively in physiology to express basal metabolic rate, oxygen consumption, cardiac output, glomerular filtration rate, drug usage, heat loss and vital capacity, and to determine average skin temperature and the area affected by severe burns. Although a great number of time-consuming and ingenious methods have been used in the past, there existed no simple, readily applicable method for measuring the true surface area of the body. The reason for this situation is the irregular, elastic and curved surface of the human skin.

The first published attempt to measure body surface area is generally attributed to Abernethy (1793),[1] although Leeuwenhoek (1719)[2] in his study of the number of pores in the skin probably was the first to estimate the surface area of the human body. Since then numerous methods of direct measurement have been employed and various formulae arrived at, in attempts to find an accurate and simple way of making this measurement.

All such methods fall into 3 main categories (Boyd):[3] (*a*) Methods of measurement in which the extent of the skin surface is converted into a plane surface; (*b*) methods of estimation based on the similarity of parts of the body to regular geometric solids having the same lengths and circumferences, and (*c*) methods of calculation based on the general assumption that the surface area of the more or less similar human bodies have an approximately constant relation to the other major bodily dimensions, especially weight and height.

Because of the technical difficulties associated with the first 2 methods, most workers have measured or estimated the surface area of only a limited number of subjects and subsequently applied the resulting determinations to obtain regression equations which were then used to calculate the surface area for a larger number of subjects.

Recently a new method of measuring the radiation surface area of the human body was developed by the CSIR[4] and is at present in use at the Human Sciences Laboratory. This method is based on the principle that the absorption of light by a black body bears a linear relationship to its surface area. However, since it measures only the radiation area of the black body (which is ±95% of the true geometrical area),[5-7] a correction factor has to be applied to convert the radiation area into true physical area. Determination of this correction factor forms the main objective of this study.

The true geometrical area of the human body is the area of the external interface between the body and its environment, assuming that this interface is smooth. This area is dependent on posture, muscle tone, state of stretch of the skin, state of hydration and other factors. That area of the body which is available for exchanging radiation with the environment is described as the radiation surface area. This naturally depends on the posture assumed.

In order to assess the accuracy of the new method and its necessary correction factor, comparisons were made with results obtained with the coating method (which is still accepted as the most reliable approach)[8] and with estimates obtained from both the extensively used Du Bois formulae.[9,10] The results from all these methods were analysed to establish the relationship they bear to the true geometrical surface area.

METHODS

Determination of surface area by all available major techniques was undertaken in order to establish their mutual relationship.

The Coating Method

The main requirement when a subject is coated is to affix the tape flat and smooth onto the skin and to remove this mould without altering the area. This operation requires practice and skill.

Different types of adhesive tape were tested to determine their suitability for coating the human skin. These included gummed paper-strips, cellophane tape and masking tape.

Then 16 subjects—6 White, 9 Bantu and 1 Bushman—were coated. The body was coated in sections: first the arms, then the legs and the trunk, and finally the head and neck. The anatomical borders were as follows:

The arms: From the postaxillary fold, across the back of the root of the upper limb, to the lateral edge of the acromion, and from the inframedial end of the posterior axillary fold, across the front of the root of the upper limb, to the lateral edge of the acromion.

The legs: A horizontal line corresponding to the circumference of the thigh just below the level of the perineum.

The head and neck: From the superior border of the manubrium sterni, along the clavicle, laterally to the acromion, and then in a straight horizontal line around the back of the neck to the opposite acromion.

Masking tape of $\frac{1}{4}$-in., $\frac{1}{2}$-in., 1-in. and 2-in. width and of different lengths was used. Care was taken that the tape always followed the natural curvature of the area and that it was not applied too loosely or too tightly.

While being coated, a particular area was maintained in the same position in order to keep the surface as uniform as possible. The arms, legs, head and neck were coated with the subject in a supine position, the back with the subject lying on his stomach, and the chest and the abdomen while the subject lay on his back. The uncovered areas on either side of the trunk were then coated while the subject stood erect, thereby joining the front and back portions.

The tape was applied directly to the skin. The adhesive surface was placed in contact with the skin except for an initial longitudinal strip, which was placed with the non-adhesive surface against the skin to facilitate subsequent removal. Strips were arranged longitudinally, transversely and obliquely until the whole area was covered. Although certain parts were thus covered by two or even three overlapping layers, nothing was left uncovered.

To remove the mould the upturned strip of tape was

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located and a single longitudinal incision was made from the distal to the proximal end. Great care was taken not to distort the mould by applying too much traction force during the process of removal. The cast was cut into flat square strips (not more than 400 sq.cm.) to allow for complete flattening, and these squares were then painted black on the adhesive sides with a water-stainer black paint.

Subsequently the surface area of the mould was determined by a photometric method (instead of the Du Bois photographic method) as follows:

In principle the apparatus (Fig. 1) measures the intensity of light reflected from a surface. A sheet of white paper

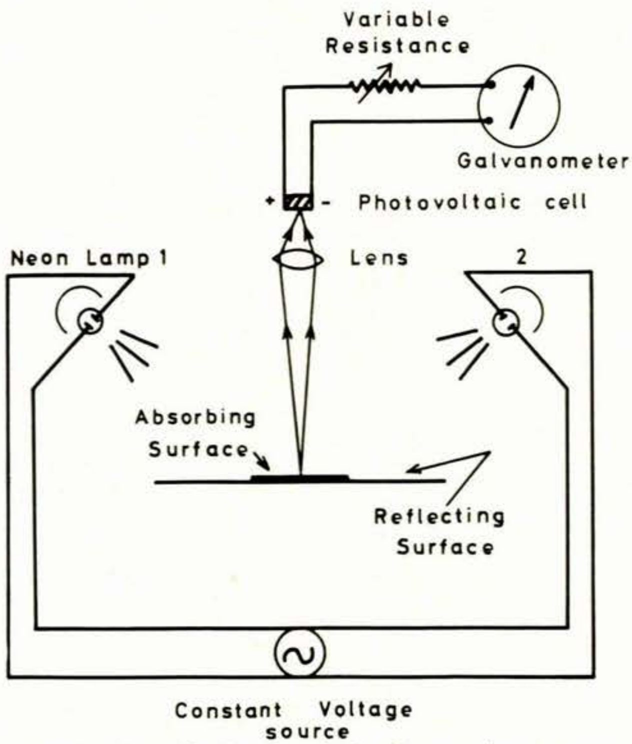

Fig. 1. Schematic diagram of the photometric apparatus used for measuring the surface area of the mould in the coating method.

