APPLIED HUMAN SCIENCE
Journal of Physiological Anthropology

Comprehensive Evaluation of Selected Methods for Assessing Human Body Composition

Shin-ichi Demura[1)], Hidetsugu Kobayashi[2)], Kiyoji Tanaka[3)], Susumu Sato[4)], Yoshinori Nagasawa[5)] and Tomohiko Murase[6)]

1) Faculty of Education, Kanazawa University
2) Fukui National College of Technology
3) Institute of Health and Sport Sciences, University of Tsukuba
4) Kanazawa Institute of Technology
5) Akita Prefectural College of Agriculture
6) Research Center of Physical Education, Aichi University

Abstract. The present study investigated the validity, reliability, objectivity, and practicability of methods with skinfold caliper (SF), ultrasound (US), bioelectrical impedance (BI), and sulfur hexafluoride (SHD) using identical subjects, and evaluated comprehensive usefulness by comparing selected methods or equations. In examining validity, underwater weighing (UW) was employed to obtain the criterion of validity. The subjects were healthy Japanese, 16 males and 15 females, aged 18 to 32 years. The prediction equation developed by Nakadomo et al. (1990b) was considered to be suitable for BI. With respect to the validity, BI and SHD assessing total body when estimating body composition would be more valid than those assessing partial subcutaneous skinfold thickness. A comprehensive evaluation through an examination with respect to the validity, reliability, objectivity, and practicability suggests that the BI could be the best method to assess human body composition *in vivo*.

(Appl Human Sci, 18 (2): 43-51, 1999)

Keywords: human body composition, underwater weighing, skinfold caliper, ultrasound, bioelectrical impedance, sulfur hexafluoride dilution, validation

Introduction

Body composition *in vivo* has been indirectly estimated with the use of body density, total body water, total body nitrogen, ^{40}K whole body counting, urinary creatinine excretion, etc (Buskirk, 1987). However, none of these methods can be practically used when measuring large samples because they need large-scale facilities and devices or complex techniques and procedures.

Thickness of partial subcutaneous fat has been assessed with skinfold caliper, near-infrared rays, ultrasound, etc (Kuczmarski et al., 1994; Comway and Norris, 1987). Various equations to estimate body density and body fat from the thickness of subcutaneous fat have been proposed, with high correlation between both variables (Brozek and Keys, 1951; Hayes et al., 1988; Katch and McArdle, 1973; Nagamine and Suzuki, 1964; Wilmore and Behnke, 1970). In recent years, a bioelectrical impedance method to estimate body composition is getting popular, because the cost of the device is relatively inexpensive and the procedure is simple (Nakadomo et al., 1990a; Tanaka et al., 1992). Hydrodensitometry, or underwater weighing, where the subjects must participate in a series of complex procedures, has been employed to determine the criterion of validity when examining a prediction equation. The estimation of percent body fat requires a precise measurement of residual volume, whereas a recently developed sulfur hexafluoride dilution method requires neither the underwater measurement nor an assessment of the residual volume.

As noted above, various methods and prediction equations to estimate body composition have been proposed, and the usefulness of each method or equation has been separately examined. However, there are some doubts whether the usefulness can be applied to different populations or different conditions.

The present study examined the validity, reliability, objectivity, and practicability of methods with skinfold caliper, ultrasound, bioelectrical impedance, and sulfur hexafluoride using identical subjects, and evaluated comprehensive usefulness by comparing selected methods or equations. In examining validity, underwater weighing was employed to obtain the criterion of validity.

Table 1 Physical characteristics of subjects

Group		Age (years)	Height (cm)	Weight (kg)
Male [n=16]	Mean	21.6	170.4	64.8
	SD	3.57	5.63	7.41
	Range	18.0 ~ 32.0	159.7 ~ 179.8	45.9 ~ 74.1
Female [n=15]	Mean	20.4	160.3	55.3
	SD	0.95	4.48	6.02
	Range	19.0 ~ 22.0	150.2 ~ 167.0	48.5 ~ 67.5

Methods

Subjects

The subjects were healthy Japanese, 16 males and 15 females, aged 18 to 32 years. The physical characteristics of the subjects are summarized in Table 1. Mean height and weight did not differ significantly from the Japanese standard for the same age (Laboratory of Physical Education, Tokyo Metropolitan University, 1990). Prior to measurement, the purpose and procedure of the study were explained in detail and informed consent was obtained from all subjects.

