肥満女性における身体組成推定式の交差妥当性

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Cross-validation of prediction equations for body composition in obese women

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本研究は，水中体重秤量法（UW法）によって求める身体組成を妥当基準と仮定し，既に報告されている身体組成推定式の交差妥当性を検討することを目的とした。対象は，UW法に基づく体脂肪率（%BF）が30%以上の成人肥満女性（44.4±13.4歳）25名であった。交差妥当性の検討に含めた身体組成推定式は，Db＝1.1628−0.1067(Wt·Z/Ht^2) ----式1（中塘ら，1989），Db＝1.0897−0.00133TS ---- 式2（長嶺・鈴木，1964），%BF＝8.87＋0.223KI-0.180S ----式3（田中・中塘，1986）で，Dbは身体密度（g/cm^3），Wtは体重（kg），Zはインピーダンス（ohms），Htは身長（cm），TSは上腕三頭筋部と肩甲骨下縁部の皮下脂肪厚の合計値（mm），KIは桂指数，Sは肩甲骨下縁部の皮下脂肪厚（mm）を指す。体脂肪率は，式1と式2から推定した身体密度をBrožekらの式（%BF＝4.570/Db−4.142）に代入することにより求めた。データ解析の結果，式1（34.9±7.0%），式2（39.9±9.8%），式3（31.2±4.0%）を利用して推定した3種の体脂肪率はすべてUW法から得た体脂肪率（34.0±3.7%）と有意な相関関係（それぞれr＝0.83，0.74，0.75）にあることが認められた。相関の程度のみから判断すれば，いずれの式も簡便法としては有用と考えられる。しかし，式2と式3から推定した体脂肪率の平均値はUW法による体脂肪率と有意な差異を示した。式3から推定した体脂肪率の標準偏差はUW法による同標準偏差とほぼ一致した。推定の標準誤差は式3（2.66%）利用の場合に最も小さく，式1で3.90%，式2で6.51%となった。これらの成績は，肥満成人女性のみを対象として，インピーダンス法や皮下脂肪厚法に基づいて作成された推定式を利用する場合，式1と式3から得られる身体組成の誤差が比較的小さいことから，両式による簡易評価は可能であることを示唆する。今後，これらの式の交差妥当性を，他の標本についても検討すべきと考える。本稿では，近年とくに欧米で広範囲に採用されている電気抵抗法の一つであるインピーダンス法の原理やその問題点，皮下脂肪厚法の限界などについても述べた。

キーワード：身体組成の推定，肥満女性，交差妥当性，水中体重秤量法，インピーダンス法

Introduction

There is considerable information regarding the associations between obesity and a number of disorders such as diabetes mellitus, hypertension, cardiovascular disease, etc. In general, as the degree of obesity increases, additional concerns arise with regard to health problems. Analysis of recent data from the Framingham Study[4] indicates that individuals who were more than 130%

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of desirable weight suffered a greater incidence of cardiovascular disease, in both sexes and in two different age groups, than those who were less than 110% of desirable weight. Therefore, useful prediction equations of assessing the degree of obesity or leanness is of vital importance for screening individuals at risk of obesity or emaciation.

Many prediction equations to estimate human body composition have been described(2,7,25,29,30) using a linear regression model with skinfold thickness measurements as predictor variables. Examples for Japanese males and/or females are equations by Nagamine and Suzuki(17), Nagamine et al.(18), Sato(22), Tanaka et al.(28), Kikkawa et al.(10), Komiya and Kikkawa(11), Tanaka and Nakadomo(27), etc. However, most of these equations fail to account for the effect of age on body fat distribution and the non-linear (*i.e.*, curvilinear) relationship between skinfold fat and body density (Db). In the recent study of Tanaka and Nakadomo(27), women exceeding 30% fat as determined by underwater weighing were significantly underestimated by skinfold thickness method. Accordingly, these authors developed population specific equations to estimate percent body fat (%BF) of Japanese obese middle-aged women. It should be noted that most of the published equations have not been adequately cross-validated.