was attached to the easel of a photographic enlarger (Leitz, Wetzlar) and illuminated by a pair of fluorescent neon lamps (National FL 10 watt, Daylight) connected to a constant voltage source. These lamps produced a fairly uniform illumination over an area of about 20 by 30 cm. The enlarger was brought into focus on the white sheet by placing a photographic negative in the holder of the enlarger. The negative was then replaced by a light-intensity detector consisting of 2 Barrier-layer replacement cells for a Weston photo-electric light meter, mounted in parallel. The output of the cells was led through a series resistor to a galvanometer (Cambridge No. L 394201, resistance 61·7 ohms, sensitivity 21·5 divisions/amp).

The galvanometer was zeroed by shielding the photocells from light. Full scale deflection was then set, with the reflecting white sheet in full view, by adjusting the position of the neon lamps and the series resistor. When an absorbing surface was introduced over part of the reflecting surface, the intensity of the reflected light diminished and the output of the photocells dropped by an amount proportional to the area of the absorbing surface. Because of possible distortion in the enlarger lens, the centres of the absorbing and reflecting sheets were positioned on the principal axis of the enlarger's optical system.

By introducing different pieces of painted masking tape—each of precisely known area—into the light-sensitive field, deviations were produced on the galvanometer scale for each one. A graph with deviation in units on the galvanometer scale against area in sq.cm. or sq.in., was then plotted (Fig. 2). The flat pieces of the cut mould, painted black, were first measured one by one, and thereafter the surface area of each was read from the standard graph. Total surface area (sq.cm. or sq.in.) was obtained by addition.

Each ear was measured by cutting a piece of soft cardboard to fit round the rest of the ear, flattening the pinna onto the cardboard and demarcating along the outside margin. The total area of the ear was thus twice that indicated on the cardboard. This was determined by means of a planimeter. For the penis, length and circumference were measured and for the scrotum the area was determined by a soft bag which covered the scrotum. The

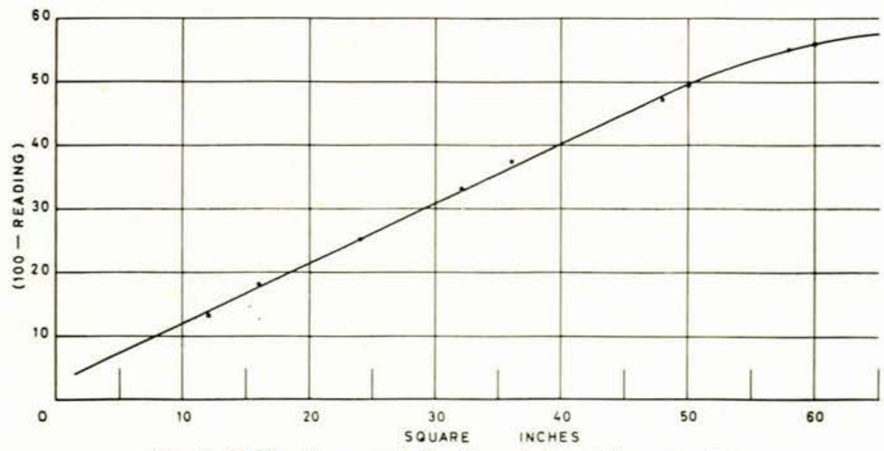

Fig. 2. Calibration graph for the photometric apparatus.

genitals were measured on 3 subjects only, and for the rest of the subjects the average area thus obtained was added to each total.

The total time required to coat a subject was ±7 hours (arms, 1½ hours; legs, 2 hours; trunk, 2½ hours; and head and neck, 1 hour); and that to measure the surface area of the mould was ±5 hours.

To determine the repeatability of the coating method the right arm of one subject was coated 3 times. The results were 202·6, 200·5 and 204·2 sq.in., giving a maximum error of 1·85%.

The Linear Method

The surface area of the 16 subjects was also determined by means of the Du Bois linear method.[9] Each subject was measured in the nude for weight and height. The latter was made with the subject lying flat on his back on the measuring surface. Care was taken to ensure that the legs were fully extended and in a straight line with the body. The feet were kept together, with the toes pointing directly forward and the soles in firm contact with the foot-board. With the subject in this position the body landmarks were palpated and marked with a skin pencil as indicated in Fig. 3. A Stanley, TY3ME, 3-meter steel tape was used for all measurements. Great care was taken with the circumference measurements, since the tape had to be pulled as firmly as possible without distorting the skin.

The Height-Weight Formula

A total of 200 subjects, including the above 16, was measured in the usual manner for height and weight, and these results were used to calculate the surface area by means of the Du Bois height-weight formula.

The Photodermoplanimeter

In this instrument (Fig. 4) use is made of the principle that the area of a body which radiates to its surroundings is the same as the area available for absorbing light from the surroundings.