Equations to estimate body composition

Up to the present, various prediction equations to estimate percent body fat have been proposed (Brozek et al., 1963; Siri, 1961; Lohman, 1992; Forbes et al., 1992). With the representative equation (*equation 1*) for adults developed by Brozek et al. (1963), the percent body fat can be estimated from the body density of each subject. Underwater weighing (UW) has been assumed to be one of the most precise methods to estimate body density. Body density can be calculated using the equation (*equation 2*) of Goldman and Buskirk (1961), which assesses underwater weight and residual volume.

$$\%BF = 100\ (4.57 / Db - 4.142) \quad \text{........ 1)}$$
$$Db = W / \{(W - Ww / Dw) - RV - VGI\} \quad \text{........ 2)}$$
$$= W / (V - RV - VGI) \quad \text{........ 3)}$$

(where, %BF: percent body fat, Db: body density, W: body weight, V: body volume, Ww: underwater body weight, Dw: water density, RV: residual volume, VGI: volume of gas in the viscera)

Body density can also be calculated by *equation 3*, which assesses body volume. The sulfur hexafluoride dilution (SHD) method has the advantage that V — RV can be directly obtained without the underwater measurement. This advantage permits measurements of body composition on aged or physically handicapped persons. If the problems of cost and accuracy are solved, SHD could become widely used in research and clinical fields.

The bioelectrical impedance (BI) method can estimate fat-free mass (FFM) or body density by means of the impedance and height and/or weight. Percent body fat is simply estimated from the FFM in the equation, $\%BF=100\ \{1 - (FFM/W)\}$. The skinfold (SF) method and the ultrasonic (US) method determine body density as the estimate of percent body fat by assessing the thickness of subcutaneous fat.

Measurement and procedure for each method

Each subject was given 5 trials for UW and 2 trials for other methods (SF, US, BI, and SHD). In addition, a retest was performed under identical conditions 1 week after the first measurement in order to determine the test-retest reliability.

For all methods, the subjects were instructed not to eat and exercise, and to urinate and evacuate 2 hours before the measurement.

Underwater weighing, UW—Underwater weight was assessed in a stainless water tank with depth of 1.5 meter and water temperature of 35 to 37 degrees Centigrade. The subjects, after changing into a swimsuit, sat on a chair attached to a weighing scale (AD-6204, A&D), and the underwater weight was assessed during maximum expiration. Residual volumes for males and females were calculated as vital capacity multiplied by 0.28 and 0.24, respectively (Wilmore and Behnke, 1970). Body density was estimated by assuming 150 ml of gas in the viscera.

Skinfold method, SF—Two skinfolds at the triceps and subscapular on the right side of the body were measured with a Lange skinfold caliper (Cambridge Scientific Co.). Skilled testers with more than 2-year experience and conducting at least 100 measurements a year measured the skinfolds.

Ultrasonic B-mode method, US—The thickness of subcutaneous fat at the triceps and subscapular were measured with an ultrasonic B-mode device (EUB-200, Hitachi Medical Corp.). Ultrasonic gel was applied to the surface of the probe, and special care was taken in order not to add excessive pressure to the skin.

Bioelectrical impedance method, BIa and BIb—Bioelectrical impedance was measured in a supine position (SIF-891, Selco) and at a standing position (TBF-101, Tanita Corp.) using a tetrapolar lead system at a frequency of 50 kHz. For the measurement in the supine position (BIa), the subjects lay on a bed with the arms not touching the body and the legs separated

Table 2 Prediction equations selected in this study

Method	Reference	Group	Equation	(No.)
SF	Nagamine & Suzuki	Male	$Db\ (g/ml) = 1.0913 - 0.00116\ X$	.... (1)
		Female	$Db\ (g/ml) = 1.0897 - 0.00133\ X$	.... (2)
	Tahara et al.	Male	$Db\ (g/ml) = 1.08584 - 0.00110\ X$	.... (3)
		Female	$Db\ (g/ml) = 1.07406 - 0.00093\ X$	.... (4)
US	Ishida et al.	Male	$Db\ (g/ml) =-1.0957 - 0.0018\ X$	.... (5)
		Female	$Db\ (g/ml) =-1.0919 - 0.0044\ X$	.... (6)
BI	Lukaski et al.	Male	$FFM\ (l) = 5.214 + 0.827\ (Ht^2/Z)$	.... (7)
		Female	$FFM\ (l) = 4.917 + 0.821\ (Ht^2/Z)$	.... (8)
	Segal et al.	Male	$Db\ (g/ml) = 1.1554 - 0.0841\ (Wt \cdot Z)\ /\ Ht^2$	.... (9)
		Female	$Db\ (g/ml) = 1.1113 - 0.0556\ (Wt \cdot Z)\ /\ Ht^2$	..... (10)
	Lohman	Male	$FFM\ (l) = 0.485\ (Ht^2/Z) + 0.338\ (Wt) + 5.32$	..... (11)
		Female	$FFM\ (l) = 0.476\ (Ht^2/Z) + 0.295\ (Wt) + 5.49$	..... (12)
	Nakadomo et al.	Male	$Db\ (g/ml) = 1.1492 - 0.0918\ (Wt \cdot Z)\ /\ Ht^2$	..... (13)
		Female	$Db\ (g/ml) = 1.1628 - 0.1067\ (Wt \cdot Z)\ /\ Ht^2$	..... (14)