As one of the most recently introduced methods of human body composition assessment, tetrapolar bioelectrical impedance (BI) technique has been under careful examination to confirm its validity(3,6,13,14,19,23) and objectivity(26). The underlying assumption that BI measurements can be used to determine lean body mass (LBM) in normal, healthy adults has been thoroughly described (for details, see Lukaski et al.(15)). Briefly, the BI method is based upon the principle that the resistance of a conductor to an applied electrical current is directly proportional to the length of the conductor and inversely proportional to its cross-sectional area. Furthermore, the method relies upon the assumption that the conduction of a low frequency alternating electrical current is much greater in lean body tissues than in adipose tissues, and an impedance plethysmograph measures the resistive impedance to body tissues by the introduction of an 800 μA, 50kHz conduction current signal through surface electrodes on the proximal and distal body sites. Within the human body, electricity can be conducted by water and electrolytes which are mostly contained in lean body tissues. Consequently, the differentiation of LBM from fat can be obtained from the magnitude of an impedance measurement. Previous research has suggested that BI is highly correlated with underwater weighing(13,19,23,26) and total body water method(12,13,23).

However, it has been reported, using American populations, that men exceeding 24% or women exceeding 30% (hydrodensitometry) fat are underestimated by BI technique(16). It is, therefore, suggested that modified or new prediction equations should be developed in the very near future for expansion of the data base at the extremes of body composition range or for applying them to specialized populations like obese men and women. A major limitation of the body composition prediction equations published so far is the lack of cross-validation studies. In particular, validation research for obese individuals has been very limited. The present study was undertaken to determine the validity of %BF estimated from the BI technique and from previously reported regression equations when compared to underwater weighing criterion method. The reason why underwater weighing is generally considered the "gold standard," or criterion reference method is the facts that (a) it provides the most accurate measurement and that (b) its measurement errors are substantially small (See Methods for more details).

Methods

Subjects and Overview

Twenty-five obese women with a body fat content of 30% or greater (as determined by underwater weighing), aged 44.4±13.4 (mean±

SD) years, volunteered to participate in this study. Each volunteer gave consent after being thoroughly informed of the purpose, requirements, and procedures of this study. The volunteer reported to the Exercise Physiology Laboratory, Osaka Prefectural College of Nursing, 3 to 5 hours after consuming a light meal, since foods promote the formation of intestinal gas. Exercise, caffeine, alcohol, and smoking were also prohibited for as long as 3 hours or more prior to the examination. Body composition was assessed from three techniques; BI analysis, underwater weighing, and skinfold thickness method. The order of assessing body composition was randomized for each subject, while evaluators remained constant for each technique utilizing identical protocols. All measurements were made at least in duplicate.

Anthropometry

Barefoot standing body height (Ht) was measured to the nearest 0.1 cm with a standiometer. Body weight (Wt) was measured on a calibrated scale accurate to ± 0.01 kg. Katsura index (KI), a modified Broca index, was calculated as

$KI = [\ Wt / \{(Ht - 100) - 0.9\}] \cdot 100$.

Skinfold thicknesses were measured to 0.1 mm at four sites on the right side of the body with an Eiken caliper calibrated to exert a constant pressure of $10\,g/mm^2$. The selected sites and their anatomical landmarks were as follows: [triceps] over the triceps on a longitudinal line midway between the olecranon and the acromion, with the arm held vertically; [subscapular] an oblique fold on a lateral and downward line at the inferior angle of the scapula; [abdominal] a horizontal fold 2 to 3 cm to the right of the umbilicus or adjacent to the umbilicus but not including umbilical tissue; and [suprailiac] a semi-vertical or oblique fold on the iliac crest anterior to the midaxillary line. Two independent measures were taken of each fold. If the second measure was not within 10% of the first, subsequent folds were taken until two folds within 10% were attained.

Body density (Db) was estimated from the sum of the triceps and subscapular skinfold, using the equations developed by Nagamine and Suzuki[17] for respective sex. Percent body fat (%BF) was derived from Db according to the formula described by Brožek et al.[1] Lean body mass (LBM) was calculated as the difference between Wt and fat weight (FW), where FW equaled Wt times %BF.

Hydrodensitometry

Db was measured in the fasting state from hydrostatic (or underwater) weighing by applying Archimedes' principle in a stainless steel tank in which a swing seat was suspended from a four-strain guage system (Sougou Keisou, TR215K, Osaka, Japan). Bathing caps were prohibited because they trap air bubbles. The subject was instructed to seat in a sling cage and then to submerge while expiring maximally. In addition, the subject was required to remain as motionless as possible at the point of maximal expiration for approximately 3 to 5 seconds while underwater weight was recorded. The recording of underwater weight was initiated immediately before bubbles stopped coming from the subject. For some subjects, 1.2-kg weights were added to the subject tied with a weightless string so as to obtain an adequate reading. The underwater weight was the heaviest value that was reproduced twice among 5 to 10 measurements. The mean standard error of a single Db measurement for 10 subjects was approximately $0.0002\,g/ml^3$, which was calculated to correspond to a 0.1% error in %BF. The correlation coefficient between paired Db measurements made on the same day with 1 hour apart was r=0.989.

