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Estimating Body Fat Percentage through Body Mass Index and Handgrip Strength in Middle and Older-aged Asian Adults

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ABSTRACT

Objectives: To determine the ability of handgrip strength combined with body mass index (BMI, kg/m^2) to estimate body fat percentage (BF%) in middle-aged and older Asian adults. **Methods**: Middle-aged and older Asian adults (n=459, males=197) were randomly divided into a validation and model development group (n=303) and cross-validation group (n=156). A whole-body scan using dual energy x-ray absorptiometry measured BF%. Bland-Altman plots, standard error of the estimates, total errors and mean absolute errors were used to compare prediction equations. Stepwise regression analysis was used to determine a new prediction equation for middle-aged and older Asian adults. Right and left handgrip strength, age, sex and BMI were included in the analysis. **Results**: A previously developed prediction equation that included handgrip strength poorly predicted BF% in our current sample with the mean difference being -6.0 ± 4.2%. Predicted BF% values were significantly lower than measured BF% values (22.7% vs. 28.7%, p<0.05). A new prediction equation was developed that included sex, BMI, left handgrip strength and age. Validation of the new equation revealed a constant error of 0.2 ± 3.9% with there being no significant difference between measured and predicted BF% (28.2% vs. 28.5%, p=0.467). Previously developed BF% equations using BMI, but not handgrip strength, had similar constant errors and mean absolute errors compared to the new prediction equation. **Conclusion**: Handgrip strength does not appear to improve the estimation of body fat percentage from BMI prediction equations in middle and older-aged Asian adults.

Keywords: Body fat percentage, Dual-energy X-ray absorptiometry, Middle-aged and older Asians

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Introduction

The obesity crisis continues to remain a challenge in our society with the prevalence increasing over the past two decades from 27.5% to 43.0% for men and from 33.4 to 41.9% for women[17]. Some of the most severe consequences of obesity are the development of non-communicable diseases such as diabetes and cardiovascular disease[6]. Obesity and overweight are defined as excessive fat accumulation of the body and accurate assessment of obesity requires measurements of body fat percentage (BF%). Common methods that are used to assess BF% include dual-energy x-ray absorptiometry, air displacement plethysmography, underwater weighing and bioelectrical impedance[10] and ultrasound [20]. Unfortunately, some of these methods are expensive, not readily available or require unique training. Body mass index (body mass divided by height squared, BMI) is often used as an indirect assessment of body fat as it has been shown to correlate well with BF%[12]. In addition, the measurements of body mass and height are done in a medical clinic and require little training. Unfortunately, these measurements can be misleading as one systematic review and meta-analysis noted poor sensitivity of BMI to label individuals as obese when they had excessive body fat[18]. Further, athletic individuals with large amounts of muscle mass can be identified as obese when they have low levels of body fat.

One way to help improve the ability of BMI to estimate BF% is through prediction equations. For example, Womersley and Dunn (1977) [23] and Jackson et al. (2002) [13] created prediction equations for BF% only using BMI while Deurenberg et al. (1991) [8] and Gallagher et al. (2000) [11] included other variables such as age, sex and ethnicity. Recently, Nickerson et al. (2020) [15] aptly pointed out that when validated, these equations produced large errors in individual predictions of BF%. They suggested that this could be because these equations did not have a variable that took fat-free mass into account. Accordingly, they developed a new prediction equation that used handgrip strength to estimate BF% and found it to be more accurate than other prediction equations [15]. Although it is interesting to use grip strength as a factor for estimating BF%, it is unclear if this equation can be widely applied to all populations.

