ORIGINAL ARTICLE

Development of predictive equations for body density of sumo wrestlers using B-mode ultrasound for the determination of subcutaneous fat thickness

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Objective: To develop an equation for predicting the body density of sumo wrestlers.
Methods: The following were measured: subcutaneous fat thickness measured at nine sites using B-mode ultrasound equipment; circumference at seven sites; hand to leg bioelectrical impedance. The subjects consisted of 24 college sumo wrestlers (mean age 19.7 years, mean body weight 111.2 kg) and 24 matched obese controls (mean age 19.1 years and mean body weight 111.2 kg). In addition, body density was measured by the underwater weighing method, and the percentage of fat was calculated from the measured body density.
Results: Linear regression analysis was used to estimate the relation between body density and other variables, and a predictive equation for the body density was derived: y = 1.088–0.00036 × (fat thickness at nine sites) (r^2 = 0.90) for the sumo wrestler group and y = 1.083–0.00033 × (fat thickness at nine sites) (r^2 = 0.91) for the control group. A multiple regression analysis was performed using the body density as the objective variable, and other measured items as the explanatory variables. This was used to derive a predictive equation: y = 1.121–0.00038 × (fat thickness of abdomen)–0.00043 × (circumference of hips)–0.00142 × (fat thickness of triceps) (r^2 = 0.94) for the sumo wrestler group, and y = 1.076–0.00070 × (fat thickness of abdomen)–0.00140 × (fat thickness of tibialis) (r^2 = 0.91) for the control group. The difference between the two equations was due to the difference in body fat distribution. Neither of these predictive equations is applicable to non-overweight non-athletes.
Conclusion: This is the first predictive equation developed for the body density of sumo wrestlers.

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Obesity is one of the biggest continuing public health problems, particularly in the developed countries of the world. It causes diseases such as arteriosclerosis, stroke, diabetes mellitus, and cardiac ischaemia.[1] Recently, the tendency to obesity has also appeared as a major social problem in Japan. Accordingly, the prevalence of and mortality from diabetes mellitus,[2 3] which is representative of obesity related diseases, have recently been rapidly increasing in this country. According to a diabetes survey by the Japanese Ministry of Health and Welfare in 1997, there were 6.9 million people with over 6.1% of haemoglobin A_1c or who were being treated at diabetic clinics or hospitals.[3] This tendency to obesity has also contributed to a recent increase in the incidence of hyperlipidaemia, cerebrovascular diseases, and myocardial infarction in Japan.[4 5]

Sumo, a traditional Japanese sport, is very popular at both amateur and professional levels. Most sumo wrestlers are deliberately overweight to help them win their matches, so they are prone to obesity related disease (diabetes mellitus, myocardial infarction, hyperlipidaemia, etc) and weight related injuries.[6–8] Indeed, the prevalence of these conditions and injuries in sumo wrestlers is far higher than in other athletes and the general population.[6–8] Consequently, their life expectancy is 10 years shorter than that of the general Japanese population.[9] Furthermore, the tendency to even greater obesity is increasing in sumo wrestlers, which must have a bad effect on both their health and performance. Recently, however, weight classification has been adopted in international championships as well as many tournaments in Japan. It is thus important for sumo wrestlers to be able to control their weight within their given class while maintaining their performance.

The first step towards maintaining an ideal body weight is to evaluate body density, which is difficult because there is no accurate and easy method. For example, underwater weighing, the most accurate method, has not been much used because of the technical difficulties and because of a lack of baths large enough to allow subjects as big as sumo wrestlers to be fully immersed. In addition, measurement of subcutaneous fat thickness and bioelectrical impedance, which are popular methods because of their comparative simplicity and convenience, are much less accurate than the underwater weighing method, especially for athletes and overweight subjects.[10] Sumo wrestlers are probably the most difficult subjects for evaluation of body density no matter what method is used, because they are both trained athletes and obese. It is thus important to develop a method for determining body density of sumo wrestlers to enable them to control their weight, thus preventing obesity related diseases, while maintaining their competitive athletic performance.