Residual lung volume (RV) was estimated "in water," with the subject in the sitting position, prior to the measurement of underwater weight by a closed-circuit helium-dilution method with FRC Computer System (Fukuda Sangyo, COMF-100), since the pressure of the water on the chest causes a reduction in RV of approximately 200 ml. The test-retest correlation coefficient for RV in water was r=0.945 (n=10). The mean difference between repeats was 95 ± 58 ml. Errors of this magnitude was calculated to affect the estimates of %BF by only 0.5-0.6%.

The total volume of gas trapped in the gastrointestinal tract, air sinus, etc. (VGI) was assumed constant (*i. e.,* 150 ml) for all subjects[19,27,28]. A tare weight for the chair was also measured or adjusted to zero every time before each subject entered the water tank. Water density is affected by the temperature of the water, so that a mercury thermometer was used to determine water temperature to within 1°C and was positioned about 50 cm below the surface of the water.

Consequently, Db, expressed as g/cm^3, was calculated from the following equation:

$$Db=Wa/[(Wa-Ww-t)/Dw-(RV+VGI)],$$

where Wa = weight in air (kg), Ww = weight in water (kg), t = tare weight (kg), and Dw = density of water (g/cm^3). %BF and LBM were derived from Db as described in the previous section.

Bioelectrical Impedance (BI) Analysis

The principle that BI measurements can be used to estimate LBM has been thoroughly described (for details see Lukaski et al.)[15]. Assessment of BI was detected as the sum of resistance and reactance by use of a portable four-terminal impedance plethysmograph (Selco, SIF–891, Yokohama, Japan) and was read directly from the device. The tetrapolar configuration was adopted in order to minimize contact impedance or skin-electrode interaction.

The subject rested supine comfortably on a clinical bed with the legs separated sufficiently and the arms not touching the body (Fig. 1). Thus, the thighs were not touching each other and the arms were resting at the sides. After cleaning all skin contact areas with alcohol, a thin layer of Keratin electrolyte gel (Fukuda Denshi, Osaka, Japan)[20] was applied to each electrode before attaching to the skin. Current-introducing ECG electrodes (Nihon Kohden, Tokyo, Japan)[21] were positioned in the middle of the dorsal surfaces of the dominant hand and the ipsilateral foot proximal to the metacarpo-phalangeal and metatarso-

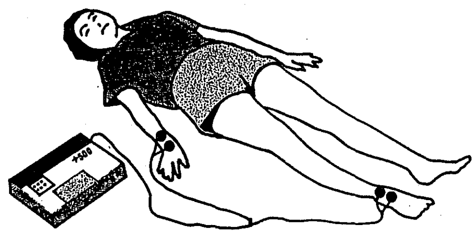

Fig. 1 Diagrammatic representation of impedance plethysmograph using a four-electrode arrangement.

phalangeal joints, respectively. Detector electrodes were positioned on the proximal point of the dominant wrist and the ipsilateral ankle with the foot extended. The distance between the current–introducing electrodes and the detector electrodes was maintained at 3 cm in both extremities. A thin layer of Keratin electrolyte gel was applied to each electrode before attaching to the skin. An excitation current of 800 μA at 50 kHz was introduced into the subject at the distal electrodes of the hand and foot, and the voltage drop was detected by the proximal electrodes (Fig. 1).

Db was estimated from the following empirically derived formula developed for Japanese adult women: $Db = 1.1628 - 0.1067 \{Wt (R^2 + Xc^2)^{0.5}/Ht^2\}$, where Wt = body weight in kilograms, R = resistance in ohms, Xc = reactance in ohms, and Ht = height in centimeters. Bioelectrical impedance (Z) was defined as the hindrance to the flow of an alternating current and was detected as the sum of the R and Xc; *i.e.*, $Z=(R^2+Xc^2)^{0.5}$. %BF and LBM were derived from the Db as described in the previous section.

