A formula for the estimation of the body surface area of Saudi male adults

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ABSTRACT

Objectives: Human body surface area (BSA) is the preferred denominator for physiological indices of body metabolism and for drug dosages. The Du Bois & Du Bois height/weight nomogram, used for fast and convenient estimation of patients' BSA, is not suitable for all populations due to ethnic differences in body shape and build. The purpose of this study was to obtain direct measurements of BSA and use the data to construct a prediction formula for Saudi male adults.

Methods: Body surface area was measured in 21 adult male Saudis at Assir Central Hospital in Abha, Kingdom of Saudi Arabia between 2000 and 2003, using a coating technique. Areas of the coating material were determined with a compensating planimeter. Other anthropometric indices were measured or calculated according to standard procedures. Measured values of BSA were subjected to linear regression analysis using the least squares method to obtain a formula for predicting BSA from heights and weights.

Results: Mean body mass index (BMI) was 25.1 ± 1.6 kg/m^2; linearity, 2.46 ± 0.13 cm/kg; surface to mass ratio, 0.025 ± 0.0008 m^2/kg; relative sitting height (RSH), 0.51 ± 0.005. The closest fit to measured BSA values was given by the biexponential regression equation:

$$BSA=0.02036 \times H^{0.516} \times W^{0.427} \pm 0.01283$$

This formula predicts BSA of Saudi male adults more accurately than all existing equations tested and yields a convenient BSA table for Saudis.

Conclusion: The use of our formula, with prediction accuracy superior to those of existing formulae, should facilitate the establishment of normal values of other physiological indices. It should also lead to more reliable and precise drug dosages and expedite rapid decision making in critical care situations.

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The body surface area (BSA) of humans is of great interest due to its extremely wide application in diverse areas of physiology and clinical medicine. It has long been accepted as the most appropriate biometric unit for normalizing physiological indices related to body metabolism in individuals of different body sizes. These include the basal metabolic rate,[1,2] blood volume, [3,4] cardiac output,[5-7] renal clearance,[8] and ventilation.[9] In clinical medicine, BSA is widely used for determining drug dosages especially in anesthesiology,[10,11] gastroenterology[12] and cancer chemotherapy[13-15] and for calculating the needs of patients for pareneteral fluids and electrolytes in critical care medicine.[16,17] Direct measurement of human body surface area is an extremely laborious and time-consuming task. Consequently, most workers do not measure BSA directly; rather they obtain estimates from previously published prediction formulae. The most commonly used source is the biexponential formula of DuBois and DuBois[18] derived from direct measurements on 9 North American subjects including a child and a cretin. Their study[19] involved coating the entire body with a mold, which was later cut away and spread out so that its area could be measured. From their results, they derived a prediction formula for calculating BSA from height and weight.

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Subsequently, most workers have obtained BSA from the DuBois and DuBois[18] formula or from the nomogram constructed from this formula.

It has long been observed that human morphology varies with climate and nutrition.[20] Other studies have suggested ethnic differences in the relationship between height and weight on the one hand and BSA on the other, Tanner.[21] Nwoye[22] carried out direct measurements of BSA of Africans and found that the DuBois and DuBois formula systematically underestimates their BSA, by between 6 and 22%. Thus, a formula derived from data on one racial group should not be expected to accurately estimate BSA in other racial groups.

Very few studies of BSA of Asian peoples have been published. Fujimoto and Watanabe[23] reported studies on the BSA of Japanese showing no difference from values predicted with the DuBois formula. Studies of BSA of Indians found both under and over-estimation by the Du-Bois formula. In a study of 16 West Bengali Indians, Bannerjee and Sen[24] reported significant underestimation while Mehra[25] found a slight overestimation of the BSA of Punjabis. To our knowledge, no direct study of BSA has been carried out on Saudis or other Middle East subjects. The present study was therefore undertaken to obtain direct measures of the BSA of Saudi male adults so as to test the applicability of existing formulae and, if necessary, to derive from measured values a new height and weight formula that accurately predicts their BSA.

Methods. The subjects were 21 male, medically fit, adult Saudis. Their selection was biased to include persons of diverse body shapes and stature as well as from different regions of the country.