SF: Skinfold method, US: Ultrasonic B-mode method, BI: Bioelectrical impedance method, Db: body density, FFM: fat-free mass, X: sum of skinfold thickness (triceps and subscapular), Ht: height (cm), Wt: weight (kg), Z: impedance (W).

sufficiently. After all skin contact areas were cleaned with diluted alcohol, two ECG electrodes were positioned with thin Keratin electrolyte gel (Fukuda Denshi Corp.) on the dorsal surface of the right hand and foot at the distal metacarpal and metatarsal, respectively. The distance between the current-introducing electrodes and the detector electrodes was maintained at 3 cm for both extremities. For the measurement in a standing position (BIb), the subjects stood on a device with the soles of the feet separately touching an electrode plate to detect the bioelectrical impedance between both extremities.

Sulfur hexafluoride dilution method, SHD—The measurement was conducted using a weighing device (BSF-200, Simazu Corp.) and the calibration was completed against a standard device with a volume of 60 liters. After the subject entered the measurement chamber, sulfur hexafluoride gas was perfused into the chamber. After the gas was refluxed and stirred well, the total body volume was assessed.

Selected prediction equations for each method

Various prediction equations for estimating body density or fat-free mass have been proposed, and validity differs according to the applied equation. The prediction equations presented in Table 2 were selected with consideration to the characteristics of the subjects (i.e., age, sex, race) and the validity against each method. For SF, equations by Nagamine and Suzuki (1964) and Tahara et al. (1995a, 1995b) have been selected because the former has been widely used for Japanese and the latter have been recently developed using a large Japanese population. For US, an equation of Ishida et al. (1985) has been only proposed for Japanese. For BI, four equations by Lukaski et al. (1986), Segal et al. (1985), Lohman (1992), and Nakadomo et al. (1990b). were selected from among many equations developed for Japanese and non-Japanese. For all methods, the percent body fat was calculated with the equation of Brozek et al. (1963).

Examination of practicability

Practicability is also an important factor in evaluating the method, and is evaluated by (1) the simplicity of conducting the measurement, (2) the ease of use of the device or equipment, (3) the space required for measuring, (4) the cost of conducting measurements, (5) the existence of comparative standards, etc. The present study determined the practicability of each method with a questionnaire in which the subjects indicated the degree of distress. In addition, time to prepare and complete measurements was measured, and the cost was also investigated.

Results

Table 3 shows basic statistics for both the first and second trials of the 6 methods. Mean percent body fat obtained from the first trial of UW was 16.7% for males and 24.7% for females. For all methods, there were no significant differences in the *t*-test, and the correlation coefficients between the 2 trials were 0.92 or greater, indicating high reliability. From these results, the mean of the consecutive 2 trials was defined as a representative value.

Basic statistics for separate first and second measurements of all methods indicating test-retest reliability are shown in Table 4. There were no significant differences in the *t*-test for all methods, and all of the correlation coefficients were significant, although obtained slightly lower than those shown in Table 3.

Table 3 Basic statistics in the consecutive first and second trials for 6 methods

Method	Group	Variable	1st trial		2nd trial		t-test	r
			Mean	SD	Mean	SD		
UW	Male	Ww (kg)	2.71	0.45	2.74	0.42	ns	0.92*
		Db (g/ml)	1.06	0.01	1.06	0.01	ns	0.94*
		%BF (%)	16.7	3.43	16.5	3.44	ns	0.94*
	Female	Ww (kg)	1.24	0.58	1.18	0.59	ns	0.98*
		Db (g/ml)	1.04	0.01	1.04	0.01	ns	0.99*
		%BF (%)	24.7	5.08	25.2	5.34	ns	0.99*
SF	Male	triceps (mm)	9.3	2.51	9.4	2.60	ns	0.99*
		subscapular (mm)	10.1	1.36	10.1	1.47	ns	0.97*
	Female	triceps (mm)	12.5	3.20	12.6	3.20	ns	0.99*
		subscapular (mm)	11.4	2.66	11.4	2.66	ns	0.99*
US	Male	triceps (mm)	5.8	1.68	5.9	1.81	ns	0.96*
		subscapular (mm)	4.9	0.89	4.8	0.83	ns	0.96*
	Female	triceps (mm)	9.1	1.96	9.1	1.78	ns	0.95*
		subscapular (mm)	5.9	1.10	5.9	1.13	ns	0.92*
BIa	Male	Z (W)	44.8	4.76	44.9	4.90	ns	0.99*
	Female	Z (W)	51.9	5.39	52.1	5.40	ns	0.99*
BIb	Male	Z (W)	45.2	5.59	45.3	5.28	ns	0.98*
	Female	Z (W)	49.4	5.95	49.5	5.78	ns	0.99*
SHD	Male	BM (l)	62.3	7.02	62.2	6.96	ns	0.99*
		Db (g/ml)	1.05	0.01	1.06	0.01	ns	0.96*
	Female	BM (l)	52.1	6.03	52.0	6.08	ns	0.99*
		Db (g/ml)	1.03	0.02	1.03	0.02	ns	0.93*