One concern about this new equation was that it was developed in young and middle-aged individuals (18-45 years) who were non-Hispanic whites and Hispanic. This may partly explain some of the discrepancy in their findings since the other studies had a wide range of ages, and the equation by Nickerson et al. (2020) [15] did not include age as a predictor variable. With aging, there is an increase in fat mass[19,24], and this equation may not be as applicable for older adults. Furthermore, different ethnicities may have a different BF% despite having a similar BMI value [14]. For example, a regression analysis revealed that Japanese men had significantly greater levels of BF% at any BMI value when compared to Caucasian Australian men [14]. We hypothesized that due to the differences in body composition with aging and ethnicity, that the Nickerson equation would not be as accurate as previously reported when used with middle-aged and older Asian adults. Thus, the purpose of this study was to validate the previous equation and compare it to previously developed equations. Further, if the Nickerson equation was not a good predictor, we would develop a new prediction equation that included handgrip strength and BMI of Asian adults to determine if it could improve on other previously developed BF% prediction equations.

Methods

Participants

Apparently healthy participants (n=459) were recruited from the university campus of the National Institute of Fitness and Sports in Kanoya, Kagoshima, Japan and from the surrounding areas. Data was collected from June 2015 to October 2016. Participants were randomly separated into two groups. One group was used to validate the Nickerson et al. (2020)

[15] equation and to develop a new equation if needed (n=303) and the other group was used to cross-validate the newly developed equation (n=156). Participants were separated so that there was approximately twice as many participants in the model development group [9]. Participants' ages varied from 49 to 79 and characteristics of each group can be found in Table 1. Prior to measurements, the participants were interviewed and assessed by a physician about their health history and current physical condition. Participants were excluded from the study if they had cardiovascular disease, cancer myositis, neuromuscular disorders or had metal in their bodies (e.g. artificial joint replacement and stent implantation) as determined from self-reported questionnaires. Most participants (70%) reported doing recreational sports (e.g. ground golf) a minimum of two times a week. Participants provided written informed consent prior to data collection. The study was approved by the institutional review board of the National Institute of Fitness and Sports in Kanoya, Kagoshima, Japan and the study was done according to the Declaration of Helsinki.

Table 1. Participant characteristics. BMI = body mass index, DXA = dual-energy x-ray absorptiometry, HGS = handgrip strength.

	Model Development Group		Validation Group	
	Females (n=174)	Males (n=129)	Females (n=88)	Males (n=68)
Age (years)	67.5 ± 7.9	68.5 ± 7.5	67.6 ± 7.5	67.6 ± 8.3
Height (cm)	151.3 ± 5.7	163.4 ± 6.0	151.8 ± 5.6	162.8 ± 6.2
Body Mass (kg)	53.3 ± 7.8	64.3 ± 9.4	53.7 ± 8.7	63.3 ± 8.8
BMI (kg/m^2)	23.3 ± 3.3	24.0 ± 3.0	23.3 ± 3.4	23.8 ± 2.7
% Fat DXA	32.9 ± 6.1	22.9 ± 5.4	32.2 ± 6.3	23.1 ± 5.0
Right HGS (kg)	24.1 ± 4.2	36.8 ± 6.3	25.0 ± 3.8	36.1 ± 6.2
Left HGS (kg)	22.9 ± 3.8	35.6 ± 5.8	23.6 ± 3.7	35.0 ± 5.2

Anthropometric measurements

Body mass was measured using an electronic weight scale (Tanita WB-260A, Tokyo, Japan) and was rounded to the nearest 0.1 kg. Height was measured using a height scale (YL-65, Yagami Inc., Nagoya, Japan) and rounded to the nearest 0.1 cm. Body mass index was calculated by dividing the weight in kg by the body mass in meters squared (kg/m^2).

Dual-energy x-ray absorptiometry (DXA) measurements

Prior to doing the DXA scan, participants were asked not to do any vigorous exercise 24 hours before testing and to not eat for 3 hours before testing. However, they were encouraged to stay hydrated and were provided with water ad libitum. A whole body DXA scan was used to measure BF% of participants (Discovery A, Hologic Inc., Bedford, MA, USA). The test-retest reliability was reported in a previous manuscript [20].