All anthropometric measurements were made in the late afternoon, at least 4 hours after the last meal. Height, weight and relative sitting height (RSH) were measured, as described by Eveleth and Tanner,[26] on an Avery height and weight scale (Avery, Birmingham, England) with the subjects nude except for their traditional Saudi (underpant) shorts. Linearity (height-weight ratio) and surface to mass ratio (BSA/weight) were calculated from directly measured values. Body surface area was obtained by summing up the areas of 10 regions, demarcated as shown in **Figure 1**. Each area was measured directly using the coating technique as previously described.[22] The coating material used was a thin polythene sheet of uniform thickness (approximately 76μ). It made possible the measurement of obscure areas (such as the skin between the toes and fingers and the back of the ear) without folding or stretching. The limbs and the head were measured on one side only and then doubled. Areas corresponding to the different regions were obtained by direct measurement of its polythene covering using a compensating planimeter or by weighing the polythene and computing its area from a standard curve. Both methods gave identical results.

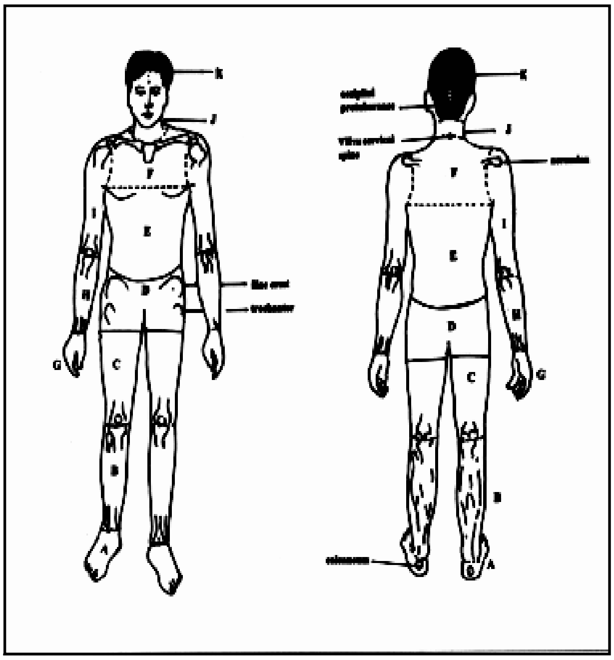

Figure 1 - Anterior and posterior views of the landmarks and boundaries used for direct measurement of surface areas.

The topography and boundaries used to demarcate the 10 regions are as follows (**Figure 1**): ***Foot (A)*** - demarcated by a line drawn around the ankle starting from the lower end of the tibia and fibula and passing over the malleoli at the sides. Posteriorly, the lines meet just above the attachment of the tendocalcaneus. ***Lower leg (B)*** - from region A to a horizontal line drawn around the upper part of the leg at the level of the lower border of the patella. ***Thigh, loin and buttocks (C)*** - From region B to a line drawn around the lower part of the trunk at the level of the highest point of the iliac crest and meeting anteriorly just below the navel. ***Trunk (D)*** - From region C to a line drawn around the upper part of the thorax, passing in front at the level of the sternal angle to join the highest point of the anterior wall of the axilla on both sides and at the back, at the level of the sixth thoracic spine. The axilla was measured separately and added to ***Upper part of the chest (E)*** - From region D to a line drawn around the root of the neck, passing in front through the suprasternal notch and posteriorly at the seventh cervical spine. ***Hand (F)*** - Demarcated by a line drawn around the wrist joint, passing in the middle anteriorly, at the level of the lower ends of the ulna/radius. ***Forearm (G)*** - From region F to a line drawn around the elbow joint, passing just below the medial epicondyle of the humerus and over the upper part of the olecranon, posteriorly. ***Upper arm (H)*** - From region G to a line drawn over the tip of the acromion to join the highest points of the anterior and posterior walls of the axilla. ***Neck (I)*** - From region E to a line drawn across the upper part of the neck, passing anteriorly, at the upper border of the thyroid cartilage