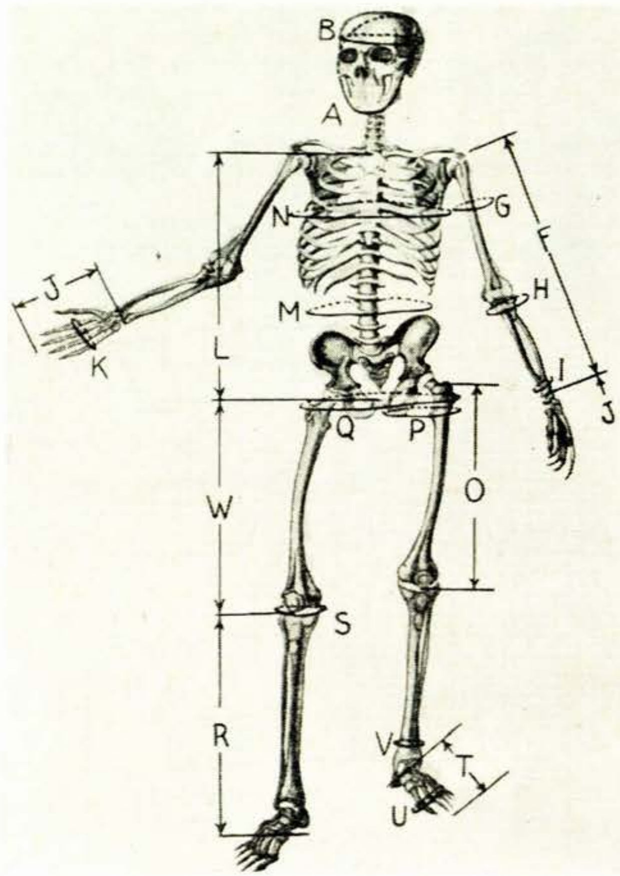

Fig. 3. Measurements used in linear formula.

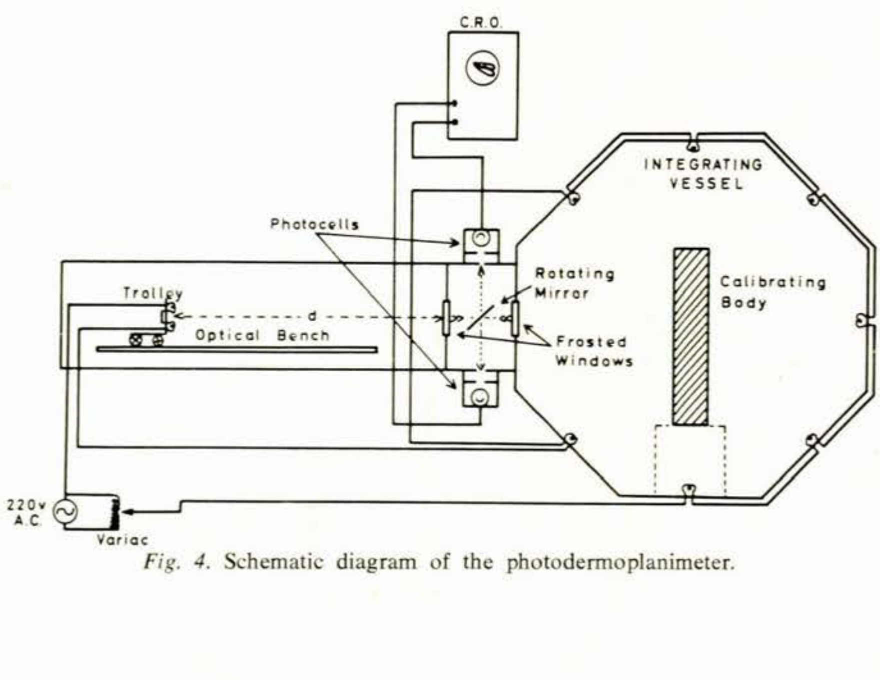

Fig. 4. Schematic diagram of the photodermoplanimeter.

An isotropic flux of white light is produced in a large vessel. When a man enters the vessel, he absorbs some of this light, and so decreases the light intensity at a frosted glass window in the wall of the vessel. This decrease in intensity is related to the area absorbing the light.

The integrating vessel for producing the isotropic light flux consists of a 10-ft cube with the corners filled in. This is done to bring its shape close to that of a sphere, which theoretically produces the most uniform light flux. The vessel is illuminated by 30 evenly distributed and shielded 6-volt, 50-watt lamps connected in series. It has a wire grid on which the man stands, so that he is in the centre of the vessel during measurements. The inside of the vessel is painted with 80%-reflecting, matt white paint.

The intensity at the frosted glass window in the wall of the vessel is measured by comparing it with a similar window illuminated by 4 comparison lamps (Fig. 4). These lamps are mounted on a trolley which runs along an optical bench. The position of the trolley (the distance 'd' in Fig. 4) determines the light intensity at the reference window. To minimize the effects of mains voltage fluctuations, the comparison lamps are connected in series with the lamps inside the vessel.

The light intensities at the 2 frosted windows are compared by a photometer designed to give accurate results with a minimum of photometric skill. The light from the 2 windows is reflected by a double-sided mirror on 2 photoconductive cells. The mirror rotates rapidly, switching the light from each window onto each photocell alternately. When the outputs of the two cells are put on the x and y plates of an oscilloscope respectively, two elongated ellipses appear on the screen. The light intensities at the 2 windows are equal when the positions of these 2 ellipses coincide. This photometric system is not affected by differences in the properties of the 2 photocells, or by differences in the reflectance of the 2 sides of the mirror.

The light intensity at the reference window can be adjusted by moving the trolley, holding the comparison lamps, along the optical bench. The position of the trolley can be read off accurately from a sliding rule attached to it.

As the amount of light absorbed by a body is dependent not only on its area, but also on the nature of the surface, the man to be measured is painted with 2 coats of black water-stainer over the entire body; the skin will then absorb about 99% of the white light falling on it. Because all subjects are painted with the same paint, the amount of light they absorb becomes a function of their absorbing (and therefore radiating) areas only.