UW: Underwater weighing, BIa: Bioelectrical impedance method in the supine position, BIb: Bioelectrical impedance method in the standing position, SHD: Sulfur hexafluoride dilution, %BF: percent body fat, BM: body mass, Ww: water weight, ns: not significant, *p<0.05.

Table 4 Basic statistics in the separate first and second measurements for 6 methods

Group	Method	Variable	1st measurement		2nd measurement		t-test	r
			Mean	SD	Mean	SD		
Male	UW	Ww (kg)	2.68	0.48	2.69	0.52	ns	0.95*
		%BF (%)	16.8	3.08	16.9	3.01	ns	0.90*
	SF	triceps (mm)	9.4	2.68	8.9	2.43	ns	0.87*
		subscapular (mm)	10.1	1.52	9.8	1.67	ns	0.79*
		%BF (%)	13.4	1.85	13.1	1.68	ns	0.83*
	US	triceps (mm)	6.0	1.90	5.8	1.88	ns	0.88*
		subscapular (mm)	4.8	1.11	4.4	0.89	ns	0.56*
		%BF (%)	9.7	1.69	9.2	1.49	ns	0.67*
	BIa	Z (W)	44.7	4.87	44.6	4.89	ns	0.99*
		%BF (%)	17.4	1.96	17.4	2.07	ns	0.99*
	BIb	Z (W)	45.7	5.64	45.5	5.72	ns	0.98*
		%BF (%)	18.1	1.93	18.2	1.92	ns	0.98*
	SHD	BM (l)	62.3	7.04	62.2	7.01	ns	0.96*
		%BF (%)	21.9	4.33	20.9	4.33	ns	0.90*
Female	UW	Ww (kg)	1.19	0.43	1.18	0.60	ns	0.93*
		%BF (%)	23.0	6.25	23.6	7.01	ns	0.93*
	SF	triceps (mm)	13.7	3.64	13.6	3.53	ns	0.73*
		subscapular (mm)	13.5	3.10	13.4	3.02	ns	0.92*
		%BF (%)	19.6	3.44	19.5	3.36	ns	0.73*
	US	triceps (mm)	9.3	1.99	9.1	1.53	ns	0.81*
		subscapular (mm)	5.9	1.12	5.9	1.41	ns	0.57*
		%BF (%)	31.4	5.03	31.4	5.11	ns	0.65*
	BIa	Z (W)	51.7	5.48	51.9	5.30	ns	0.99*
		%BF (%)	22.9	3.00	22.8	2.99	ns	0.99*
	BIb	Z (W)	49.4	6.15	49.6	6.00	ns	0.99*
		%BF (%)	25.1	3.42	25.1	3.43	ns	0.99*
	SHD	BM (l)	52.1	6.01	52.0	6.06	ns	0.98*
		% BF (%)	27.1	6.30	27.0	6.50	ns	0.88*

ns: not significant, *p<0.05.