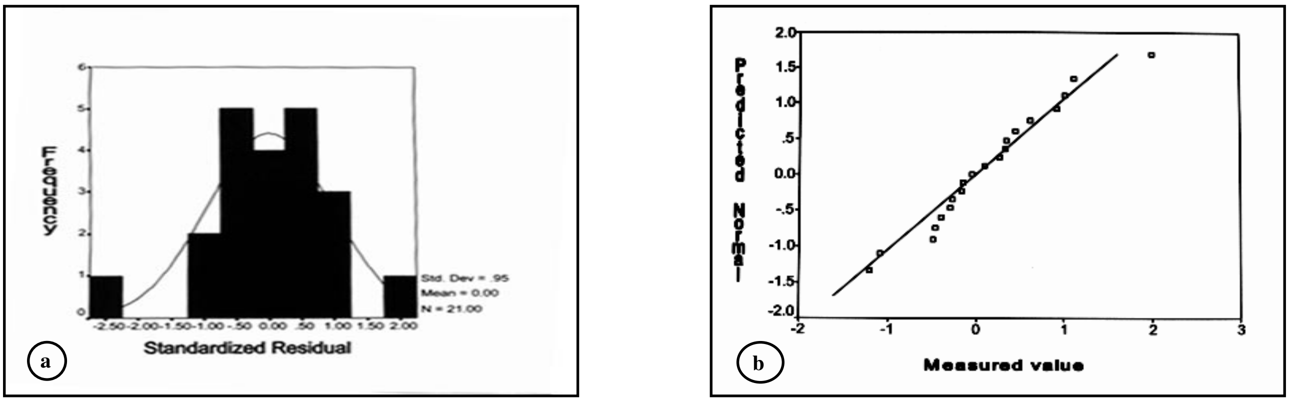

Figure 2 - Tests for normality **(a)** A frequency distribution of standardized body surface area residuals. **(b)** Q - Q plot of standardized body surface area residuals. Both plots confirm that the study sample is drawn from a normally distributed population.

Table 1 - Measured body surface area and other anthropometric data for the study population (N=21)

N	Subject	Age (years)	Weight (kg)	Height (cm)	Sitting height (cm)	BSA (m^2)
1	NHAQ	20	122.2	171	88.3	2.311
2	MFAD	29	99.7	182.1	99.7	2.130
3	MAAH	20	57	173	84.8	1.678
4	AMAG	27	66.5	177.3	87	1.757
5	MAAD	20	62	183.5	94.9	1.720
6	AFSB	32	54.5	169	83.7	1.575
7	TATS	20	98.5	170.2	83.6	2.057
8	IMAG	21	96.2	166.7	87.7	1.941
9	MAAB	19	58.3	167.7	84.9	1.618
10	AMAA	25	52.8	153.2	82.6	1.491
11	WHAS	21	127	177	93	2.423
12	AAAH	24	78	175	84.9	1.854
13	MMAA	21	62	168	85.1	1.689
14	ASIN	20	65.7	180	89.5	1.824
15	HASQ	25	74.3	170.5	84	1.808
16	MMAT	20	64.5	175	86.9	1.741
17	FAAG	26	86	173	85.5	1.945
18	AMAS	21	73.5	175	89	1.827
19	MIBA	19	58.6	171	84	1.641
20	AAFQ	25	51.6	168.5	88	1.547
21	ASAA	20	59.8	171.2	98.2	1.703

BSA - body surface area

and posteriorly, midway between the external occipital protuberance and the seventh cervical spine. ***Head (J)*** - Above region I. A median line enabled one side of the head to be measured accurately, and the value was then doubled.

Data analysis and statistics. Data from all 21 subjects of this study was used to compute a biexponential regression equation using the Statistical Package for Social Sciences (SPSS) software package, version 9.0 as described by Norusis[27] and according to the model developed by DuBois and DuBois,[18] thus:

$$BSA = a_0 H^{a_1} W^{a_2} e \qquad (1)$$

or in logarithmic form,

$$\ln(BSA) = \ln a_0 + a_1 \ln H + a_2 \ln W + \ln e \qquad (2)$$

Where H = height in cm. W = weight in kg. a_0 is a (constant); a_1 and a_2 are partial regression coefficients determined by a least squares procedure, e is a random error term with mean 1 and constant variance.[28]

The resulting equation satisfied the assumptions of normality, linearity and constant variance[28] as shown in **Figure 2.**