The photodermoplanimeter is calibrated by a substitution method. A number of rectangular prisms of known area are introduced in place of the man. These prisms have their surfaces coated with a paint with optical properties matching those of the water-stainer used to paint the man. Although the inverse square law of optics predicts a dependence on distance squared, in the narrow range of areas used, approximating to that of the man, it is found that the distance moved by the trolley when a body is introduced is linearly dependent on the radiation area of that body.

Operation of the photodermoplanimeter is simple. A suitable lamp current is set up, and, with the integrating vessel empty, the position of the trolley is adjusted until the 2 ellipses on the oscilloscope screen coincide. The position of the trolley is read off. The painted man enters the vessel and the ellipses are brought into coincidence again. The new trolley position is noted. The difference in these 2 positions is the measure of radiating surface area.

The subject to be measured was washed to ensure a thoroughly clean skin and was then totally spray-painted with the light-absorbent paint. This process usually took ±5 minutes. The subject was then dried in front of a fan heater for 10 minutes. Under ordinary circumstances the head should be shaved and also painted. In the present study this was not done, since the Bantu mine recruits have very short hair.

The subject entered the integrating sphere, faced the control window and assumed a specific posture. Five different postures were used to determine the maximum radiation area. These were as follows:

1. Legs apart and arms sloped downwards.
2. Legs apart and arms horizontal.
3. Legs apart and arms sloped upwards (spread-eagle).
4. Arms outstretched upwards.
5. A foetal position.

Readings usually took less than 20 seconds per person and 200 subjects were measured.

A zero reading, with the box empty, was taken immediately before the actual reading and also immediately afterwards. The mean of the 2 was subtracted from the actual reading to obtain the displacement. The area corresponding to this displacement was read off from the calibration graph. An example of this graph is given in Fig. 5.

RESULTS

The radiation areas of 23 subjects measured with the photodermoplanimeter in 5 different postures are presented in Table I.

In the first posture the subjects stood with legs $3\frac{1}{2}$ - 4 ft apart and arms sloping downwards to form angles of

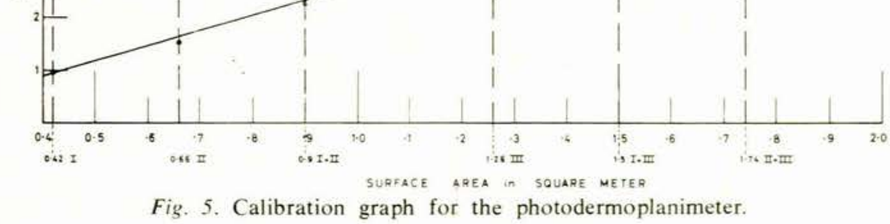

Fig. 5. Calibration graph for the photodermoplanimeter.

±45° with the trunk. The average area for this position was 1·69 sq.m. In the second posture arms were stretched out horizontally and the average area measured was 1·73 sq.m. In the third posture, the spread-eagle position, arms were stretched upwards to form angles of 135° with the trunk. The average area amounted to 1·76 sq.m. The fourth posture was a 'hands-up' position, giving a radiation area of 1·74 sq.m. The fifth posture, simulating the foetal position, in which the subject reduced his radiation area as much as possible by crouching and embracing the knees, gave an average area of 1·09 sq.m.

TABLE I. RADIATION AREA FOR 5 DIFFERENT POSTURES

Subject No.	Weight (kg.)	Height (cm.)	Area in sq. m. Posture 1	Posture 2	Posture 3	Posture 4	Posture 5	Maximal percentage reduction in radiation area
1	57·7	171·5	1·63	1·71	1·72	1·71	1·10	36·0
2	60·8	170·2	1·64	1·71	1·73	1·70	1·06	38·8
3	68·3	170·2	1·73	1·81	1·83	1·81	1·19	34·8
4	63·4	165·1	1·65	1·67	1·74	1·72	1·12	35·7
5	57·6	161·3	1·54	1·58	1·60	1·59	1·05	34·4
6	57·7	161·9	1·56	1·59	1·60	1·59	1·01	37·2
7	53·0	165·7	1·56	1·59	1·61	1·60	1·02	36·7
8	58·2	167·6	1·65	1·67	1·70	1·69	1·07	37·2
9	78·6	175·9	1·91	1·95	1·99	1·95	1·29	35·2
10	58·2	165·7	1·60	1·66	1·69	1·65	1·06	37·3
11	56·2	157·5	1·51	1·55	1·58	1·55	1·02	35·4
12	65·2	169·5	1·69	1·72	1·75	1·73	1·10	37·3
13	64·2	169·5	1·77	1·83	1·87	1·84	1·06	43·2
14	70·5	174·6	1·83	1·88	1·88	1·88	1·07	43·0
15	60·3	156·2	1·53	1·58	1·60	1·59	0·96	40·1
16	69·6	174·6	1·76	1·80	1·83	1·79	1·15	37·5
17	63·0	167·0	1·65	1·71	1·74	1·70	1·09	37·4
18	62·8	171·5	1·69	1·72	1·74	1·69	1·05	40·0
19	63·6	174·0	1·73	1·75	1·77	1·77	1·06	39·5
20	74·4	181·6	1·86	1·92	1·94	1·90	1·21	37·6
21	70·4	174·0	1·82	1·87	1·89	1·86	1·12	40·5
22	63·3	172·7	1·72	1·77	1·79	1·77	1·03	42·8
23	69·2	167·6	1·76	1·83	1·86	1·83	1·11	40·3
Average	63·7	168·9	1·69	1·73	1·76	1·74	1·09	38·1
Standard deviation			0·110	0·115	0·115	0·111	0·072	

The data pesented in Table I were statistically analysed and a level of 5% was used for significance tests. This showed that: (*i*) the surface area for posture 3, the spread-eagle position, is significantly higher than that for any of the other postures; (*ii*) the surface for posture 2 is not significantly different from that for posture 4; and (*iii*) the maximum percentage reduction in radiation area (posture 5) varies from 34·4 to 43·2%, with an average of 38·1%.