Handgrip strength measurements

Handgrip strength was measured using Smedley hand dynamometer (TKK 5401 Grip-D, Takei Scientific Instruments, Niigata, Japan). Participants were told during testing to keep the arm straight and slightly away from the body while standing. The handgrip device was adjusted so that the middle phalanx of the participant's hand was placed on the inner handle. Right and left hands were both tested randomly. Participants performed one test trial and after resting 1 minute were then told to maximally squeeze the handgrip device. Another minute of rest was given and then a second maximal trial was done. Measurements were recorded in kilograms. Both the right and left hands were tested, and the highest value of each hand being used for data analysis. The test-retest reliability of handgrip strength was reported previously [3]. Relative handgrip strength was calculated using the formula by Nickerson et al. [15] (Maximum right hand grip strength (kg) + maximum left hand grip strength (kg))/body mass (kg)).

Statistical Analysis

The Nickerson et al. equation (Nickerson et al., 2020) [15] was used to estimate body fat %: BF% = 21.504 – (12.484 x relative handgrip strength (kg)) – (7.998 x sex) + (0.722 x BMI) where sex = 0 for females and 1 for males.

We also used previously developed BF% equations using BMI in Asians from two other studies.

- Gallagher et al. (2000) [11] DXA criterion: BF% = 76.0 - (1097.8 * (1/bmi)) - (20.6*sex) + (0.053*age) + (95.0 * Asians * (1/bmi)) - (0.044 * Asians * age) + (154 * sex * (1/bmi)) + (0.034*sex*age) where Asians = 1 and sex = 1 for males and 0 for females.
- Gallagher et al. (2000) [11] 4C criterion: BF% = 63.7 - (864 * (1/bmi)) - (12.1 * sex) + (0.12 * age) + (129 * Asians * (1/bmi)) - (0.091 * Asians * age) where Asians = 1 and sex = 1 for males and 0 for females.
- Deurenberg et al. (1991) [8] Underwater weighing criterion: BF % = (1.2 * bmi) + (0.23*age) - (10.8 * sex) - 5.4 where sex = 1 for males and 0 for females.

A Bland-Altman plot was used to investigate how accurate the estimated BF% was compared to the measured BF% from the DXA scan. The difference between the predicted and measured BF% was plotted against the average of the predicted and measured BF% and 95% limits of agreement were included on the plot. Limits of agreement were calculated by multiplying the standard deviation of the mean difference by 1.96 and then adding or subtracting that from the mean difference (constant error). Standard error of the estimate and total error were calculated with the following equations:

$$SEE = Standard\ devaition\ of\ DXA * \sqrt{(1-r^2)}$$

$$TE = \sqrt{\frac{\sum(Predicted\ value - DXA\ value)^{\wedge}2}{N}}$$

In the SEE equation, r is the correlation between the DXA value and predicted value. The absolute error was calculated and compared between equations. The absolute error represents the difference between the measured and actual value. Paired t-tests and correlation coefficients were also calculated between the estimated and measured BF%. Significance was set at an alpha level of 0.05.

Stepwise multiple linear regression was used to determine a new prediction model if a sufficient lack of agreement was found between the estimated and actual BF%. Sex, age, height, body mass, BMI, maximum right handgrip strength and maximum left handgrip strength were included initially. Significance to be included in the model was set at P≤0.05. Body fat % from DXA was used as the criterion variable. Linearity of data for the prediction equation was tested by plotting residuals vs. fitted values, homogeneity of variance was tested using a scale-location plot, normality of residuals was tested using Q-Q plots and outliers were tested using a residuals vs. leverage plot. The equation was cross validated using similar methods that were used to test the validity of the Nickerson equation as discussed above.

Results

Validation of Nickerson Equation

The differences in predicted (Nickerson equation) vs. measured (DXA) BF% were plotted against the averages of the predicted and measured BF% (Figure 1). The mean bias or constant error was -6.0 ± 4.2% with the 95% limits of agreement being ± 8.2% (-14.1 to 2.2%).

Table 2. Accuracy of different BMI prediction equations to estimate body fat percentage (BF%). SEE = standard error of the estimate, TE = total error.