Results. **Table 1** shows age and measured anthropometric data for 21 male adult Saudi subjects. The subjects' ages ranged from 18-32 years; heights from 153-184 cm, sitting heights from 82-98 cm; weights from 52-127 kg and BSA from 1.49-2.42 m^2. The mean BMI was 25.1 ± 1.6 kg/m^2 (SEM), with 33% of the subjects, underweight; 38%, ideal weight; 10%, overweight; 19%, obese.[29] The mean values for linearity, RSH and surface to mass ratio were 2.46 ± 0.13 cm/kg, 0.51 ± 0.13 and 0.025 ± 0.0008 m^2/kg, Using the least mean squares method, linear regression analysis was applied to the data of **Table 1** to give the following height and weight BSA prediction formula:

$$BSA = 0.02036H^{0.516}W^{0.427} \pm 0.0128$$

This equation satisfied the assumptions of normality (**Figures 2a and 2b**), linearity and constant variance (**Figure 3**) and gave accurate predictions of the BSA of our subjects from their heights and weights. The mean deviation:

$$\text{Mean deviation} = \frac{\text{predicted BSA - measured BSA}}{\text{measured BSA}}$$

was 0.008 ± 0.007 (N.S. p=0.05).

Pearson's linear correlation between measured and predicted values was 0.995 ($p<0.001$), indicating an excellent fit of predicted to measured values. Ninety-nine percent of the variability of BSA was explained by height and weight. The prediction accuracy of the present formula was compared to 5 existing formulae, selected on the basis that they enjoy widespread use or they were derived from data on non-Caucasian populations (**Table 2**). Body surface area values predicted from all 5 equations tested, overestimated measured values. Mean percentage deviation of predicted from measured values (predicted –measured/measured x 100) ranged from + 0.56 to + 15.6 while the corresponding value for this study was only – 0.37. Predicted values from 4 of 5 previously published formulae were significantly different from observed values ($p<0.0005$). The only exception came from Mehra,[25] which although showing a slight overestimation, did not differ significantly from measured BSA (**Table 2**). Our data was used to construct a BSA table, as a function of height and weight (**Table 3**), to provide a handy tool for rapid estimation of Saudi male BSA in critical care situations.

Discussion. Data from this study has yielded a biexponential formula for the accurate prediction of BSA in adult Saudi males, if their heights and weights are known. Our formula satisfies all the assumptions for multiple regression. It also satisfies the dimensionality requirement that $a_1 + 3a_2 = 2$[30] (equation one, page 10). The value of $a_1 + 3a_2$ in this study, 1.8, is satisfactorily close to 2. Unlike the case in Africans,[22] the weight constant in this study ($a_2=0.427$), is close to the height constant ($a_1=0.516$) indicating that weight contributes almost equally to BSA, as does height.

The prediction accuracy of our formula is superior to those of all 5 formulae, tested. All of them overestimate, to varying degrees, the BSA of Saudis

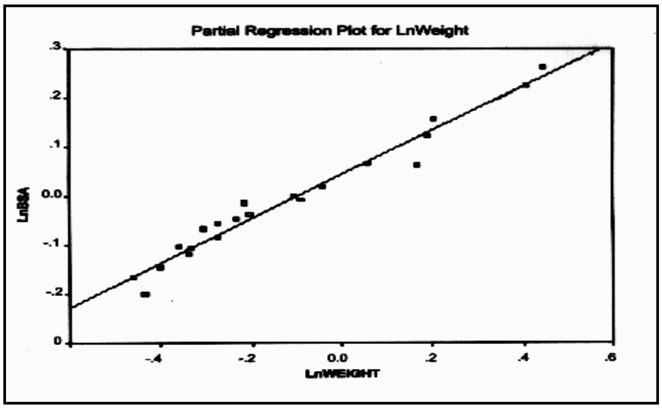

Figure 3 - Test for linearity. Partial regression plot of log body surface area against log weight confirming linearity of the regression equation. A similar relationship was obtained between log body surface area and log height.