Statistics

Equations which were cross-validated against hydrodensitometry were $Db=1.1628-0.1067(Wt \times Z/Ht^2)$ ---- EQ1 (Nakadomo et al., 1990a)[19], $Db = 1.0897 - 0.00133TS$ ---- EQ2 (Nagamine and Suzuki, 1964)[17], and $\%BF = 8.87 + 0.223KI - 0.180S$----EQ3 (Tanaka and Nakadomo, 1986)[27], where TS, sum of the triceps and subscapular skinfolds (mm); KI, Katsura index; and

S, subscapular skinfold (mm). Db values derived from EQ1 and EQ2 were substituted to the equation of Brožek et al.[1], %BF=4.570/Db−4.142.

Pearson product-moment correlation coefficients were computed to evaluate the validity of these equations. Cross-validation also involved standard error of estimate (SEE) and total error (E) for each equation. SEE was computed as $Sy\sqrt{1-r^2}$, where Sy = standard deviation of the hydrodensitometrically determined %BF. E was computed as the square root of the mean of the sum of squares of the residuals (*i.e.*, $E=\sqrt{\Sigma(y-\hat{y})^2/n}$), where y = the criterion value and $\hat{y}$ = the estimate.

Results

Physical characteristics of the 25 obese women are shown in Table 1. Reliability coefficients for BI measurements and skinfold thickness measurements were very high (r = 0.994 and r = 0.983, respectively). Cross-validation statistics are presented in Tables 2 and 3.

All %BFs derived from EQ1 (34.9±7.0%), EQ2 (39.9 ± 9.8%), and EQ3 (31.2 ± 4.0%) significantly correlated (r=0.829, 0.737, and 0.752, respectively) with hydrodensitometry %BF (34.0±3.7%). The coefficient of correlation squared or the coefficient of determination resulted in 68.7%, 54.3%, and 56.6%, respectively. However, mean %BFs derived from EQ2 and EQ3 significantly differed from hydrodensitometry mean %BF. SD for EQ3 was very similar to the hydrodensitometry SD. Standard error of estimate (SEE) for EQ3 (2.66%) was smaller than SEEs for EQ1 (3.90%) and EQ2 (6.51%). Total error (E) resulted in 3.93% for EQ3, 4.54% for EQ1, and 9.51% for EQ2.

Figures 2, 3, and 4 show absolute %BF differences in 25 obese subjects when %BFs derived from EQs 1, 2, and 3 were compared to hydrodensitometry %BF (criterion). The largest difference was found when %BF values derived from EQ2 were compared to criterion. Absolute %BF differences of ±6% or greater were less frequently observed for the comparison of EQ1 *vs.* criterion than for the comparison of EQ 3 *vs.* criterion.

Table 1 Physical characteristics of the subjects

	mean	±	SD
Age, yr	44.4	±	13.4
Ht, cm	155.4	±	4.5
Wt, kg	63.2	±	12.4
KI[a]	126.9	±	23.2
Skinfold thickness			
triceps, mm	28.9	±	7.3
subscapular, mm	33.4	±	9.8
abdominal, mm	37.5	±	8.1
suprailiac, mm	38.8	±	9.3
sum of the four, mm	138.6	±	30.4
Fat[b], %	34.0	±	3.7
LBM, kg	41.4	±	6.0

[a]Katsura Index (KI)=[Wt/{(Ht-100)・0.9}]・100
[b]%BF was calculated from body density by using the Brožek et al. (1963) equation, which was determined by underwater weighing.

Table 2 Correlations of %BF calculated from EQ1, EQ2, and EQ3 with densitometrically determined %BF

	predicted %BF	densitometry %BF 34.0±3.7
EQ1	34.9±7.0	r=0.829*b
EQ2	39.9±9.8*a	r=0.737*b
EQ3	31.2±4.0*a	r=0.752*b

*a Significantly ($p < 0.05$) different from densitometry %BF
*b Significant ($p<0.05$)

Table 3 Standard error of estimate (SEE) and total error (E) for EQ1, EQ2, and EQ3

	SEE	E
EQ1	3.90%	4.54%
EQ2	6.51%	9.51%
EQ3	2.66%	3.93%

Discussion

Reliable, rapid, and inexpensive screening

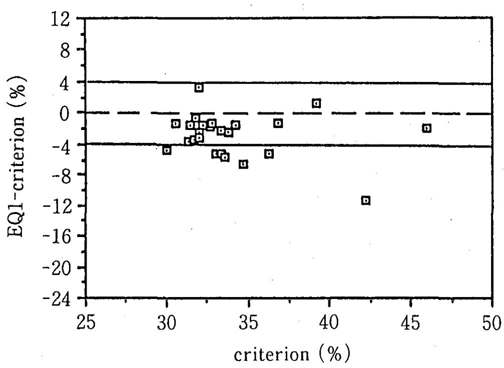

Fig. 2 Scatter diagram for %BF derived from EQ1 minus densitometry %BF (criterion) on Y-axis versus criterion on X-axis. Dashed line indicates no difference between the predicted %BF and criterion, while solid lines denote ±4% error in absolute value.