Accuracy of equations (n=303)											
Study	**Measured BF% (DXA)**	**Predicted BF% (equation)**	**Mean Bias (Constant Error)**	**T-test**	**R^2**	**SEE**	**TE**	**Mean Absolute Error**	**95% Limits of Agreement**		
Criterion DXA	28.7 (7.6)								Critical Difference	Upper Limit	Lower Limit
Nickerson 4C (2020)	28.7 (7.6)	22.7 (6.5)	-6.0 (4.2)	p<0.001	0.71	4.2	7.3	6.3 (3.6)	8.2	-14.2	2.2
Gallagher DXA (2000)	28.7 (7.6)	28.4 (7.4)	-0.31 (4.3)	p=0.215	0.71	4.2	4.3	3.5 (2.5)	8.4	-8.8	8.1
Gallagher 4C (2000)	28.7 (7.6)	28.8 (6.9)	0.15 (4.1)	p=0.51	0.71	4.1	4.1	3.4 (2.3)	8.1	-7.9	8.2
Deurenberg Underwater (1991)	28.7 (7.6)	33.9 (6.3)	5.3 (4.6)	p<0.001	0.64	4.6	7.0	5.8 (4.0)	9	-3.7	14.3

Table 3. Accuracy of new BMI equation using handgrip to estimate body fat percentage (BF%). SEE = standard error of the estimate, TE = total error.

Accuracy of equations with validation sample (n=156)											
Study	**Measured BF% (DXA)**	**Predicted BF% (equation)**	**Mean Bias (Constant Error)**	**T-test**	**R^2**	**SEE**	**TE**	**Mean Absolute Error**	**95% Limits of Agreement**		
									Critical Difference	Upper	Lower
Thiebaud DXA	28.2 (7.3)	28.5 (6.4)	0.23 (3.9)	p=0.465	0.72	3.9	3.9	3.2 (2.3)	7.7	-7.4	7.9
Nickerson 4C (2020)	28.2 (7.3)	22.4 (6.4)	-5.8 (4.0)	p<0.001	0.71	4.0	7.1	6.0 (3.7)	7.9	-13.7	2.1
Gallagher DXA (2000)	28.2 (7.3)	28.1 (7.6)	-0.12 (4.2)	p=0.72	0.71	4.0	4.2	3.4 (2.6)	8.3	-8.4	8.2
Gallagher 4C (2000)	28.2 (7.3)	28.6 (7.0)	0.37 (4.1)	p=0.269	0.71	4.0	4.1	3.3 (2.5)	8.1	-7.7	8.4
Deurenberg Underwater (1991)	28.2 (7.3)	33.7 (6.5)	5.5 (4.4)	p<0.001	0.66	4.3	7.0	5.9 (3.7)	8.6	-3.1	14

The mean absolute error was 6.3 ± 3.6%, the SEE was 4.2% and the total error was 7.3%. The correlation coefficient between measured and predicted BF% was 0.84 with a p-value < 0.001. A paired t-test revealed that the estimated BF% by the Nickerson equation (22.7%) was significantly lower than the measured (28.7%) BF% by DXA (p<0.001).

The Gallagher prediction equation using DXA as the criterion had a constant error of -0.31 ± 4.3%, an SEE of 4.2% and a total error of 4.3%. The Gallagher prediction equation using a 4-compartment model as the criterion had a constant error of 0.15 ± 4.1%, an SEE of 4.1% and a total error of 4.1%. The Deurenberg prediction equation had a constant error of 5.3 ± 4.6%, an SEE of 4.6% and a total error of 7.0% (Table 2).

Development of New Equation

Based on the results of the Nickerson equation compared to DXA and the other prediction equations, we developed a new equation that included handgrip strength and BMI in Asian adults to see if it would improve on previously developed equations. Stepwise multiple linear regression produced a model that had an R^2 of 0.726 and an SEE of 4.0% and produced the following equation:

BF% = 12.743 – (8.062 x Sex) + (1.321 x BMI (kg/m^2)) – (0.225 x Left HGS (kg)) – (0.080 x Age).

Sex: 1 = males, 0 = females.

