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Comparison of Validity and Accuracy of Circumference, SKF, and BIA Method in Predicting % Body Fat

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Abstract

The purpose of this study was to compare the difference in the percent body fat(% body fat) values estimated by the circumference method, the skinfold method(SKF), the bioelectrical impedance analysis(BIA), and the underwater weighing(UWW) and to examine the accuracy of three different field methods by comparing with reference method. Twenty-nine adults(women = 13 and men =16) volunteered to participate(age = 25 to 49 years) in this study. Body weight and height were measured, and body mass index(BMI) was calculated. Body circumferences, SKF thicknesses, BIA, and UWW were measured from five technicians(beginner level) under the guidance of a trained technician. Several validated equations appropriated to race, gender, and age were used to estimate % body fat from SKF method. The prediction equations for estimating % body fat using circumference method were developed considering only gender and age. The % body fat from BIA was calculated with the value of free fatty acids(FFA) estimated from the preset equation for the device. The data were analyzed by using one-way ANOVA to examine the difference in the % body fat results measured from four different methods, and Pearson correlation coefficients and regression analysis were measured to assess the validity and accuracy for three body composition measurements. Statistical significant was set at P < 0.05. The results showed that the % body fat values measured by four different measurements were statistically similar. However, there were differences in the accuracy for estimating % body fat among different measurements, and it was found that the SKF method was the most accurate method, and the circumference method was the lowest method for predicting % body fat. In conclusion, these results suggested that the estimation of body composition from the circumference and SKF method, and BIA can be estimated relatively accurately, even if measured by an untrained technician when following prescribed measurement methods and procedures. Our data also suggested that the population-specific equations appropriate to subject should be used to estimate body composition because they will probably predict more accurate estimates.

[Keywords] ***Kinesiology, Obesity, Anthropometry, Body Mass Index, Body Composition***

1. Introduction

Obesity is a serious health problem that reduces life expectancy by increasing the risk of metabolic disorders such as coronary artery disease, hypertension, and type II diabetes including osteoarthritis and certain types of cancer. It is known that the prevalence of hypertension, hyperlipidemia, and type II diabetes is two to three times greater in obese individuals[1][2]. According to the Korean National Health Statistics of the Ministry of Health and Welfare, the obesity adults(> 19 yrs) in Korea are increased 34.8 % in 2017[3]. The increased health risks associated with obesity are related, not only to the total amount of body fat, but also to the abdominal fat, especially visceral fat[4].

In World Health Organization(WHO), obesity is defined as a body mass index greater than 30 kg/m^2[5]. However, this definition is inappropriate because it does not take into account the individual's body composition. In other words, because BMI only calculates height and weight to determine obesity, lean individuals who have little body fat but who weigh more than their ideal weight can be determined as overfat or obese. As a result, BMI can lead to an erroneous conclusion about one's level of body fatness and health risk[6].

The body is made up of various tissues and substances, and determining actual body composition such as fat mass and fat-free mass(ex. water, muscles, bones, and internal organs) can better determine health status and potential risk for disease as well as the prediction of optimal sports performance. There are various methods to measure body composition to estimate the amount of body fat. Among them, underwater weighing(UWW) is well known as one of the gold standard methods for measuring body composition[7]. However, UWW has some disadvantages related with spatial constraints, highly technical and costly, and a subject's difficulty submerging themselves for several seconds.

On the other hand, there are several field methods for measuring body composition. Anthropometry has been used to assess body size and the proportions of body segments by measuring body circumferences and body segments. SKF technique measures the thickness of subcutaneous adipose tissue. These measurements were used to develop numerous anthropometric equations for predicting the total body density and body fat. Nowadays, there are excellent anthropometric equations using SKF or circumference method. Another method of measuring body composition is BIA. Although this technique is more expensive than circumference and SKF method, BIA is fast and noninvasive.

As the body composition measurement, the most representative advantage of circumference and SKF method, and BIA are quick and relatively inexpensive way for measuring body composition compared to UWW. In addition, these methods are suitable for field and clinical settings because they are easy to administer to large groups. However, it was suggested that these three body composition measurement methods have problems with accuracy due to technician's skill, the type of equipment, subjects' factors, prediction equations, and environmental which can result in significant measurement error[8].