A predictive formula has been developed for body density in non-overweight athletes using subcutaneous fat thickness, body circumference, and electrical impedance.[10–13] The values for body density from the underwater weighing method were used as the yardstick in these studies. However, once again it is difficult to adapt these methods for sumo wrestlers because of the difficulty of applying the underwater weighing method, so a predictive equation for sumo wrestlers has not yet been developed.

In this study, we measured body density using the underwater weighing method, and simultaneously measured subcutaneous fat thickness by ultrasound, body circumference, length, and bioelectrical impedance as indices for the

Abbreviations: BMI, body mass index; CT, computed tomography; MRI, magnetic resonance imaging degree of obesity. We further developed a predictive equation for the body density of sumo wrestlers, using the values of other indices.

SUBJECTS AND METHODS

Subjects

The experimental subjects were 24 male sumo wrestlers who belonged to the Sumo Club in the Nippon Sport Science University (sumo group). The control group consisted of 24 matched volunteers who did not exercise regularly. They differed from the sumo group in body weight and age by no more than 5% and 2 years respectively. The mean (SD) ages and weights of the sumo and control groups were 19.7 (1.2) and 19.1 (2.1) years and 111.2 (21.9) and 111.2 (17.1) kg respectively. Members of the control group had shown a tendency to obesity since at least 10 years of age, and had not participated in or trained regularly for any sport; nor had they exercised on a daily basis over the three years before entering the trial.

This study was performed with the approval of the ethics committee of Hirosaki University School of Medicine, and written consent was obtained from all subjects, after the purpose, content, and possible risks associated with the measurements had been explained to them.

Measurement of body density using the underwater weighing method

Body density was determined by weighing subjects in a water bath.[14] We constructed a large water bath (158 cm long, 125 cm wide, and 150 cm deep) specifically for overweight people (over 100 kg). Body density was calculated using the following equation:

$$\text{Body density} = \frac{\text{BWA}}{\left(\frac{\text{BWA-BWW}}{\text{Water density}}\right) - \text{Residual volume of lung}} - 100$$

where BWA = body weight in air, and BWW = body weight during water submersion.

Residual lung volume was measured using a closed circuit oxygen rebreathing, nitrogen dilution method.[15] The percentage of body fat (%fat) was calculated from body density using the formula of Brozek *et al*,[16] and body weight was multiplied by %fat to obtain body fat mass. The fat-free body mass was then obtained by subtracting the body fat mass from the body weight.

Body bioelectrical impedance

Body bioelectrical impedance was measured from the back of the right hand to the back of the right foot using an SIF-891 impedance measurement apparatus with four electrodes (50 kHz; 800 μA; Selco, Kanagawa, Japan). The subject lay supine on a non-conductive surface, limbs abducted slightly. Measurements were taken 10 minutes after this posture had been adopted. The subject was fasted but not dehydrated and had not, within the preceding 12 hours, undertaken strenuous exercise, ingested alcohol, or taken diuretics. The skin surface at the sites of electrode placement was cleaned with alcohol.

Body dimensions

Body dimensions were measured at four sites: upper arm, forearm, thigh, and leg. Circumferences were measured at seven sites: the chest (fourth costosternal joint), the narrowest part of the abdomen (the level of the "natural" waist between ribs and iliac crest), the hip (maximum posterior extension of buttocks), the right upper arm, right forearm, right thigh, and right leg.

Subcutaneous fat thickness

Table 1 Body compositions of sumo wrestlers and controls

	Sumo group		Control group	
Body height (cm)	177.8	(5.3)	174.5	(3.5)*
Body mass index	35.2	(6.4)	36.5	(5.3)
Body weight (kg)	111.2	(21.9)	111.2	(17.1)
Body density	1.043	(0.018)	1.026	(0.011)**
% body fat	24.1	(7.3)	31.4	(5.1)**
Total body fat (kg)	28.0	(13.3)	35.4	(10.4)*
Fat-free body mass (kg)	83.1	(10.1)	75.7	(8.5)**

Values are mean (SD).
*p<0.05, **p<0.01 compared with sumo group.