Linearity of data, homogeneity of variance and normality of residuals were all verified when examining the appropriate plots. No extreme outliers were indicated when examining the residuals vs. leverage plot.

Validation of new equation

A cross-validation sample of 156 participants was used with the new prediction equation. The difference in predicted and measured BF% were plotted against the average of the measured and predicted BF% (Figure 2). The mean difference or constant error was 0.23 ± 3.9% and the limits of agreement were -7.5 to 7.9%. The mean absolute error for the new prediction equation was 3.2 ± 2.3%. The average BF% using the new equation was 28.5 ± 6.4%, and the average BF% using DXA was 28.2 ± 7.3%. The correlation coefficient between the measured and new prediction equation was 0.85, p<0.001. There was no significant difference between the mean of the measured (28.2%) vs. the new predicted (28.5%) BF% (p=0.465). The SEE was 6.4% and the total error was 3.9%.

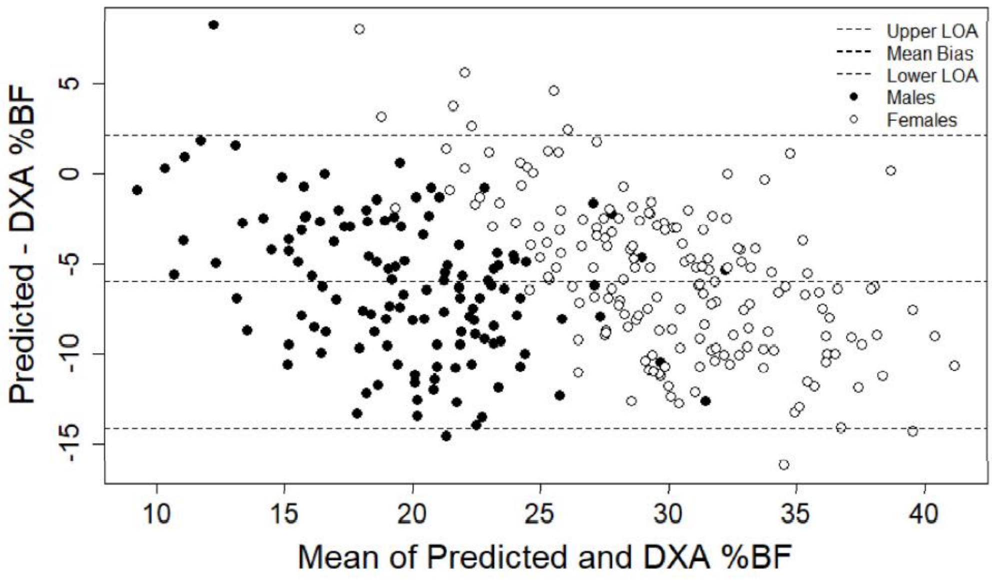

Figure 1. Bland-Altman Plot of Nickerson equation. LOA = limits of agreement, BF % = body fat percentage, DXA = dual energy x-ray absorptiometry