Table 5 Basic statistics in objectivity of the measurements for 4 methods

Group	Method	Variable	tester A		tester B		*t*-test	r
			Mean	SD	Mean	SD		
Male	UW	Ww (kg)	2.58	0.64	2.66	0.61	ns	0.95*
		%BF (%)	17.6	4.24	17.0	3.59	ns	0.89*
	SF	triceps (mm)	9.9	15.30	10.1	15.80	ns	0.87*
		subscapular (mm)	9.4	2.68	8.8	2.4	ns	0.74*
		%BF (%)	13.4	1.85	13.1	1.69	ns	0.93*
	US	triceps (mm)	5.5	1.79	4.8	1.06	ns	0.91*
		subscaplar (mm)	4.6	0.96	4.1	0.57	ns	0.65*
		%BF (%)	9.9	1.67	9.0	0.98	ns	0.95*
	SHD	BM (l)	63.0	5.75	62.9	5.77	ns	0.96*
		%BF	21.9	5.27	20.9	5.10	ns	0.82*
Female	UW	Ww (kg)	1.17	0.44	1.18	0.62	ns	0.94*
		%BF (%)	22.9	6.05	23.0	6.55	ns	0.89*
	SF	triceps (mm)	13.7	3.64	13.4	3.29	ns	0.75*
		subscapular (mm)	13.0	3.31	13.4	3.07	ns	0.97*
		%BF (%)	19.3	3.45	19.4	3.12	ns	0.92*
	US	triceps (mm)	9.1	1.95	9.3	1.54	ns	0.87*
		subscapular (mm)	5.9	1.10	6.2	1.42	ns	0.77*
		%BF (%)	31.4	5.03	32.3	5.10	ns	0.87*
	SHD	BM (l)	54.7	5.96	54.7	5.97	ns	0.98*
		%BF (%)	27.9	6.29	27.8	6.49	ns	0.81*

ns: not significant, *$p<0.05$.

Basic statistics in objectivity of the measurement for the 4 methods are shown in Table 5. There were no significant differences in the *t*-test, and the correlation coefficients were 0.65 or greater, indicating relatively high objectivity.

Table 6 shows the mean percent body fat estimated with the selected prediction equations in Table 2 and the correlation coefficients of UW with SF, US, BIa, and BIb methods. The correlation coefficients of UW with SF when applying the equation by Nagamine and Suzuki (1964) were 0.47 for males and 0.48 for females. Significant differences between the means of both methods were found for males. When applying the equations by Tahara et al. (1995a, 1995b), the correlation coefficients were 0.44 for males and 0.44 for females, and a significant difference was not found for males and females. The correlation coefficients of US using the equation of Ishida et al. (1985) were 0.56 for males and 0.54 for females, and significant differences between the means were found for both males and females. Four different equations were used with both bioelectrical impedance methods in the supine and standing positions. The correlation coefficients of the BIa ranged from 0.58 to 0.63 for males and 0.64 to 0.67 for females, thus being consistent over the 4 equations. With the equation by Nakadomo et al. (1990b), a significant difference was not found. The correlation coefficients for BIb were relatively lower than those for BIa, and no significant difference was found only when the equation of Nakadomo et al. (1990b) was applied, as was the case for BIa. From these results, with respect to the validity of the selected body composition methods, the prediction equations developed by Nagamine and Suzuki (1964), Ishida et al. (1985), and Nakadomo et al. (1990b) can be applied to the SF, US, and BI methods, respectively.

Table 7 shows the correlation coefficients with UW for each method to estimate percent body fat. The correlation coefficients indicate moderate correlations, although higher correlation coefficients (0.82 and 0.94) were obtained for SHD. As a whole, higher correlations were obtained from females than from males. Relative differences in SF and US for males and females were different from those of UW, and there were no significant differences in BIa and BIb with UW for males and females. With respect to SHD, a significant difference was obtained for males and females.

The degree of distress perceived in the measurement indicating the practicability was investigated for each method. Sixty-three and sixty-four percent of the subjects perceived the distress in UW for males and females, respectively, whereas the percentages in SF, US, BIa, BIb, and SHD ranged from 0 to 14 % for males and females. The degree of distress was highest for UW, and relatively low for the remaining methods.

The length of time required to prepare and complete the measurement for each subject, expressed as minute, is summarized in Table 8. The methods of SF, US, and BI indicate shorter time durations to complete the measurement. Though SHD required a longer time to calibrate the device, the time required to complete the

Table 6 Percent body fat (%BF) estimated with the selected prediction equations

Method	Equation	No.	Group	%BF (%) Mean	SD	r
SF	Nagamine & Suzuki	(1)	Male	12.8**	1.77	0.47
		(2)	Female	19.8	3.42	0.48
	Tahara et al.	(3)	Male	14.8	1.61	0.44
		(4)	Female	21.3	2.39	0.44
US	Ishida et al.	(5)	Male	9.7**	1.93	0.56*
		(6)	Female	31.4**	5.01	0.54*
BIa	Lukaski et al.	(7)	Male	7.9**	4.29	0.60*
		(8)	Female	16.5**	4.94	0.64**
	Segal et al.	(9)	Male	11.4**	1.80	0.58*
		(10)	Female	21.1	1.58	0.67**
	Lohman	(11)	Male	8.7**	2.65	0.61**
		(12)	Female	17.3**	3.06	0.64**
	Nakadomo et al.	(13)	Male	17.4	2.01	0.63**
		(14)	Female	23.1	2.97	0.66**
BIb	Lukaski et al.	(7)	Male	8.4**	4.47	0.39
		(8)	Female	12.7**	6.85	0.39
	Segal et al.	(9)	Male	11.7**	1.98	0.54*
		(10)	Female	20.0*	2.03	0.56*
	Lohman	(11)	Male	9.0**	2.67	0.51*
		(12)	Female	15.0**	4.06	0.49
	Nakadomo et al.	(13)	Male	17.7	2.21	0.58*
		(14)	Female	21.0	4.01	0.59*

*p<0.05, **p<0.01.