Table II compares the repeatability of radiation area measurements on 50 subjects with the photodermoplanimeter. Most of the duplicate readings were made immediately after the first. In these instances weight and height were not measured again before the second reading, since it was assumed that these remained stable during this short interval. In those cases, however, where the first reading was made in the morning and the second in the afternoon, height and weight were again recorded before the second reading. In both cases the average radiation area recorded was 1·71 sq.m. Calculated by means of the Du Bois height-weight formula, average surface area for the same subjects was 1·66 sq.m.

Table III presents surface area measurements on 16 subjects determined by (*a*) a coating method and (*b*) the Du Bois linear formula. On 15 of the above 16 subjects the radiation area was also determined with the photodermoplanimeter. Surface area of the different anatomical regions determined by method (*a*), as well as the sum total of all the regions, is given in square inches. Similarly, total surface area, after addition of 0·2703 sq.ft for the penis, scrotum and ear areas, is also given in sq.ft. Average surface area, after conversion, thus was 1·92 sq.m. Averages for method (*b*) and the photodermoplanimeter results were 1·80 and 1·80 sq.m. respectively, and the average radiation area 1·85 sq.m.

TABLE II. REPEATED MEASUREMENTS OF RADIATION AREA FOR EACH SUBJECT ON THE SAME DAY

Subject No.	Weight (kg.) 1	Weight (kg.) 2	Height (cm.) 1	Height (cm.) 2	Area in sq. m. Photodermoplanimeter (uncorrected) 1	Photodermoplanimeter (uncorrected) 2	Du Bois height/weight formula 1	Du Bois height/weight formula 2
24	59·5	59·5	166·4	166·4	1·68	1·67	1·66	1·66
25	58·8	58·8	172·1	172·1	1·68	1·68	1·69	1·69
26	81·2	80·7	177·2	177·2	2·07	2·05	1·99	1·98
27	66·3	66·5	172·7	172·7	1·83	1·83	1·79	1·79
28	57·0	57·9	167·0	167·0	1·74	1·72	1·64	1·65
29	66·9	66·2	167·6	167·6	1·76	1·76	1·76	1·75
30	54·3	54·3	168·3	168·3	1·66	1·66	1·61	1·61
31	52·0	51·4	162·6	162·2	1·59	1·57	1·54	1·53
32	56·2	55·9	168·9	166·3	1·67	1·65	1·64	1·62
33	58·9	58·9	169·5	169·5	1·73	1·74	1·68	1·68
34	63·8	63·9	174·6	174·0	1·81	1·82	1·77	1·77
35	57·8	57·8	170·2	170·2	1·71	1·74	1·67	1·67
36	58·1	57·5	169·5	168·8	1·72	1·71	1·67	1·66
37	57·2	57·2	172·1	172·1	1·71	1·74	1·68	1·68
38	50·7	50·5	163·8	162·7	1·58	1·57	1·54	1·53
39	55·3	55·3	169·5	169·4	1·72	1·70	1·63	1·63
40	56·5	55·7	173·4	173·4	1·72	1·71	1·68	1·67
41	57·5	58·6	164·5	162·9	1·66	1·67	1·63	1·63
42	63·4	63·4	172·9	172·9	1·79	1·78	1·76	1·76
43	49·3	49·3	152·4	152·4	1·48	1·47	1·44	1·55
44	64·4	64·4	165·5	165·5	1·72	1·74	1·71	1·71
45	54·1	54·1	162·6	162·6	1·61	1·60	1·57	1·57
46	58·6	58·6	170·4	170·4	1·72	1·70	1·68	1·68
47	61·4	61·4	162·9	162·9	1·75	1·74	1·66	1·66
48	58·6	58·6	167·7	167·7	1·70	1·68	1·66	1·66
49	63·8	63·8	167·0	167·0	1·75	1·76	1·72	1·72
50	69·5	69·5	163·6	163·6	1·78	1·79	1·75	1·75
51	54·4	54·4	162·3	162·3	1·61	1·61	1·57	1·57
52	67·9	67·9	173·2	173·2	1·83	1·81	1·81	1·81
53	55·7	55·7	165·4	165·4	1·62	1·63	1·61	1·61
54	62·3	62·3	171·0	171·0	1·77	1·79	1·73	1·73
55	60·9	60·9	168·6	168·6	1·71	1·73	1·70	1·70
56	50·5	50·5	152·7	152·7	1·48	1·51	1·46	1·46
57	60·4	60·4	176·6	176·6	1·75	1·77	1·75	1·75
58	67·3	67·3	173·6	173·6	1·85	1·85	1·81	1·81
59	56·1	56·1	165·4	165·4	1·68	1·67	1·62	1·62
60	55·8	55·8	158·9	158·9	1·79	1·79	1·57	1·57
61	53·9	53·9	161·7	161·7	1·76	1·76	1·56	1·56
62	56·7	56·7	167·8	167·8	1·70	1·70	1·64	1·64
63	56·0	56·0	169·5	169·5	1·70	1·70	1·64	1·64
64	47·4	47·4	161·4	161·4	1·57	1·55	1·50	1·50
65	52·6	52·6	161·6	161·6	1·61	1·64	1·50	1·50
66	58·7	58·7	170·3	170·3	1·70	1·71	1·68	1·68
67	56·5	56·5	165·7	165·7	1·67	1·66	1·62	1·62
68	70·4	70·4	177·4	177·4	1·93	1·95	1·87	1·87
69	52·2	52·2	166·9	166·9	1·65	1·63	1·58	1·58
70	68·8	68·8	174·1	174·1	1·88	1·89	1·83	1·83
71	58·1	58·1	156·7	156·7	1·64	1·65	1·58	1·58
72	54·4	54·4	167·5	167·5	1·66	1·68	1·61	1·61
73	68·5	68·5	162·6	162·6	1·80	1·78	1·74	1·74
Av.	59·1	59·1	167·3	167·2	1·71	1·71	1·66	1·66
Standard deviation					0·103	0·104	0·105	0·105

The percentage difference between the results obtained with the coating method and with the photodermoplanimeter was calculated for each subject. The former method was found to give average results 4·1% in excess of the latter.