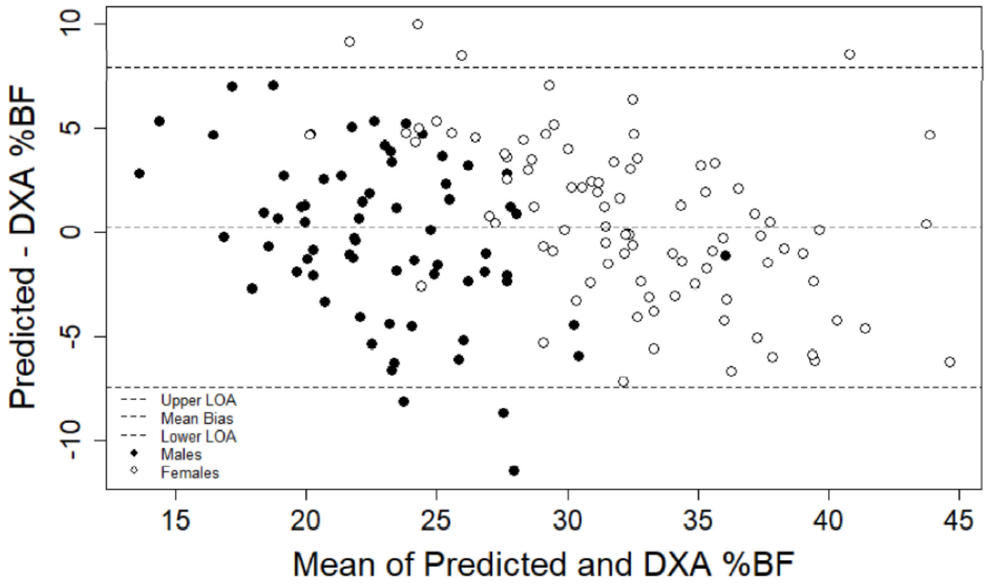

Figure 2. Bland-Altman Plot of New Prediction Equation. LOA = limits of agreement, BF % = body fat percentage, DXA = dual energy x-ray absorptiometry

Using the validation data, we found that the average BF% using the Nickerson equation was 22.4 ± 6.4%. The constant error of the Nickerson equation was -5.8 ± 4.0% with the limits of agreement ranging from 2.0 to -13.7%. The SEE was 4.0% and the total error was 7.1%. (Table 3). In addition, the absolute error was significantly greater for the Nickerson equation compared to our new equation [2.8 (95% CI: 2.1, 3.5) %, p<0.001].

The Gallagher prediction equations had constant errors of -0.12 and 0.37%, SEEs of 4.0 and 4.0% and total errors of 4.1 and 4.2% (Table 3). The Deurenberg prediction equation had a constant error of 5.5% ± 4.4%, SEE of 4.3% and a total error of 7.0%. (Table 3)

Discussion

Our findings showed that the Nickerson equation failed to accurately predict BF% in middle-aged and older Asian adults despite the addition of adding handgrip strength to BMI. We developed a new equation that included BMI, HGS and age to estimate BF% in middle-aged and older Asian individuals, but this equation was comparable to already developed BMI prediction equations.

Validation of Nickerson equation

The Nickerson equation on average underestimated BF% in our sample of middle-aged and older Asian adults by ~6% (22.7 vs. 28.7%). The Nickerson equation was developed in a sample of non-Hispanic white and Hispanic individuals with the ages varying from 18 to 45 but the average age was in the ~20s for their sample. In contrast, our sample included Asian adults with the average age in the upper 60s. Thus, a significant contrast in age was present between these two samples. A well-established finding is that BF% increases with increasing age. In particular, a positive correlation between age and visceral adipose tissue has been noted in women [24]. The sample used to develop the Nickerson equation had body fat levels that were on average around 26 to 29% for females and around 18-20% for males. In our sample, the average BF% was ~33% for females and ~23% for males. Overall, the BF% of our participants was higher than the BF% of Nickerson et al. [15].

An important factor that should also be considered are the methods used to determine the BF% of our participants. In this study, BF% values from DXA were used as the criterion while the Nickerson equation used the four-compartment model as the criterion [15]. The four compartment model is considered to be an accurate method for determining BF% as it takes into account body water (bioelectrical impedance spectroscopy), bone mineral content (DXA) and total body volume (hydrostatic weight, air displacement plethysmography or DXA) [16]. Some differences have been noted when comparing DXA BF% values to 4-compartment models. For example, one study found that DXA overestimated BF% by ~2.5% in overweight/obese adults when compared to a 4-C model [5]. On the other hand, another study found that DXA underestimated fat mass by 0.79 kg in obese older Hispano-American adults when compared to a 4-C model. DXA was also found to underestimate BF% compared to a 4-C model by ~1.8% in 18-59 year old adults (van der Ploeg, Withers, & Laforgia, 2003) [17]. These studies suggest that DXA can over or underestimate BF% compared to 4C models, but it is unlikely that a ~6% difference in the prediction equation and DXA measurements was due to this alone. In addition, when looking at the already developed Gallagher equation that used a 4-compartment model as its criterion [11], it had smaller constant and total error values than the Nickerson equation (Table 2). However, it should be noted that a prediction equation using DXA measurements was used to calculate the 4-compartment BF% in the Gallagher study.