Table 7 Relative differences of percent body fat and correlation coefficients of 5 methods with UW

Method	Male			Female		
	difference (%)	*t*-value	r	difference (%)	*t*-value	r
UW *vs* SF	3.9	4.32**	0.49	3.0	1.52*	0.49
US	6.5	6.19**	0.56*	8.2	5.31**	0.54*
BIa	0.6	1.38	0.63**	0.1	0.04	0.66**
BIb	0.8	0.70	0.58*	2.2	1.28	0.59*
SHD	4.5	4.62**	0.82*	4.1	3.34**	0.94**

*p<0.05, **p<0.01.

Table 8 Time required for measurement and price of the device

Method	required time: measurement	required time: preparation & measurement	price (1,000 yen)
UW	B	C	~ 5,000
SF	A	A	~ 640
US	A	B	~ 1,250
BIa	A	B	~ 1,200
BIb	A	A	~ 850
SHD	B	C	~ 5,000

A: 1~4 min, B: 5~9 min, C: 10 min~.

measurement was within 10 minutes. UW took 5 minutes to complete 1 trial, but the method required the longest time for both preparation and measurement due to repetitive trials. The devices for UW and SHD are much more expensive because they were manufactured on order.

Discussion

Recently, methods to assess body composition have been developed and established through various examinations, and their usefulness has been reported in separate studies (Komiya and Masuda, 1990; Lukaski et al., 1985; Shimogaki et al., 1993). Various equations to estimate body composition also have been proposed with the development of measurement devices (Lohman, 1992; Lukaski et al., 1986; Segal et al., 1985). However, each study examined the usefulness for a limited population. There are some doubts whether the methods and equations can be applied to different populations. Therefore, this study comprehensively investigated the validity, reliability, objectivity, and practicability of representative methods using identical subjects. In the present study, hydrodensitometry or UW was referred to as the method of choice for evaluating more indirect body composition techniques and their accuracy.

Test-retest reliability was examined in two aspects, in consecutive trials and measurements for a one-week interval. The correlation coefficients of UW ranged from 0.92 to 0.99, indicating sufficient reliability of the consecutive trials. Correlation coefficients indicating the reliability in separate measurements ranged from 0.90 to 0.93 (%BF). Previous studies demonstrated that the reliability of the underwater weighing could be easily affected by various factors, and that the upper limit of errors between measurements was 0.27% of percent body fat (Sindo et al., 1979). In this study, the differences in the 2 measurements for male and female were 0.1% and 0.6%, respectively. As the value for females exceeded the upper limit of the error, the mean of the measurements should be used as a representative value. Objectivity when assessing body composition, particularly with SF, must be carefully examined, because the errors derived from the low objectivity may affect the estimates of body composition. Objectivity was examined for the 4 methods, excepting BIa and BIb. The possibility of influence in the measurement error as a result of the skill or experience of a tester was reported with respect to use of skinfold caliper and ultrasonic B-mode methods (Heyward and Stolarczyk, 1996). Although the measurement errors due to a tester for UW, BI and SHD are considered to be theoretically less, objectivity should also be examined because human factors could be involved in the calibration and operation of the equipment or device. The correlation coefficients between the two testers were over 0.65, indicating high objectivity for all methods. In this study, the testers have had sufficient experience and skills for each method. This experience and skill could facilitate measurement with high objectivity. Human errors in the calibration or operation of the device may be involved with SHD because most of duties in the measurement by the tester were instructing the subjects about measurement procedures.

This study determined suitable prediction equations for selected methods. From the results of *t*-tests and correlation coefficients between 2 percent body fat for UW and each method, the prediction equation by Nakadomo et al. (1990b) was considered to be suitable for BI. The validity of these equations was experimentally demonstrated before, but similar validities were not obtained in spite of giving special consideration to the gender, age, and physical size of subjects. Therefore, the characteristics of the applicable population for the prediction equation should be specified in detail. Tanaka et al. (1992) and Nakadomo et al. (1991) demonstrated that adding the information on anthropometric characteristics of subjects could improve the degree of predictive accuracy in the bioelectrical impedance method. In addition, the kind of bioimpedance device or electrode could also affect the result (Nakadomo et al., 1990a). In using the equation developed by Nakadomo et al. (1990b), the correlations with UW were moderate (0.63 for males and 0.66 for females). This suggests the importance of selecting a suitable equation according to the characteristics of subjects.