Surface area weightings for the different body regions, expressed as percentages of the total surface area as determined by the coating method (Table III), are presented in Table IV. Average values are as follows: left arm 9·0%, left leg 18·3%, right leg 17·7%, trunk 37·5% and the head and neck 8·5%.

Table V supplies the correction factors to be added to the radiation areas within the range 1·11 - 2·58 sq.m. in order to obtain true physical surface areas.

TABLE III. SURFACE AREA DETERMINATIONS ON 16 SUBJECTS BY 4 DIFFERENT METHODS

			Area in sq. in.									Area in sq. m.			
Subject No.	Weight (kg.)	Height (cm.)	Left arm	Right arm	Left leg	Right leg	Trunk	Head and neck	Total area	Total area ÷ 0·2703 (sq. ft)	Total area (sq. ft)	Photo-dermo-plani-meter	Percent-age dif-ference	Du Bois ht/wt formula	Du Bois linear formula
19	63·60	174·0	270·0	270·5	534·0	475·5	1,081·0	247·5	2,878·5	20·26	1·88	1·77	6·2	1·77	1·79
20	74·40	181·6	292·0	288·0	627·0	583·0	1,101·5	283·5	3,175·0	22·32	2·07	1·94	6·7	1·95	1·91
21	70·40	174·0	254·5	256·0	558·5	542·0	1,124·0	254·0	2,989·0	21·03	1·95	1·89	3·2	1·85	1·82
22	63·32	172·7	240·5	255·0	511·5	495·0	1,074·5	253·0	2,829·5	19·92	1·85	1·79	3·4	1·75	1·74
23	69·20	167·6	254·0	254·5	515·5	537·5	1,104·0	307·0	2,972·5	20·91	1·94	1·86	4·3	1·78	1·81
77	126·40	175·3	345·0	319·5	685·0	660·5	1,616·0	281·5	3,907·5	27·41	2·55	2·42	5·4	2·38	2·37
78	62·60	163·8	230·0	235·5	486·5	492·0	989·5	238·0	2,671·5	18·82	1·75	1·73	1·2	1·68	1·64
79	69·50	163·6	259·0	275·5	517·0	498·0	1,033·0	228·0	2,810·5	19·79	1·84	1·79	2·8	1·75	1·76
80	47·50	152·4	198·5	200·5	390·0	390·0	911·0	162·0	2,252·0	15·91	1·48	—	—	1·42	1·40
81	63·80	173·2	256·0	264·5	520·5	512·0	1,072·5	250·0	2,875·5	20·24	1·88	1·82	3·3	1·76	1·77
82	68·50	162·6	260·0	269·0	503·5	512·0	1,058·0	254·5	2,857·0	20·11	1·87	1·83	2·2	1·74	1·69
83	58·70	170·3	243·0	249·0	506·0	492·0	1,077·0	229·5	2,796·5	19·69	1·83	1·79	2·2	1·69	1·70
1	59·00	172·1	247·0	266·0	493·5	496·5	1,027·0	246·0	2,776·0	19·55	1·82	1·72	5·8	1·70	1·71
74	58·70	172·7	171·0	264·0	530·0	509·0	964·0	220·0	2,758·0	19·42	1·80	1·73	4·6	1·70	1·73
75	69·90	170·2	276·0	276·0	576·5	546·5	1,098·0	229·5	3,002·5	21·12	1·96	1·89	3·7	1·81	1·80
76	62·70	169·5	272·5	254·0	521·0	461·5	1,072·5	245·5	2,827·0	19·90	1·85	1·75	5·7	1·72	1·75
Average	68·01	169·7									1·92	1·85	4·1	1·78	1·77
Standard deviation											0·190	0·171		0·174	0·170

Subjects 19–23 and 77 were White.

TABLE IV. RELATIVE AREAS OF DIFFERENT BODY REGIONS (PERCENTAGE OF TOTAL AREA)

Subject No.	Left arm	Right arm	Left leg	Right leg	Trunk	Head and neck
74	9·8	9·6	19·2	18·5	34·9	8·0
1	8·9	9·6	17·8	17·9	37·0	8·8
75	9·2	9·2	19·2	18·2	36·5	7·7
76	9·6	9·0	18·4	16·4	37·9	8·7
77	8·8	8·2	17·5	16·9	41·4	7·2
20	9·2	9·1	19·7	18·4	34·7	8·9
19	9·4	9·4	18·5	16·5	37·6	8·6
22	8·5	9·0	18·1	17·5	38·0	8·9
23	8·5	8·6	17·3	18·1	37·2	10·3
21	8·5	8·6	18·7	18·1	37·6	8·5
78	8·6	8·8	18·2	18·4	37·1	8·9
79	9·2	9·8	18·4	17·7	36·8	8·1
80	8·8	8·9	17·3	17·3	40·5	7·2
81	8·9	9·2	18·1	17·8	37·3	8·7
82	9·1	9·4	17·6	17·9	37·1	8·9
83	8·7	8·9	18·1	17·6	38·5	8·2
Average	9·0	9·1	18·2	17·7	37·5	8·5

TABLE V. FACTORS BY WHICH RADIATION AREA IN SPREAD-EAGLE POSITION MUST BE INCREASED TO OBTAIN TRUE SURFACE AREA

Radiation areas in sq. m.	Factor
1·11—1·35	0·05
1·36—1·60	0·06
1·61—1·84	0·07
1·85—2·09	0·08
2·10—2·33	0·09
2·34—2·58	0·10

DISCUSSION

The major objective of this study, as indicated previously, was to determine a correction factor which could be used to convert radiation area, as measured with the photodermoplanimeter, into true physical area. This intention was realized. The true physical area thus determined was then compared with results obtained by the Du Bois linear and height-weight formulae.