Another factor that could have influenced the findings in this study was the ethnicity of our participants. Several studies have discovered differences in body composition when examining different ethnicities. For example, one study found that despite having similar BMIs, Japanese individuals had higher BF%s [14]. Gallagher et al. (2000) [14] also found that Asians had a higher BF% compared to Caucasians or African Americans despite having the same BMI. These results were also found in individuals of Asian descent who lived in New York City. In that study, the average BMI of Asian adults was significantly lower than Caucasians but their BF% was greater (Wang et al., 1994) [17]. When using linear regression, they also found that if an Asian and Caucasian individual both had a BMI of 25, it would be estimated that the BF% of Caucasians would be ~34% while the BF% of Asians would be ~37% [22]. The reasons for the differences are unclear but Deurenberg et al. (2002) [7] suggested that physical activity levels, relative leg lengths and frame size could potentially explain these differences. It is evident from these studies that ethnicity could have played a role in our results and partially explain why the Nickerson equation did not estimate BF% well in our sample. Therefore, equations that are made for specific ethnicities are needed when BMI is included in the equation.

New Prediction Equation

Similar to the previous study [15], the new equation in this study also included grip strength which is a variable that indirectly takes fat-free mass into account. Our previous cross-sectional study revealed a close relationship between HGS and muscle size of the forearm flexor muscles in both Caucasians [1] and Asians [4]. In addition, forearm flexor muscle size is also an indicator of whole-body muscle mass [2]. Thus, individuals with a large forearm muscle size may have a stronger grip strength and a larger muscle mass compared to those with smaller forearm muscles. Therefore, this information could be used to help improve the prediction of BF% from BMI. Our stepwise regression analysis found that left handgrip strength was a better predictor of BF% compared to right handgrip strength but it is unclear from this study why that was the case.

Our new prediction equation seems to estimate BF% in middle-aged and older Asians well based on our cross-validation results. We found a mean difference of 0.2%. Using stepwise regression, our prediction equation included age, BMI, sex and left-hand grip strength. The variance shared in BF% by our prediction equation was around 72% and the SEE of our equation was 4.0% which is comparable to other studies. For example, the Nickerson equation had an R^2 of 0.76 and an SEE of 4.24%. Other BMI equations had R^2 values ranging from 0.75 to 0.88 and SEE values ranging from 2.2 to 5.7%

[13]. Thus, our prediction equation seems in line with other prediction equations for estimating BF% from easy to obtain variables such as BMI, handgrip strength, sex and age. However, when our prediction equation was compared to other already developed BMI equations for Asians, small differences were noted, and therefore, handgrip strength may not add significantly to estimating BF% using BMI in Asian adults.

Overall, we found that differences in ethnicity and age can significantly impact the results of a previously developed BF% equation. We also noted that handgrip strength could contribute to predicting of BF% in middle-aged and older Asian adults but other established BMI equations may produce similar estimations. While a cross-validation assessment of the new prediction equation using BMI and handgrip strength was done, future studies should determine if this equation could accurately predict BF% using other criterion measures such as the 4-compartment model.

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Conflict of Interest

The authors report no conflict of interest and the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

Author Contributions

Takashi Abe: Conceptualization (lead), methodology (support), project administration (equal), investigation (support), writing – review and editing (lead). **Takuya Akamine:** Methodology (lead), project administration (equal), investigation (lead), writing – review and editing (support). **Eiji Fujita:** Methodology (support), project administration (equal), investigation (support), writing – review and editing (support). **Jeremy Loenneke:** writing-review and editing (support), formal analysis (support). **Robert Thiebaud:** Conceptualization (supporting), writing - original draft preparation (lead), formal analysis (lead).

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