(**Table 2**). The mean percentage deviation from measured BSA in this study, -0.365 ± 0.373 (SEM), is the lowest among all equations tested (**Table 3**). Thus, our formula predicts BSA of adult male Saudis more accurately than existing formulae. It is interesting to note that the formula with the next lowest deviation is that of Mehra[25] derived from data on Punjabi Indians, a population whose ecology, climate and diet are closest to those of our subjects. By contrast, the largest deviation from measured BSA came form the African formula.[22] Indeed, our data are in good general agreement with expectations from Bergman and Allen's ecological rules, Roberts.[31] According to this rule, it is expected that Saudi anthropometric values should lie midway between those of tropical Africans and temperate northern Europeans. The mean RSH of our subjects at 0.51 is midway between published values for tropical Africans (0.50[22,26]) and northern Europeans (0.53[26]). Similarly, the mean linearity of our subjects (2.46 ± 0.13) fits perfectly with expectations from their geographical distance from the equator. However, the mean surface to mass ratio of our subjects is similar to rather than higher than that of Europeans,[26] as Allen's rule would predict. This discrepancy is probably explained by secular trends in mass brought by changes in nutrition.[20] The prediction formula derived in this study should be of immense benefit to physiologists engaged in establishing normal physiological indices for Saudis and to clinicians in several areas of their practice including the estimation of the correct volume of plasma expanders for use in the prophylaxis of shock from burn injuries and the determination of appropriate drug dosages, especially in anesthesiology and cancer chemotherapy. The table of BSA values presented in this paper, which covers a wide range of heights and weights, should facilitate rapid decision-making in critical care situations. A table was preferred to a nomogram as the latter has been shown to contain significant graphic errors.[32]

Table 2 - Comparison of the prediction accuracy of 5 selected, existing formulae to that of the present formula

Author	Prediction formula	Mean %Dev	SEM	*p* value
Du Bois and Du Bois[18]	$0.007184H^{0.725}W^{0.425}$	2.212	± 0.407	<0.0005
Nwoye[22]	$0.001315H^{1.2139}W^{0.2620}$	15.585	± 1.222	<0.0005
Bannerjee and Sen[24]	$0.0074466H^{0.725}W^{0.425}$	5.963	± 0.424	<0.0005
Mehra[25]	$0.01131H^{0.6468}W^{0.4092}$	0.555	± 0.403	N.S
Gehan and George[30]	$0.02350H^{0.42246}W^{0.51456}$	3.314	± 0.599	<0.0005
Present study	$0.02036H^{0.516}W^{0.427}$	-0.365	± 0.373	N.S

N.S - not significant, p=0.05

Table 3 - Table of the body surface area as a function of height and weight for Saudi male adults.