With this purpose, this research examined (1)the difference in % body fat measured by four different methods(circumference method, SKF method, BIA, and UWW), and (2)correlation between % body fat measured by UWW and results of % body fat measured by the other three different measurements.

2. Method

2.1. Subjects

Healthy men(N = 16) and women(N = 13) aged 25 to 49 years were participated in this study. All participants were non-smokers and habitually active in a variety of sports. The description of purpose, procedures, and risk of the study was provided prior to performing the measurements.

2.2. Experimental procedures

Five beginner level of technicians(graduate students) measured body circumference, subcutaneous thickness, BIA, and UWW of all subjects under the guidance of a trained technician. SKF and circumference for given body parts were measured in duplicate and averaged the scores. All measurements were performed in the morning from 7:00 am until 10:00 am. The subjects followed some pretest procedures that included minimum 8 hours of fasting, no high-intensity exercise, and no coffee. The subjects were allowed to drink water ad libitum before measurement. Temperature was maintained between 19℃ to 21℃ during all circumference, SKF and BIA measurements.

2.3. Subcutaneous fat measurement

Subcutaneous fat thickness(abdomen, chest, calf, midaxillary, subscapular, suprailiac, thigh, and triceps) was measured using Harpenden calipers following the following the recommendations defined by Jackson and Pollock(1985) and Jackson, Pollock and Ward(1980)[9][10]. The prediction equations for the calculation of body density(Db) were used according to gender, and the equations used are as follows. 1)Db(chest, abdomen, thigh) = 1.10938 - 0.0008267(sum of 3 sites) + 0.0000016(sum of 3 sites)^2 - 0.0002574(age) for men[11]. 2)Db(chest, triceps, subscapular) = 1.1125025 - 0.0013125(sum of 3 sites) + 0.0000055(sum of 3 sites)^2 - 0.000244(age) for men[9]. 3)Db(triceps, suprailiac, abdomen, thigh) = 1.096095 - 0.0006952(sum of 4 sites) + 0.0000011(sum of 4 sites)^2 - 0.0000714(age) for women[10]. 4)Db(chest, midaxillary, triceps, subscapular, abdomen, thigh, suprailiac) = 1.097 - 0.0046971(sum of 7 sites) + 0.00000056(sum of 7 sites)^2 - 0.00012828(age) for women[10]. 5)Db(suprailiac, triceps, thigh,) = 1.099421 - 0.009929(sum of 3 sites) + 0.0000023(sum of 3 sites)^2 - 0.0001392(age) for women[10]. 6)Db(triceps, suprailiac, abdomen) = 1.089733 - 0.0009245(sum of 3 sites) + 0.0000025(sum of 3 sites)^2 - 0.0000979(age) for women[9]. These body density values were then converted to % body fat using Siri's equation, % body fat = (4.95/Db - 4.50) × 100[13].

2.4. Girth measurement

Girths(waist, abdomen, arm, calf, chest, forearm, iliac, thigh, and hip) were measured with anthropometric tape following Callaway et al.(1988) defined method[11]. To convert into % body fat, girth scores of different body sites were used according to gender and age. All procedures and calculations followed 'Body Fat Prediction From Girths'[12]. The scores of upper arm, abdomen, and forearm girth were used for young men(18 - 26 yrs). Abdomen, thigh, and forearm girth were used for young women(18 - 26 yrs). Hip, abdomen, and forearm girth were measured for old men(27 - 50 yrs). The scores of abdomen, thigh, and calf girth were used for old women(27 - 50 yrs). Then the constant A, B, and C corresponding to these girth values were substituted into the appropriate formula to calculate % body fat. % body fat formulas used in this study were following. 1)% body fat = constant A + constant B - constant C - 10.2(for young men). 2)% body fat = constant A + constant B - constant C - 15(for old men). 3)% body fat = constant A + constant B - constant C - 19.6(for young and old women).