Subcutaneous fat thickness was measured with B-mode ultrasound equipment (Echo Camera SSD-500; Aloka Co Ltd, Tokyo, Japan) using 3.5 MHz or 7.5 MHz at nine sites on the right side: the lateral forearm (on the anterior surface 30% proximal between the styloid process and the head of the radius); the biceps and triceps (on the anterior and posterior surface 60% distal between the lateral epicondyle of the humerus and the acromial process of the scapula); the subscapular region (at a distance of 5 cm directly below the angulus inferior of the scapula); the abdomen (at a distance of 2–3 cm to the right of the umbilicus); the quadriceps and hamstrings (on the anterior and posterior surface midpoint between the lateral condyle of the femur and the greater trochanter); and the gastrocnemius and tibialis (on the anterior and posterior surface 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia). To measure the subcutaneous fat thickness, the system probe, coated with a conductive gel, was held at the measurement point in contact with the skin, with the subject in a standing position and the arms held naturally in a relaxed position at his sides. The monitor of the ultrasound system displayed the relevant measurements in millimetres. Three measurements were made at each site, and the mean value was used as the fat thickness.

Statistical analysis

Differences between the two groups were tested using Student's *t* test. Linear regressions were applied to estimate the relation between body density and other variables, using the method of least squares and the Pearson product-moment correlation (*r*). A stepwise multiple regression analysis was performed using body densities as the objective variables and other measurement values (without the total values of the nine and the six sites of subcutaneous fat thickness) as the

Table 2 Body length and circumference in sumo wrestlers and controls

	Sumo group (A)		Control group (B)		A–B
Circumference					
Chest	116.7	(11.0)	118.3	(11.9)	1.6
Abdomen	106.9	(15.6)	112.9	(12.8)	6.0
Hip	111.2	(11.4)	114.1	(9.0)	2.9
Upper arm	39.9	(4.0)	38.5	(3.7)*	1.4
Forearm	32.0	(2.6)	30.5	(2.2)*	1.5
Thigh	68.9	(6.8)	67.1	(4.4)*	1.8
Leg	44.2	(4.2)	46.0	(3.2)	1.8
Length					
Upper arm	32.4	(1.9)	32.1	(1.2)	0.3
Forearm	25.2	(1.5)	24.9	(1.4)	0.3
Thigh	40.5	(2.1)	39.3	(1.4)	1.2
Leg	41.4	(2.0)	40.8	(1.0)	0.6
Waist/hip ratio	2.52	(0.13)	2.49	(0.11)	0.03

Values are expressed in mm and are means (SD).
*Significantly different from Sumo group, p<0.05.

Table 3 Subcutaneous fat thickness of sumo wrestlers and controls

	Sumo group (A)	Control group (B)	A–B
Biceps	8.2 (3.6)	11.0 (2.9)**	2.8
Triceps	11.8 (4.1)	15.0 (2.9)**	3.2
Lateral forearm	7.5 (2.1)	8.2 (1.6)	0.7
Quadriceps	12.2 (4.0)	15.5 (3.3)**	3.3
Hamstrings	13.7 (2.7)	7.5 (3.6)**	3.8
Tibialis	7.5 (2.7)	7.9 (1.7)	0.4
Gastrocnemius	10.1 (2.7)	12.0 (2.2)*	1.9
Abdomen	35.0 (18.8)	56.2 (14.0)**	21.2
Subscapula	16.2 (8.4)	31.9 (7.3)**	15.7
Six sites	97.1 (39.2)	147.0 (34.3)**	49.9
Nine sites	122.3 (45.6)	175.1 (34.3)**	52.8

Values are expressed in mm and are means (SD).The six sites were: biceps, triceps, abdomen, subscapular, quadriceps, and hamstrings. *Significantly different from Sumo group, p<0.05, **p<0.01.

explanatory variables, to develop the predictive equations. p<0.05 was considered significant.