Height (cm)	Weight (kg)																							
	40	**42**	**44**	**46**	**48**	**50**	**52**	**54**	**56**	**58**	**60**	**62**	**64**	**66**	**68**	**70**	**74**	**78**	**82**	**86**	**90**	**94**	**98**	**102**
150	1.31	1.33	1.36	1.39	1.41	1.44	1.46	1.48	1.51	1.53	1.55	1.57	1.60	1.62	1.64	1.66	1.70	1.74	1.77	1.81	1.85	1.88	1.91	1.95
152	1.31	1.34	1.37	1.40	1.42	1.45	1.47	1.49	1.52	1.54	1.56	1.59	1.61	1.63	1.65	1.67	1.71	1.75	1.79	1.82	1.86	1.89	1.93	1.96
154	1.32	1.35	1.38	1.40	1.43	1.46	1.48	1.50	1.53	1.55	1.57	1.60	1.62	1.64	1.66	1.68	1.72	1.76	1.80	1.84	1.87	1.91	1.94	1.97
156	1.33	1.36	1.39	1.41	1.44	1.47	1.49	1.51	1.54	1.56	1.58	1.61	1.63	1.65	1.67	1.69	1.73	1.77	1.81	1.85	1.88	1.92	1.95	1.99
158	1.34	1.37	1.40	1.42	1.45	1.48	1.50	1.52	1.55	1.57	1.59	1.62	1.64	1.66	1.68	1.70	1.74	1.78	1.82	1.86	1.90	1.93	1.97	2.00
	48	**50**	**52**	**54**	**56**	**58**	**60**	**62**	**64**	**66**	**68**	**70**	**74**	**78**	**82**	**86**	**90**	**94**	**98**	**102**	**106**	**110**	**114**	**118**
160	1.46	1.48	1.51	1.53	1.56	1.58	1.60	1.63	1.65	1.67	1.69	1.71	1.76	1.80	1.83	1.87	1.91	1.94	1.98	2.01	2.05	2.08	2.11	2.14
162	1.47	1.49	1.52	1.54	1.57	1.59	1.62	1.64	1.66	1.68	1.70	1.73	1.77	1.81	1.85	1.88	1.92	1.96	1.99	2.03	2.06	2.09	2.12	2.16
164	1.48	1.50	1.53	1.55	1.58	1.60	1.63	1.65	1.67	1.69	1.71	1.74	1.78	1.82	1.86	1.90	1.93	1.97	2.00	2.04	2.07	2.11	2.14	2.17
166	1.49	1.51	1.54	1.56	1.59	1.61	1.64	1.66	1.68	1.70	1.74	1.75	1.79	1.83	1.87	1.91	1.94	1.98	2.02	2.05	2.09	2.12	2.15	2.18
168	1.50	1.52	1.55	1.57	1.60	1.62	1.65	1.67	1.69	1.71	1.78	1.76	1.80	1.84	1.88	1.92	1.96	1.99	2.03	2.06	2.10	2.13	2.16	2.20
	56	**58**	**60**	**62**	**64**	**66**	**68**	**70**	**74**	**78**	**82**	**86**	**90**	**94**	**98**	**102**	**106**	**106**	**114**	**118**	**122**	**126**	**130**	**134**
170	1.61	1.63	1.66	1.68	1.70	1.72	1.75	1.77	1.81	1.85	1.89	1.93	1.97	2.01	2.04	2.08	2.11	2.15	2.18	2.21	2.24	2.27	2.30	2.33
172	1.62	1.64	1.67	1.69	1.71	1.74	1.76	1.78	1.82	1.86	1.90	1.94	1.98	2.02	2.05	2.09	2.12	2.16	2.19	2.22	2.26	2.29	2.32	2.35
174	1.63	1.65	1.68	1.70	1.72	1.75	1.77	1.79	1.83	1.87	1.92	1.95	1.99	2.03	2.07	2.10	2.14	2.17	2.20	2.24	2.27	2.30	2.33	2.36
176	1.64	1.66	1.69	1.71	1.73	1.76	1.78	1.80	1.84	1.89	1.93	1.97	2.00	2.04	2.08	2.11	2.15	2.18	2.22	2.25	2.28	2.31	2.35	2.38
178	1.65	1.67	1.70	1.72	1.74	1.77	1.79	1.81	1.85	1.90	1.94	1.98	2.02	2.05	2.09	2.13	2.16	2.20	2.2	2.26	2.3	2.33	2.36	2.39
	60	**62**	**64**	**66**	**68**	**70**	**72**	**74**	**78**	**82**	**86**	**90**	**94**	**98**	**102**	**106**	**110**	**114**	**118**	**122**	**126**	**130**	**134**	**138**
180	1.71	1.73	1.75	1.78	1.80	1.82	1.84	1.87	1.91	1.95	1.99	2.03	2.07	2.10	2.14	2.17	2.21	2.24	2.28	2.31	2.34	2.37	2.40	2.43
182	1.72	1.74	1.76	1.79	1.81	1.83	1.85	1.88	1.92	1.96	2.00	2.04	2.08	2.11	2.15	2.19	2.22	2.26	2.29	2.32	2.35	2.39	2.42	2.45
184	1.72	1.75	1.77	1.80	1.82	1.84	1.86	1.89	1.93	1.97	2.01	2.05	2.09	2.13	2.16	2.20	2.23	2.27	2.30	2.34	2.37	2.40	2.43	2.46
186	1.73	1.76	1.78	1.81	1.83	1.85	1.88	1.90	1.94	1.98	2.02	2.06	2.10	2.14	2.18	2.21	2.25	2.28	2.32	2.35	2.38	2.41	2.44	2.48
188	1.74	1.77	1.79	1.82	1.84	1.86	1.89	1.91	1.95	1.99	2.03	2.07	2.11	2.15	2.19	2.22	2.26	2.29	2.33	2.36	2.39	2.43	2.46	2.49

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