2.5. BIA measurement

BIA was measured in a supine position on non-conducting surface, and electrodes were placed on bared hand, wrist, foot, and ankle. All subjects were maintained their arms and legs slightly abducted to side during measurement. % body fat was calculated by determining the fat mass(FM = body weight - lean body mass) and dividing FM by the subject's body weight(% body fat = (FM/body weight) × 100).

2.6. UWW measurement

Subject's body weight was measured first in air. The subject wearing a thin swimsuit sat in a lightweight chair suspended from the scale and submerged beneath the water's surface. The subject was educated to exhale as much as possible while slowly lowering under the water and to hold the breath for 5 to 8 seconds to allow the scale pointer to stabilize. UWW was measured 3 times and the average value was used to calculate Db. Residual volume(RV) was estimated using following prediction equations; 1)RV = (0.019 × height(cm)) + (0.0115 × age) - 2.24 for men [29], 2)RV = (0.032 × height(cm)) + (0.009 × age) - 3.90 for women[30]. Body density and % body fat were calculated using following prediction equations; 1)Db = Wa/{(Wa - Ww) - Dw - (RV + 0.1)} where Wa means body weight, Ww means under water weight, and Dw means water density. 2)% body fat = (4.95/Db - 4.50) × 100[13]. The water temperature was maintained between 34℃ and 36℃.

2.7. Statistical analysis

Data were analyzed using SPSS version 25.0(IBM, U.S.A). Values are expressed as means ± SD. One-way ANOVA was performed to compare mean differences in the % body fat results measured by 4 different methods.

Pearson correlation coefficients(r) were calculated to assess associations between % body fat by UWW and % body fat measured by circumference, SKF, and BIA. Regression analysis was used to determine the accuracy of each measurement method comparing associations between the absolute difference between % body fat by UWW and % body fay measured by circumference, SKF, and BIA. For all tests, statistical significant was accepted at $P < 0.05$.

3. Results

The physical characteristics of the subjects are listed in <Table 1>. The % body fat determined by four different measurements is shown in <Table 2>. All measurements except girth measurement were measured from all subjects. However, % body fat estimated by circumference measurement was calculated from only 19 subject data.

The results of an ANOVA showed that there were small differences in the results of % body fat estimated by four different measurements. Based on the value measured by UWW as criterion % body fat, % body fat predicted by SKF method showed the smallest difference(about 1.8 % lower). And the results of % body fat predicted by circumference method and BIA were about 5.7 % and 7.2 % higher than that of UWW, respectively. However, there was no significant difference in the mean differences of % body fat measured by four different measurements <Table 2>.

Table 1. Physical characteristics of the subjects.

Variable	Mean ±S D
Age(yrs)	30.72 ± 8.70
Height(cm)	171.80 ± 9.26
weight(kg)	80.88 ± 17.87
BMI(kg/m^2)	27.02 ± 3.20

Note: BMI: body mass index.

Table 2. Comparison of % body fat estimated by 4 different measurements.

Method(N)	% body fat	*F*	Sig.
SKF(29)	25.44 ± 6.09	1.38	.25
Circumference(19)	27.38 ± 5.01		
BIA(29)	27.91 ± 5.15		
UWW(29)	25.90 ± 4.68		

Note: SKF: skinfold, BIA: bioelectrical impedance analysis, UWW: underwater weighing.

The relationships between % body fat determined by UWW and those of circumference, SKF measurement, and BIA are shown in <Figure 1>, <Figure 2>, and <Figure 3>, respectively. The r values between UWW % body fat and % body fat estimated by circumference, SKF, and BIA method were 0.17, 0.59, and 0.40, respectively. The results of % body fat estimated by SKF($P < 0.01$) and BIA($P < 0.05$) were significantly correlated with UWW % body fat. However, better agreement(less variability) was observed between SKF % body fat and UWW % body fat, and r^2 value of SKF also showed highest score compared to those of other measurements.

SEE value for SKF method was smaller than those for the circumference method and BIA. Furthermore, the SEE value(3.84 % body fat) from SKF measurement was within acceptable limits(< 4 % body fat)[8]. The SEE values from anthropometric measurement(4.73 % body fat) and BIA(4.38 % body fat) were higher than 4 %.