RESULTS

Body composition

Table 1 shows the body compositions of both groups. Although the sumo wrestlers were significantly taller than the controls (p<0.05), body weights were similar in the two groups (about 111.2 kg). Therefore, body mass index (BMI) was higher in the controls than in the sumo group, although the difference was not significant. Body density was significantly higher (p<0.01) in the sumo group than in the controls. Although %fat was significantly lower (p<0.01) in the sumo group than in the controls, their fat-free body mass was higher (p<0.01).

Body length and circumference

There were no significant differences in body length variables between the two groups (table 2). As for circumference, the values for the body trunk (chest, abdomen, and hip) were lower in the sumo group than in the control group, although the differences were not significant, whereas the values of the extremities (upper arm, forearm, and thigh) were significantly higher (p<0.05 for all) for the sumo group compared with the controls.

Subcutaneous fat thickness

The values for all sites, especially the abdomen, posterior leg, and subscapular, were significantly higher (p<0.01 for all) in the control group than in the sumo group (table 3).

Correlations between body density and other measured values

Simple linear correlations

In general, the correlation (Pearson's) coefficients were higher for the sumo wrestlers than for the controls. The highest coefficient to body density was seen in the nine and the six sites (r = 0.949, p<0.001 for all), followed by the abdomen (r = 0.937, p<0.001) and the triceps (r = 0.934, p<0.001) in the sumo group. In the control group, the nine sites (r = –0.952, p<0.001) also gave the highest coefficient, followed by the six sites (r = –0.947, p<0.001), then the abdomen (r = –0.939, p<0.001) (table 4).

The predictive equations were formulated using the three values of subcutaneous fat thickness (table 5), as well as the equation of Abe *et al*[13] for an average non-athletic, non-overweight person. Although there was a significant correlation (r = 0.939, p<0.001) with the waist/hip ratio in the sumo group, it was not significant in the control group. There were no significant differences in impedance in either group.

Multiple regression analysis

The standardised regression coefficients (table 5) were significant in the sumo group for the fat thickness of the abdomen (standardised regression coefficient –0.00038, p<0.001), the circumference of the hips (–0.00043, p<0.05), and the fat thickness of the triceps (–0.00142, p<0.05), with body density as the objective variable, whereas the coefficients were significant for the fat thickness of the abdomen (–0.00070, p<0.05) and the tibialis (0.00140, p<0.0001) in the control group. The predictive equations for body density were derived using the variables shown to be significant in the above analysis. For the sumo group, y (body density) = 1.121–0.00038 × (fat

Table 4 Pearson's correlation coefficients and partial coefficients between body density and other measured items in the sumo wrestlers ans controls

	Sumo group		Control group	
Measured items	Pearson	Partial	Pearson	Partial
Body mass index	–0.863***	–0.519	–0.693**	0.481
Impedance	0.239	0.788	0.388	–0.307
Subcutaneous fat thickness				
Biceps	–0.901***	–0.848*	–0.883***	–0.468
Triceps	–0.934***	–0.387	–0.846***	–0.110
Lateral forearm	–0.912***	–0.843*	–0.586*	–0.463
Quadriceps	–0.905***	–0.672	–0.821***	0.029
Hamstrings	–0.847***	–0.602	–0.811***	–0.222
Tibialis	–0.809***	0.312	–0.570*	–0.178
Gastrocnemius	–0.716***	0.125	–0.683***	0.128
Abdomen	–0.937***	0.317	–0.939***	–0.184
Subscapula	–0.787***	–0.461	–0.747***	–0.246
Nine sites	–0.949***		–0.952***	
Six sites	–0.949***		–0.947***	
Circumference				
Chest	–0.834***	0.714	–0.650**	–0.192
Abdomen	–0.898***	0.000	–0.707***	0.337
Waist/hip ratio	–0.673***	–0.102	–0.384	–0.342
Hip	–0.895***	0.162	–0.713**	–0.353
Upper arm	–0.760***	0.832*	–0.625**	–0.297
Forearm	–0.618**	0.712	–0.427*	0.102
Thigh	–0.838***	–0.135	–0.498*	–0.114
Leg	–0.771***	–0.216	–0.578**	–0.332

*p<0.05, **p<0.01, ***p<0.001.