In this study the body surface area of 16 men was determined by (*a*) the coating method, (*b*) the photodermoplanimeter, (*c*) the Du Bois linear formula and (*d*) the Du Bois height-weight formula. Surface area of a further 200 subjects was determined by methods (*b*) and (*d*) only. Method (*a*) was not extensively employed, since coating of a subject is an extremely laborious and time-consuming task demanding great patience from both subject and operator. This probably explains why former workers coated only a limited number of subjects in order to obtain the necessary results for their formulae.

It is a fact that for reasons already given, almost every research worker of the past coated only a very limited number of subjects. In addition, racial features (e.g. Bantu, Caucasians, Orientals) account for specific differences as regards weight and height. It is therefore extremely difficult to compare the anthropometrical measurements of the subjects coated in this study with those quoted in the literature.

The only normal subject ('tall, average build') coated by Du Bois and Du Bois[10] weighed 74·05 kg. and had a height of 179·2 cm. His surface area was found to be 1·90 sq.m. Subject No. 20 of this study (Table III) had a weight of 74·40 kg., a height of 181·6 cm. and a surface area of 2·07 sq.m. By comparison this represents a difference of ±8% in favour of the latter.

However, the general method employed in this study can be considered superior to that of Du Bois and Du Bois for the following reasons:

1. The masking tape that was used is more suitable for coating the human skin than is manilla paper, since it is softer, does not form folds, is stronger, does not tear and is easily removable from the skin surface.

2. The photometric method is more accurate than the photographic method (1·8% accuracy) for measuring the total area of the removed mould, since it measures the area of the mould itself with an accuracy of 1% or better. The photographic method, on the contrary, is open to error by way of various factors: Ill-defined borders may be overshot during the process of cutting out the unexposed pieces; weight results may be incorrect, since photographic paper is hygroscopic and changes weight rapidly when exposed to air; and the photographic paper may not be of uniform thickness and weight.

In her table for Orientals, Boyd[3] quotes the different measurements supplied by Takeya.[11] One of his subjects had a height of 159·6 cm., a weight of 62·6 kg. and surface area of 1·70 sq.m. Subject No. 78 of this study (Table

III) had a height of 163·8 cm., a weight of 62·6 kg. and a surface area of 1·75 sq.m. This slight difference can probably be accounted for by the 3·2-cm. difference in height between the two subjects.

According to Best and Taylor[12] the average surface area for adult Americans is 1·6 sq.m. for women and 1·80 sq.m. for men. It is further stated that a man 175 cm. tall and weighing 75 kg. has a surface area of 1·91 sq.m.

In this study the average surface area of 16 men, as obtained by the coating method, was found to be 1·92 sq.m., which differs 6·2% from the 1·80 sq.m. found for the average American man.

Results obtained with the photodermoplanimeter (Table I) indicate that the maximum radiation area in man is found when the subject is in the spread-eagle position. This supports Halliday's findings[7] on a wooden model that the radiation area is closest to the true physical area when a body is in the spread-eagle posture.

Posture 5 (foetal position) gives the smallest effective radiation area, namely 62% of the maximum. This, therefore, represents an average reduction of 38% in total radiation area. This figure of 62% is slightly higher than the 55% found by Du Bois.[13] Using the figure supplied by Bedford,[14] the effective radiation area for two subjects was calculated to be 61 and 72%.

The maximum reduction in radiation area found between the spread-eagle and foetal positions was 43·2%, thus producing an effective radiation area of 56·8% which is in close accordance with the 56% found by Bohnenkamp and Pasquay.[5] It is doubtful whether it is at all possible to reduce the radiation area any further. A young and athletic person of normal build, such as those studied, would be able to reduce his area maximally as compared with an older and more obese person.

Radiation area was measured with the photodermoplanimeter on 50 subjects. Surface area of the same 50 subjects was also determined by means of the Du Bois height-weight formula (Table II). In the case of the Du Bois height-weight formula, reproducibility is dependent on the extent to which height and/or weight can change between readings taken on the same day and also on the accuracy of the different readings. For the radiation method, reproducibility is dependent on the amount that a subject's surface area can change between determinations, on the efficiency of the method and on the accuracy of the readings.

The measure used to express the degree of reproducibility is the coefficient of variation of a single observation, and this has been estimated for the 50 pairs of readings obtained with each method. Coefficient of variation is the standard deviation of a single observation divided by the mean, i.e. the mean of 50 determinations. For convenience the coefficient of variation has been multiplied by 100 to express it as a percentage. For the radiation method it was found to be 0·65% and for the Du Bois height/weight formula 0·19%. Such a low coefficient of variation indicates a very high degree of reproducibility. That the results obtained with the Du Bois height/weight formula are more reproducible than those of the photodermoplanimeter is due to the fact that in the former method measurements of height and weight only are involved. whereas measurement of the radiation area by means of the latter method is a much more complex procedure.

Because this study was made essentially to determine the total surface area and not the weighting of the different body regions, the exact anatomical borders described (Table IV) were not always meticulously adhered to. Nonetheless, the percentage areas found for the left and right leg, trunk, head and neck are in fairly close agreement with the weightings of Hardy and Du Bois.[16] Hardy states that the various weighting factors were computed from the linear formula measurements on 16 subjects, but he does not describe the exact borders of the different regions. Apparently the boundaries between the trunk and legs were different; Hardy probably also included the neck in the trunk area.