Figure 1. Relationship between % body fat determined from UWW and circumference method.

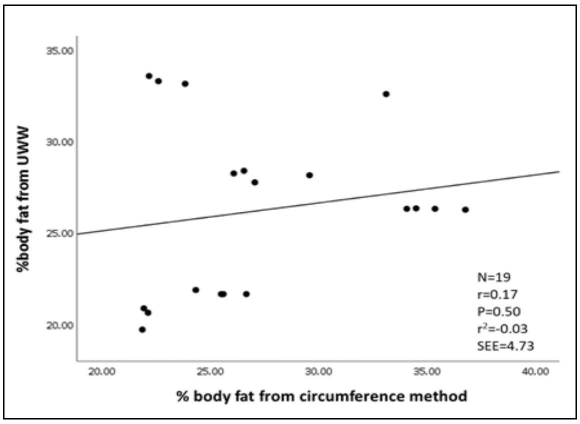


Figure 2. Relationship between % body fat determined from UWW and SKF method.

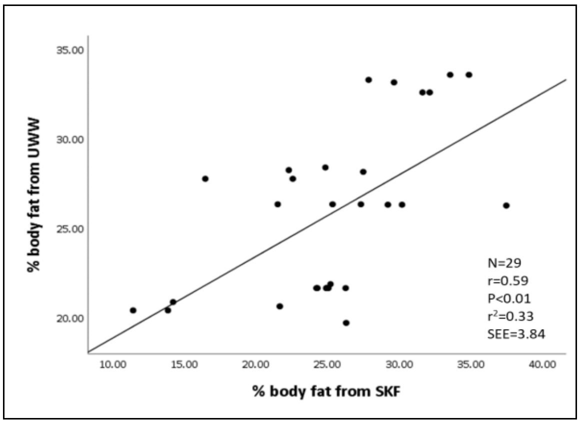
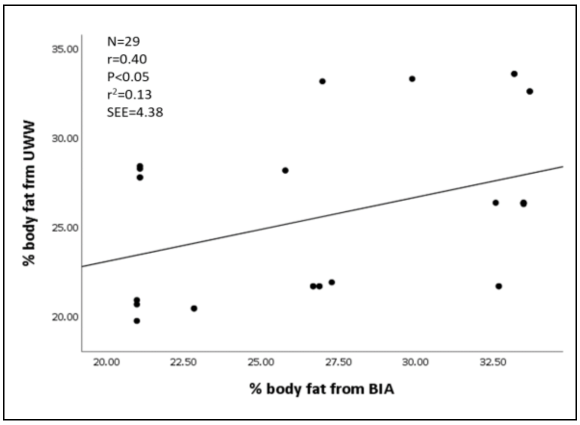


Figure 3. Relationship between % body fat determined from UWW and BIA.



4. Discussion

The principal findings of this study were that there were no significant differences in the mean values of % body fat estimated by four different measurements(SKF, circumference, BIA, and UWW method), but that there are differences in the accuracy of individual estimates of % body fat among those different measurements.

In this study, it was found that as an anthropometric method, circumference measurement to predict % body fat was the least accurate method. It was suggested that the acceptable errors for estimating % body fat by circumferences are ≤ 3.5 % body fat[14]. However, the *r* value(*r* = 0.165) from circumference method was lowest, and SEE score(SEE = 4.73) was higher than the suggested level. This was highest among other % body fat estimating methods.

The accuracy of circumference methods is affected by equipment, technician skill, and the prediction equation, and subject factors[11]. Above all, anthropometric prediction equations should be selected based on age, gender, and level of body fatness, and there are various available equations developed according to those factors in the research field[15][16][17]. However, the formulas used in this study to estimate % body fat are only based on the age and the constants for the circumference values at the sites of body, but race and body fatness are not considered. Thus, the low validity of circumference method in predicting % body fat is likely due to the lack of accuracy of the % body fat estimating formula used in the present study. Also, small sample size(N = 19) in the circumference method may have affected this result.