Table 5 Prediction equation for body density using multi-measurement of subcutaneous fat thickness and hip circumference

	Sumo group	Control group
Simple regression equation		
Nine sites	y = 1.088 – 0.00036x (r^2 = 0.90)	y = 1.083 – 0.00033x (r^2 = 0.91)
Six sites	y = 1.084 – 0.00042x (r^2 = 0.90)	y = 1.079 – 0.00036x (r^2 = 0.90)
Abdomen	y = 1.074 – 0.00087x (r^2 = 0.88)	y = 1.071 – 0.00080x (r^2 = 0.88)
Abe's equation for non-athletic men of normal weight		
Nine sites	y = 1.090 – 0.00050x (r^2 = 0.79)	
Six sites	y = 1.087 – 0.00056x (r^2 = 0.78)	
Abdomen	y = 1.078 – 0.00112x (r^2 = 0.76)	
Multiple regression equation		
Sumo group	y = 1.121 – 0.00038 × (fat thickness of abdomen) – 0.00043 × (circumference of hip) – 0.00142 × (fat thickness of triceps) (R^2 = 0.94; SEE 0.0045)	
Control group	y = 1.076 – 0.00070 × (fat thickness of abdomen) – 0.00140 × (fat thickness of tibialis) (R^2 = 0.91; SEE 0.0034)	
Abe's equation for non-athletic men of normal weight		
	y = 1.091 – 0.00065 × (fat thickness of abdomen) – 0.0029 × (fat thickness of quadriceps) – 0.0010 × (fat thickness of subscapula) (R^2 = 0.824)	

SEE, Standard error of estimate.

thickness of abdomen)–0.00043 × (circumference of hips)–0.00142 × (fat thickness of triceps) (r^2 = 0.94). For the control group, y = 1.076–0.00070 × (fat thickness of abdomen)–0.00140 × (fat thickness of tibialis) (r^2 = 0.91).

DISCUSSION

Although the two groups in this study were very similar in body length and weight, their body compositions were very different. The value of %fat obtained from body density by the underwater weighing method was 24.1% in the sumo group and significantly higher at 31.4% in the controls ($p<0.01$). The distribution of body fat was also different between the groups. It was concentrated on the trunk in the controls rather than the extremities, in contrast with the sumo group, although the subcutaneous fat thickness at all sites was greater in the controls than in the wrestlers. Although there was a significant correlation between body density and waist/hip ratio in the sumo group, there was no such correlation in the controls. This is because fat accumulates predominantly in the internal and external abdomen in sumo wrestlers unlike in controls.

There are many current methods for evaluating body composition: underwater weighing, BMI, potassium measurement, computed tomography (CT), magnetic resonance imaging (MRI), bioelectrical impedance analysis, and measurement of subcutaneous fat thickness by B-mode ultrasound or calipers.

The BMI approach is popular because it is easy, but its inaccuracy in athletes is well recognised.[17] In our study, the Pearson coefficient of BMI to body density was –0.863 ($p<0.01$) in the sumo group and –0.693 ($p<0.05$) in the controls, lower than the corresponding values for subcutaneous fat thickness. The bioelectrical impedance method is also popular because of its ease of use. Once again, however, the inaccuracy of this method has been reported in both obese subjects and athletes.[10 18] It is particularly difficult to measure sumo wrestlers because they are both overweight and highly trained athletes. Moreover, in this study, there was no significant correlation between the impedance value and body density.