An interesting feature of his regional division of total body area is that it consists of eleven multiple areas of 9% each as follows: Head and neck 1 × 9, left arm 1 × 9, right arm 1 × 9, left leg 2 × 9, right leg 2 × 9 and trunk 4 × 9.

Factors for converting surface area obtained by any one method into true geometrical area were calculated and are given in Table VI.

TABLE VI. FACTORS FOR CONVERTING SURFACE AREA

Area determined with:	*Increase area by:*
Photodermoplanimeter	4·06%
Du Bois height/weight formula	6·71%
Du Bois linear formula	6·89%

To convert a result obtained with the Du Bois height/weight formula to radiation area, it is necessary to increase that figure by 2·55%.

Radiation area was found to be 2·55% larger than the surface area as determined with the Du Bois height/weight formula. Therefore, computations of radiation energy exchange for human beings using 95% of the Du Bois surface area (which is the usual procedure), as well as the use of the Du Bois formula in the computation of basal metabolic rate, are questionable.

Many research workers have pointed out that the Du Bois formulae underestimate true physical surface area, and have proposed new factors for correcting the linear formula and new constants for the height/weight formula. Takahira[17] stated that when the surface area of Japanese men is calculated with the Du Bois height/weight formula, better results are obtained if a constant of 72·46 is used instead of the accepted 71·84. According to Takeya[11] the Du Bois height/weight formula with a constant of 75·05 is best for calculating the surface area of Japanese. This represents an increase of 4·5% in total body surface area. Banerjee and Sen[18] suggested a constant of 74·66; an increase of 4%. Tucker and Alexander[19] likewise found that the Du Bois height/weight formula underestimates surface area to the extent of 6%.

In this study it was also found that the Du Bois height/weight formula underestimates the true surface area, as determined by the coating method, by 6·71%. If a new constant, C, is calculated as follows:

$$C = 71{\cdot}84 \times \frac{\text{measured surface area}}{\text{Du Bois calculated surface area,}}$$

then from the available data in Table III the derived figure is 76·54.

If this constant is used instead of the Du Bois constant of 71·84, better results are obtained for White and Bantu South African males of normal build.

It must be pointed out that, firstly, Du Bois coated only a very limited number of subjects, viz. 5 for the linear formula and 9 for the height/weight formula. Secondly, his subjects, in the one instance at least, cannot be considered normal and representative, since one was a cretin, another a typhoid patient, the third a tall, thin man with long, slim bones, sinewy muscles and very little subcutaneous fat, the fourth a very short and stout woman and the fifth a tall subject of average build.

These factors may perhaps account to some extent for the fairly general criticism mentioned above. It must be stated that the subjects used in the present study were all of normal build, except No. 77 who was of average height but slightly obese.

No difference was found between Bantu and White men in terms of the increase required to convert radiation area to true surface area. The findings of this study indicate that the actual geometrical surface area of different individuals is dependent on anthropometrical build rather than on racial characteristics between White and Bantu South Africans.

The surface area of a further 200 subjects was determined with the photodermoplanimeter and also by means of the Du Bois height/weight formula. These data are on file at the Human Sciences Laboratory, and the results on this large sample corroborate the finding that the Du Bois height/weight formula underestimates radiation area by 2·98% and thus total surface area by 6·71%.

Photodermoplanimetry must be regarded as the best possible method to date for the measurement of radiation area. To convert this radiation area to true surface area results have to be increased by 4·06%. Identical results are obtained if the Du Bois height/weight formula is used with the new constant of 76·54. Since the coating method is very laborious and the availability of a photodermoplanimeter is extremely limited, it is suggested that the existing constant in the Du Bois height/weight formula be replaced by this new constant for the normal South African male population. This would ensure a more accurate value for a measure so extensively applied in physiology.

REFERENCES

1. Abernethy, J. (1793): *Op. cit.*[5]
2. Leeuwenhoek, A. A. (1719): *Op. cit.*[3]
3. Boyd, E. (1935): *The Growth of the Surface Area of the Human Body*. Minnesota: The University Press.
4. Halliday, E. C. and Hugo, T. J. (1963): J. Appl. Physiol., **18**, 1285.
5. Van Graan, C. H. and Wyndham, C. H. (1964): Nature (Lond.), **204**, 998.
6. Guibert, A. and Taylor, C. L. (1952): J. Appl. Physiol., **5**, 24.
7. Halliday, E. C. (1959): Report on a test of two physical methods for the measurement of the surface area of the human body. Pretoria: CSIR.
8. Sendroy, J. jnr and Cecchini, L. P. (1954): J. Appl. Physiol., **7**, 1.
9. Du Bois, D. and Du Bois, E. F. (1916): Arch. Intern. Med., **17**, 863.
10. *Idem* (1915): *Ibid.*, **15**, 868.
11. Takeya, K. (1929): Fukuoka Acta med., **22**, 51.
12. Best, C. H. and Taylor, N. B. (1966): *The Physiological Basis of Medical Practice*, 8th ed. Baltimore: Williams & Wilkins.
13. Du Bois, E. F. (1939): Bull. N. Y. Acad. Med., **15**, 143.
14. Bedford, T. (1935): J. Hyg. (Lond.), **35**, 303.
15. Bohnenkamp, H. and Pasquay, W. (1931): Pflügers Arch. fef. Physrol., **228**, 79.
16. Hardy, J. D. and Du Bois, E. F. (1938): J. Nutr., **15**, 461.
17. Takahira, H. (1925): Report of the Imperial Government Institute for Nutrition, Tokyo, vol. 1, p. 61.
18. Banerjee, S. and Sen, R. (1955): J. Appl. Physiol., **7**, 585.
19. Tucker, G. R. and Alexander, J. K. (1960): *Ibid.*, **15**, 781.