In addition, circumferences are affected by muscle mass and skeletal size, including fat mass. Therefore, these measures are not only related to fat mass, but also lean body mass. Thus, circumferences can erroneously judge a person with high muscle mass as obese, and this characteristic of the circumference method may have affected this low validity. In this study, % body fat estimated by circumference method was 5.7 % higher compare to those from UWW. On the other hand, there are several advantages of circumference method. It is more reliable than skinfolds, and circumferences can always be measured regardless of body size and fatness.

The validity of the BIA method to predict % body fat is known to similar to the SKF method[14][19]. In this study, the % body fat estimated by BIA was also highly correlated with the % body fat determined by reference method, and the correlation coefficients were statistically significant(BIA: *r* = 0.40, *P* = 0.03). However, as SEE value(SEE = 3.84) from SKF was smaller than those from BIA(SEE = 4.38) and circumference(SEE = 4.73) method, the accuracy to predict % body fat from BIA was found to be low compared to SKF method. In addition, the % body fat estimated by BIA method tend to overestimate about 5 %.

The BIA method estimates body composition using the principle that electric current flows at different rates through the body depending on its composition[18]. It is known that the relative predictive accuracy of the BIA method is similar to the SKF method[14][19]. Also, in a study of Aandstad et al.(2014), various equations used for estimating % body fat from BIA method were highly correlated with the % body fat determined from a reference method(DXA scans)[20].

However, in this study, % body fat from BIA method was calculated by FFA which was estimated based on the preset equation for the device. Thus, this relatively low accuracy of BIA method compared to SKF method found in this study is likely to be the result of using a formula that lacks specificity for the subject being measured. Therefore, it is not recommended to use FFM estimates obtained directly from a BIA analyzer for calculating % body fat unless it is known which equations are programmed in the device.

On the other hand, it was reported that Inbody as a multifrequency bioelectrical impedance analysis had higher validity than that observed from all single frequency bioelectrical impedance analyses[20]. Therefore, the use of multifrequency bioelectrical impedance analysis may be a reasonable measurement for % body fat in environments where accurate prediction formulas are not available. In addition, BIA may be preferable because it is rapid, noninvasive, relatively inexpensive, and it does not require a high degree of technician skill[8][18].

The correlation coefficient between % body fat from SKF method and UWW was highest among those from other methods in this study(SKF: r = 0.59, *P* = 0.001). The accuracy of the SKF method(SEE = 3.84) also higher than the circumference and BIA method. This result means that % body fat can be estimated more accurately from SKF method compared to circumference and BIA. In addition, SKF method showed a small underestimation of % body fat(about 1.8 %) compared to UWW.

The SKF method indirectly measures the thickness of subcutaneous fat tissue, and major advantages of the SKF method are that it is easy to administer at a relatively low cost, it is rapid, and it is less sensitive to fast changes in hydration status[21][22]. It was demonstrated that the subcutaneous fat measured by SKF is highly correlated with the value obtained from magnetic resonance imaging[23]. However, the validity and reliability of SKF method are depend on the technician's skill, types of caliper, gender, race, age, and the prediction equation for estimating % body fat[24].

In particular, since there are over 100 equations to predict body composition from anthropometric measurement, it is important to select the most population-specific equation for estimating % body fat correctly. It was suggested that effective SKF equations generally estimate body fat within 3.5 % compare to the values from UWW[14][25][26][27]. The equations used in this study were population-specific equations developed taking into account various subject's factors such as race, gender and age. As a result, it was found that % body fat can be estimated more accurately from SKF method. Also, the result found in this study was in accordance with previous studies[20][28].

5. Conclusion

It was examined the difference and the accuracy in % body fat estimated by four different % body fat measurement methods in this study. The values of % body fat predicted from the four different methods were not significantly different each other. However, in predicting % body fat, the SKF method was found to be the most accurate, and the circumference method was the lowest. These results suggested that SKF method is more accurate field method to predict % body fat. However, given the limitations of this study, which did not use population-specific equations in BIA and circumference measures, these results also suggested that it is important to use accurate prediction equations that are appropriate for various factors such as race, age, gender for accurate prediction of body composition.

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