CT and MRI are also possible methods for evaluating body composition.[19 20] One major disadvantage of the CT method is the high levels of potentially harmful irradiation, although it offers the advantages of clear images and precision.[20] CT and MRI systems are also extremely expensive and require large facilities and well trained expert staff. For sumo wrestlers to control their weight, it is necessary to measure body composition repeatedly, so the method must be easy and as non-invasive as possible.

Methods of measuring subcutaneous fat thickness include the use of calipers and B-mode ultrasound. The caliper method is not easily applied to sumo wrestlers, because it is difficult to gather up both skin and subcutaneous fat because of their high body tone. On the other hand, B-mode ultrasound simply requires holding the probe against the skin, and images are easily acquired[21]; therefore it is useful for both sumo wrestlers and non-athletes. Moreover, this method is more precise for obese subjects than using calipers.[12 22]

Table 6 Comparison of values for body density estimated in this study with those estimated by inserting the data into the equation of Abe *et al*[13]

	Sumo group	Control group
Simple regression equation		
Estimated by Abe's equation (nine sites)	1.029 (30.0)	1.003 (45.7)
Estimated by Abe's equation (six sites)	1.033 (27.0)	1.005 (40.0)
Estimated by Abe's equation (abdomen)	1.039 (25.7)	1.015 (35.1)
Estimated by this study (nine sites)	1.044 (23.8)	1.025 (31.7)
Estimated by this study (six sites)	1.043 (24.1)	1.026 (31.4)
Estimated by this study (abdomen)	1.044 (23.8)	1.026 (31.4)
Multiple regression equation		
Estimated by this study	1.044 (23.8)	1.026 (31.3)
Estimated by underwater weighing method	1.044 (23.8)	1.026 (31.3)

Values in parentheses are % body fat.

Take home message

A method is required for evaluating body density in sumo wrestlers to enable them to control their weight, thus preventing obesity related diseases, while maintaining their competitive athletic performance. This study is the first to develop an accurate, easily managed, and repeatable predictive equation for the body density of sumo wrestlers, by comparatively simple multi-measurement of subcutaneous fat thickness and hip circumference.

Kuczmarski *et al*[12] developed a predictive simple regression equation for the body density of white subjects from the results of B-mode ultrasound, and Abe *et al*[13] developed a similar predictive equation for members of the general Japanese population, also from the results of B-mode ultrasound. However, there has been no report on sumo wrestlers.

The highest coefficients of determination (r^2) in this study were observed for the sum of the subcutaneous fat thickness for the nine and six sites. Therefore, a simple regression equation using the sum of the subcutaneous fat thicknesses gave the best prediction.

The values of the nine sites, six sites, and abdomen in this study were inserted into the equation of Abe *et al,*[13] and the results are shown in table 6. The values were lower than the body density from the underwater weighing method by 0.005–0.015 (%fat is 1.9–6.2%) in the sumo group and 0.011–0.021 (%fat is 3.8–14.4%) in the controls. Thus, a predictive equation for body density in this study is not yet available for non-athletes of normal weight.

The predictive equation for body density from the multiple regression equation given in the Results section gives a higher r^2 value for the sumo wrestlers (0.94) than for the controls (0.91). This may be due to differences in body fat distribution as mentioned above.

We believe we are the first to develop an accurate, easily handled, and repeatable predictive equation for the body density of sumo wrestlers, by the comparatively simple multi-measurement of subcutaneous fat thickness and hip circumference. This equation may be useful in controlling the body weight of sumo wrestlers, while allowing them to maintain their competitive strength. One weak point in this study is the lack of a comparable equation for non-overweight athletes or other overweight athletes such as judoists, wrestlers, and weightlifters. Furthermore, it should be noted that the B-mode ultrasound method cannot be used for assessment of visceral fat mass.[23] Another problem of this method is the difficulty in standardising the pressure that is applied through the transducer to the scan site.[24]

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