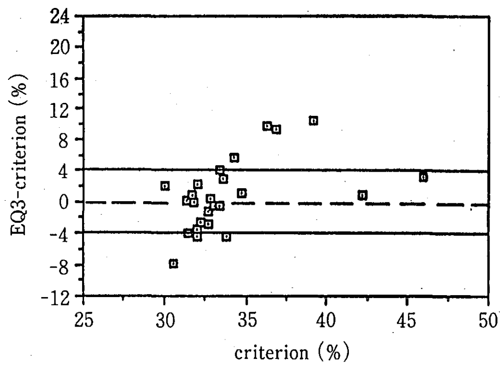

Fig. 4 Scatter diagram for %BF derived from EQ3 minus densitometry %BF (criterion) on Y-axis versus criterion on X-axis. Dashed line indicates no difference between the predicted %BF and criterion, while solid lines denote ±4% error in absolute value.

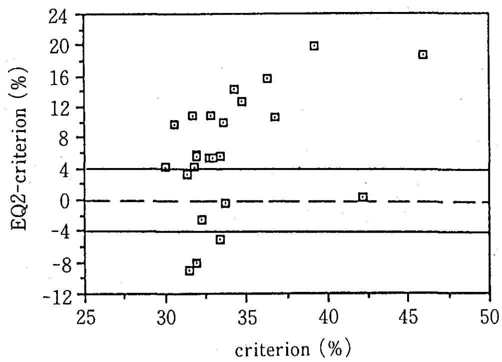

Fig. 3 Scatter diagram for %BF derived from EQ2 minus densitometry %BF (criterion) on Y-axis versus criterion on X-axis. Dashed line indicates no difference between the predicted %BF and criterion, while solid lines denote ±4% error in absolute value.

methods are undoubtedly useful when determining body composition analysis in large numbers of subjects. In this context, convenient prediction equations are very frequently developed to provide a valid method of measuring Db or %BF. The most reliable method of estimating human body composition may be the direct measurement of Db from underwater weighing. In fact, underwater weighing has been regarded as one of the criterion reference methods for determining Db but is cumbersome for screening large numbers of subjects. It cannot be applied to some particular persons who are handicapped or diseased or to many younger or older individuals. Furthermore, underwater weighing is too expensive to appropriate for field use.

The BI method has been suggested to offer the advantage of rapid analysis with reliable determination of Db or LBM. Since the impedance or resistance (Z) measured along an electrical conductor is directly proportional to the resistivity and length (L) of the conductor, and inversely proportional to the cross-sectional area (A) of the conductor, body resistivity (BR) can be determined from BR = A x Z/L. For convenience and from previous findings, this equation can be modified as BR = Wt x Z/Ht^2 for the estimation of Db. Until recent years, more emphasis has been consistently placed upon the use of skinfold thickness measurements to estimate Db. We attempted to compare the usefulness of BI measurements and skinfold thickness measurements with hydrodensitometric determinations for the reliable, rapid assessment of body composition.

In general, equations to estimate body composition have the disadvantage of population-specificity. The population-specificity may be due to the multicollinearity of the independent variables, which causes errors when the equations are applied to groups with different multivariate structures of the independent variables. The original regression analysis provides evidence of an equation's validity, but the strongest evidence is obtained with cross-validation research.

Analysis of our data indicated that mean %BF determinations did not differ significantly between BI technique and hydrodensitometry. SEE and E for EQ1 were 3.90% and 4.54%, respectively, both of which were smaller than those for EQ2 but were larger than those for EQ3. The correlation coefficient comparing %BF values by BI technique (*i.e.,* EQ1) with hydrodensitometry was highest ($r = 0.829$). The magnitude of the correlation indicates that approximately 70% of the total variance in hydrodensitometry %BF is accounted for by BI %BF. These findings and previous results suggest that BI measurements may be marginally useful for determining body composition in adult obese women as well as in normal male and female populations.