As shown in Table 7, the validity for females was, on the whole, better than that for males. Similar results in the *t*-test and correlation coefficient were obtained for BIa and BIb, while the relative difference and correlation of US for males was low compared with other methods. The differences in SF for males and females were not large, but the correlation was smaller than that of US. Considering the high reliability for both methods and the results demonstrated in previous studies, these results may be attributed to the selected prediction equations or the tester. Although the correlation coefficients for SHD were relatively high among the selected methods, the relative differences for male and female were significant. From these results with respect to the validity, BI and SHD assessing total body when estimating body composition were considered to be more valid than those assessing partial subcutaneous skinfold thickness.

In general, precise results can be obtained in laboratory measurements requiring complex procedures and relatively long time periods, while field measurements can be used for large-scale samples with simpler procedures and shorter time periods. Although the validity of field measurements is less than that of laboratory measurement, virtually no differences were observed in this study. These results support the use of field measurements as well as laboratory measurements.

The degree to which actual alterations in body composition are determined may depend on the precision of the assessment technique utilized. Tanaka et al. (1993) reported that aerobic exercise induced significant decreases in body fat, independent of the duration of exercise, and that a combination of abdominal girth, BI and/or skinfold measurements would be advantageous in estimating primarily exercise-induced alterations in body fat. BI may not be appropriate to detect acute small changes in body composition but may be of more value longitudinally for larger body composition changes.

The degree of distress that the subjects perceived in the measurement was higher in the measurement requiring total body assessment. Compared with UW and SHD, special preparation, such as a change of clothes, is

Table 9 Results of comprehensive evaluation for 6 methods

Method	Validity	Reliability	Objectivity	Practicability
UW	A	A	A	C
SF	B	A	A	A
US	B	A	A	A
BIa	A	A	A	A
BIb	A	A	A	A
SHD	A	A	A	C

A: excellent, B: good, C: fair.

not necessary to complete the measurement for SF, US, BIa, and BIb; and additionally the time required for such measurement is much shorter. Among the selected methods, the bioelectrical impedance method would be an excellent method, because high reliability, validity, and objectivity were demonstrated, and the cost of device is not so expensive. SHD can be used in the laboratory, but it is very expensive and it takes a long time to calibrate. UW would be a valid method, but it has some disadvantages, such as a longer time period for preparation and measurement, higher distress for the subjects, and so on.

A comprehensive evaluation of validity, reliability, objectivity, and practicability of the selected methods to assess body composition are summarized in Table 9. High reliability and objectivity were found in all methods.

The practicability of SF and US can be acceptable but the validity unacceptable, and the practicability of UW and SHD can be unacceptable but the validity acceptable. For BIa and BIb, both the validity and practicability are acceptable.

In summary, all the methods selected in this study have high reliability and objectivity. From the examination using UW as the criterion method, validity for BIa, BIb, and SHD, requiring total body measurement, would be higher than that of SF, requiring the assessment of partial subcutaneous skinfold thickness. Within the limitation of a small sample size, a comprehensive evaluation through an examination with respect to validity, reliability, objectivity, and practicability suggests that the bioelectrical impedance method could be the best method to assess body composition *in vivo* from among the selected methods.

References

Brozek J, Keys A (1951) The evaluation of leanness-fatness in man: norms and interrelationships. Br J Nutr 36: 32-34

Brozek J, Grande F, Anderson JT, Keys A (1963) Densitometric analysis of body composition: revision of some quantitative assumption. Ann NY Acad Sci 110: 113-140

Buskirk ER (1987) The 1986 C. H. McCloy research lecture; Body composition analysis: The past, present and future. Res Q Exerc Sport 58: 1-10

Comway JM, Norris KH (1987) Noninvasive body composition in humans by near infrared interactance. In Ellis KJ, Yasumura S, Mogan WD eds. *In vivo* body composition studies. The Institute of Physical Sciences in Medicine, Bookheaven, NY, 163-170

Forbes GB, Simon W, Amatruda JM (1992) Is bioimpedance a good predictor of body-composition change? Am J Clin Nutr 56: 4-6

Goldman RF, Buskirk ER (1961) Body volume measurement by underwater weighing; description of a method. In Brozek J, Henschel A eds. Techniques for measuring body composition. National Academy of Sciences, Washington D.C., 78-89

Hayes PA, Sowood PJ, Belyavin A, Cohen JB, Smith FW (1988) Subcutaneous fat thickness measured by magnetic resonance imaging, ultrasound, and calipers. Med Sci Sports Exerc 20: 303-309