The insensitivity of the current prediction equations used with BI and skinfold thickness methods at an extreme of the body cmposition range is an important matter of additional research. It is usually seen that prediction equations are most valid for use with subjects representative of the same sample employed to construct the equation. The problem with different subjects is that the regression slope and/or intercept may differ, which produces systematic errors.

The skinfold thickness approach is based upon the assumptions that (a) the sites selected for measurement, either singly or in combination, are representative of the average of the total subcutaneous adipose tissue and that (b) the thickness of the subcutaneous adipose tissue reflects a constant proportion of the total body fat. Neither of these assumptions has been proven to be true in humans, particularly in obese individuals. The application of skinfold thickness measurements may be restricted to individuals with moderately firm subcutaneous tissue. In subjects "with flabby easily compressible tissue or with not easily deformable very firm tissue" (p. 541; Lukaski et al.[15]), the measurement error increases greatly. It should be noted that skinfolds contain adipose tissue which consists of not only fat but also water, connective tissue, blood vessels, and nerves. In addition, the precision of a measurement of skinfold thickness is dependent upon the constancy of the caliper pressure (*i.e.,* 10 g/mm^2), the exactness of the body site measured, and the skillfulness of the evaluator. In some subjects it is difficult to get the same reading twice.

In the tetrapolar impedance method, variability not only in the instrument but also in the body site and in the evaluator remains relatively constant. Inter-evaluator errors are neither affected by the degree of fatness nor by the firmness of the subcutaneous adipose tissue. In this context, the BI method is considered to have higher objectivity than the skinfold thickness method[26]. From an analysis of intraindividual coefficients of variation for repeated measurements of impedance (Z) over three consecutive days in 10 young women, we found no significant difference in the observed variability between the BI method (2.4%) and the skinfold thickness method (2.8%).

It has been shown in adults[12-14,19] and children[3] that BI technique provides reproducible and acceptably accurate estimates of body composition. The apparent advantages of BI technique over most other methods are short assessment time, ease of use, subject convenience, and high reproducibility[23]. This technique is particularly suitable for hospitalized patients[19,23]. However, the validity of BI technique has been questioned in many other recent studies[5,6,8,9,23,24]. Electrode placement, the type of electrode, body position, physical activity, and hydration status may be factors that can influence BI measurements.

Finally, it should be born in mind that the fat compartment of the body consists of two types: essential fat and subcutaneous adipose tissue; the "subcutaneous" means "beneath the layers of the skin." While essential fat is internal and surrounds vital organs, subcutaneous adipose fat is next to the skin and is the component measured with the caliper. The hydrodensitometry may measure both essential fat and subcutaneous adipose fat, but the skinfold thickness method will not. It is uncertain whether the BI method measures two types of fat. More research is needed to refine the technique and/or validate the prediction equations developed.

In conclusion, none of the prediction equations examined in the present study is very accurate and suitable for body composition screening of Japanese obese women. Particularly, limitations to the estimation of body composition only from skinfold thickness was noted. The estimations for most subjects obtained by EQ1 and EQ3 appear to be within the error of the method. We suggest that these equations still need to be cross-validated on other specialized samples. At present, EQ1 and EQ3 are preferred to EQ2 for wide usage in clinical settings.

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References

1) Brožek J, Grande F, Anderson JT, and Keys A (1963): Densitometric analysis of body composition: revision of some quantitative assumptions. Ann N Y Acad Sci 110: 113-140.
2) Durnin JVGA and Womersley J (1974): Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 32: 77-97.
3) Houtkooper LB, Lohman TG, Going SB, and Hall MC (1989): Validity of bioelectrical impedance for body composition assessment in children. J Appl Physiol 66: 814-821.
4) Hubert HB (1984): The nature of the relationship between obesity and cardiovascular disease. Int J Cardiol 6: 268-274.
5) Hutcheson L, Latin RW, Berg KE, and Prentice E (1988): Body impedance analysis and body water loss. Res Q Exerc Sport 59: 359-362.
6) Jackson AS, Pollock ML, Graves JE, and Mahar MT (1988): Reliability and validity of bioelectrical impedance in determining body composition. J Appl Physiol 64: 529-534.
7) Katch FI and McArdle WD (1973): Prediction of body density from simple anthropometric measurements in college-age men and women. Hum Biol 45: 445-454.
8) Katch FI, Keller B, and Solomon R (1986): Validity of BIA for estimating body fat in cardiac and pulmonary patients, and black and white men and women matched for age and body fat. (Abstract) Med Sci Sports Exerc 18: S17.
9) Keller B and Katch FI (1986): Validity of BIA to predict body fat in underfat, normal, and overfat males and females, and comparison to sex-specific fatfold equations. (Abstract) Med Sci Sports Exerc 17: S17.
10) Kikkawa K, Komiya S, and Komuro T (1983): On establishing of predictive model of total body water (I). J Phys Fitness Japan 32: 39-48. (in Japanese)
11) Komiya S and Kikkawa K (1985): Equation for estimating percent fat of Japanese men. J. Phys Fitness Japan 34: 259-268. (in Japanese).
12) Kushner RF and Schoeller DA (1986): Estimation of total body water by bioelectrical impedance analysis. Am J Clin Nutr 44: 417-424.
13) Lukaski HC, Johnson PE, Bolonchuk, WW, and Lykken GI (1985): Assessment of fat-free mass using bioelectrical impedance measurements of the human body. Am J Clin Nutr 41: 810-817.
14) Lukaski HC, Bolonchuk WW, Hall CB, and Siders WA (1986): Validation of tetrapolar bioelectrical impedance method to assess human body composition. J Appl Physiol 60: 1327-1332.
15) Lukaski HC (1987): Methods for the assessment of human body composition: traditional and new. Am J Clin Nutr 46: 537-556.

16) Miles DS and Stevens AG (1985): Body composition measured by bioelectrical impedance and hydrostatic weighing. (Abstract) Med Sci Sports Exerc 17: 272-273.
17) Nagamine S and Suzuki S (1964): Anthropometry and body composition of Japanese young men and women. Hum Biol 36: 8-15.
18) Nagamine S, Yamakawa K, Isobe S, Ichinose Y, and Kaga A (1974): Body composition and body density in adolescent boys and girls. Jpn J Nutr 32: 198-204. (in Japanese)
19) Nakadomo F, Tanaka K, Hazama T, and Maeda K (1990a): Validation of body composition assessed by bioelectrical impedance analysis. Jpn J Appl Physiol 20: 321-330.
20) Nakadomo F, Tanaka K, Hazama T, and Maeda K (1990b): Assessment of body composition by bioelectrical impedance analysis: effects of skin resistance on impedance. Ann Physiol Anthrop 9: 109-114. (in Japanese)
21) Nakadomo F, Tanaka K, Yokoyama T, and Maeda K (1990c): Effects of different electrodes on bioelectrical impedance values. Ann Physiol Anthrop 9: 41-45. (in Japanese)
22) Sato K (1975): Studies of the body fat mass of the Japanese——on the body fat mass at adolescence——. J Phys Fitness Japan 24: 134-150. (in Japanese)
23) Segal KR, Gutin B, Presta E, Wang J, and VanItallie TB(1985): Estimation of human body composition by electrical impedance methods: a comparative study. J Appl Physiol 58: 1565-1571.
24) Shore P and Taylor WG (1986): The validity of bioelectric impedance analysis in body composition analysis in young adult males. (Abstract) Med Sci Sports Exerc 18: S16.
25) Sloan AW (1967): Estimation of body fat in young men. J Appl Physiol 23: 311-315.
26) Tanaka K, Nakadomo F, Hazama T, Inagaki A, and Masuura Y(1990): Variation of body composition measurements among evaluators. Clin Sports Med 7: 939-945. (in Japanese)
27) Tanaka K and Nakadomo F (1986): Prediction of percent body fat in obese women. J Phys Fitness Japan 35: 270-276. (in Japanese)
28) Tanaka K, Kato H, Kikuchi K, Nagatomo M, Nakajima H, Shibayama H, Ebashi H, Nishijima Y, Matsuzawa M, and Ogawa S(1979): Anthropometric and body composition characteristics of Shindeshi sumo wrestlers. J Phys Fitness Japan 28: 257-264. (in Japanese)
29) Wilmore JH and Behnke AR (1969): An anthropometric estimation of body density and lean body weight in young men. J Appl Physiol 27: 25-31.
30) Wilmore JH and Behnke AR (1968): Predictability of lean body weight through anthropometric assessment in college men. J Appl Physiol 25: 349-355.