Heyward VH, Stolarczyk LM (1996) Applied body composition assessment. Human Kinetics, Champaign, IL, 21-43

Ishida Y, Tsunoda N, Kanehisa H, Fukunaga T (1985) Assessment of subcutaneous fat thickness by A-mode ultrasonic method. Jpn J Phys Fitness Sports Med 34: 91-97 (in Japanese)

Katch FI, McArdle WD (1973) Prediction of body density from simple anthropometric measurements in college men and women. Hum Biol 45: 445-454

Komiya S, Masuda T (1990) Estimation of human body composition by bioelectrical impedance measurements; equation for estimating total body water in Japanese subjects. Jpn J Phys Fitness Sports Med 39: 53-59

Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL (1994) Increasing prevalence of overweight among U.S. adults: the National Health and Nutrition Examination Surveys, 1960 to 1991. J Am Med Assoc 272: 205-211

Laboratory of Physical Education, Tokyo Metropolitan University (1990) Physical fitness standards of Japanese people. 4th ed. Fumaido, Tokyo (in Japanese)

Lohman TG (1992) Advances in body composition assessment. Current issues in exercise science series. Monograph No.3. Human Kinetics, Champaign, IL

Lukaski HC, Johnson PE, Bolonchuk WW, Lykken GI (1985) Assessment of fat-free mass using bioelectrical impedance measurements of the human body. Am J Clin Nutr 41: 810-817

Lukaski HC, Bolonchuk WW, Hall CB, Siders WA (1986) Validation of tetrapolar bioelectrical impedance method to assess human body composition. J Appl Physiol 60: 1327-1332

Nagamine S, Suzuki S (1964) Anthropometry and body composition of Japanese young men and women. Hum Biol 36: 8-15

Nakadomo F, Tanaka K, Hazama T, Maeda K (1990a) Assessment of body composition in Japanese females by bioelectrical impedance analysis. Jpn J Phys Fitness Sports Med 39: 164-172 (in Japanese)

Nakadomo F, Tanaka K, Hazama T, Maeda K (1990b) Validation of body composition assessed by bioelectrical impedance analysis. Jpn J Appl Physiol 20: 321-330

Nakadomo F, Tanaka K, Watanabe H, Watanabe K, Maeda K (1991) Assessment of body composition by bioelectrical impedance analysis; influence of electrode placement. Jpn J Phys Fitness Sports Med 40: 93-101 (in Japanese)

Segal KR, Gutin B, Presta E, Wang J, Van Itallie TB (1985) Estimation of human body composition by electrical impedance methods: a comparative study. J Appl Physiol 58: 1565-1571

Shimogaki K, Negishi H, Sugimoto T, Fukase M, Fujita T (1993) Age- and gender-related changes in body composition in Japanese subjects. J Bone Miner Res 8: 397-402

Sindo M, Tanaka H, Moriyama Y (1979) Densitometry for body composition. Fukuoka University Physical Rev Educ 9: 41-53 (in Japanese)

Siri WE (1961) Body composition from fluid spaces and density: analysis of methods. In Brozek J, Henschel A eds. Techniques for measuring body composition. National Academy of Sciences, Washington D.C., 223-244

Tahara Y, Yukawa K, Tsunawake N, Saeki S, Nishiyama K, Urata H, Katsuno K, Furuyama Y, Michimuko R, Moji K, Takemoto T (1995a) Body density assessment utilizing skinfold thickness and age in Japanese women. Jpn J Public Health 42: 84-94 (in Japanese)

Tahara Y, Yukawa K, Tsunawake N, Saeki S, Nishiyama K, Urata H, Katsuno K, Furuyama Y, Michimuko R, Uekata M, Moji K, Takemoto T (1995b) Body density assessment utilizing skinfold thickness and age in Japanese men. Jpn J Public Health 42: 950-961 (in Japanese)

Tanaka K, Nakadomo F, Watanabe K, Inagaki A, Kim HS, Matsuura Y (1992) Body composition prediction equations based on bioelectrical impedance and anthropometric variables for Japanese obese women. Am J Hum Biol 4: 739-745

Tanaka K, Hiyama T, Watanabe Y, Asano K, Takeda M, Hayakawa Y, Nakadomo F (1993) Assessment of exercise-induced alterations in body composition of patients with coronary heart disease. Eur J Appl Physiol 66: 321-327

Wilmore JH, Behnke AR (1970) An anthropometric estimation of body density and lean body weight in young women. Am J Clin Nutr 23: 267-274

Received: September 29, 1998
Accepted: January 19, 1999

Correspondence to: Shin-ichi Demura, Faculty of Education, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1164, Japan