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New Percentage Body Fat Prediction Equations for Japanese Females

Masaharu Kagawa[1),2)], Chiharu Kuroiwa[3)], Kazuhiro Uenishi[4)], Miki Mori[5)],
Andrew P. Hills[2)] and Colin W. Binns[1)]

1) School of Public Health, Curtin University of Technology
2) ATN Centre for Metabolic Fitness, Institute of Health and Biomedical Innovation, Queensland University of Technology
3) Department of Physical Therapy, Koriyama Institute of Health Science
4) Laboratory of Physiological Nutrition, Kagawa Nutrition University
5) Laboratory of Administrative Dietetics, Kagawa Nutrition University

Abstract Anthropometry is a simple and cost-efficient method for the assessment of body composition. However prediction equations to estimate body composition using anthropometry should be ‘population-specific’. Most popular body composition prediction equations for Japanese females were proposed more than 40 years ago and there is some concern regarding their usefulness in Japanese females living today. The aim of this study was to compare percentage body fat (%BF) estimated from anthropometry and dual energy x-ray absorptiometry (DXA) to examine the applicability of commonly used prediction equations in young Japanese females. Body composition of 139 Japanese females aged between 18 and 27 years of age (BMI range: 15.1–29.1 kg/m^2) was measured using whole-body DXA (Lunar DPX-LIQ) scans. From anthropometric measurements %BF was estimated using four equations developed from Japanese females. The results showed that the traditionally employed prediction equations for anthropometry significantly ($p<0.01$) underestimate %BF of young Japanese females and therefore are not valid for the precise estimation of body composition. New %BF prediction equations were proposed from the DXA and anthropometry results. Application of the proposed equations may assist in more accurate assessment of body fatness in Japanese females living today. *J Physiol Anthropol 26(1): 23–29, 2007* http://www.jstage.jst.go.jp/browse/jpa2
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Introduction

An accurate and precise estimation of total body fat, often expressed as percentage body fat (%BF), is an important component in body composition research. Among the large number of body composition assessment methods in common use, anthropometry including skinfold and girth measurements is a simple, portable, and cost-efficient field method. Anthropometry allows estimations of body composition using prediction equations that were derived from underwater weighing and other advanced methods (Brozek and Keys, 1951; Durnin and Womersley, 1974; Lohman, 1981). The accuracy and precision of anthropometry are, however, largely dependent on the skill and experience of the anthropometrists who take the measurements (Wagner and Heyward, 1999; Wang et al., 2000) and also the protocol used, including the type of skinfold caliper (Schmidt and Carter, 1990). Further, many prediction equations used in anthropometry are based on the concept of the two-compartment model that divides the human body into fat mass (FM) and fat-free mass (FFM). The model involves an assumption of constant densities of FM and FFM but this is not true in all individuals. As a result, prediction equations are only applicable to the group whose characteristics are similar to the group the equation was originally established from (i.e., the equation is population-specific).

In Japan the most commonly used prediction equation in body composition research using anthropometry is known as the Nagamine and Suzuki equation, predicting body density using the sum of triceps and subscapular skinfolds (Nagamine and Suzuki, 1964). The equation was proposed from anthropometric measurements of 112 Japanese females (18–23 years of age; mean age 21.3 years) and body density data using water displacement. However, the equation was proposed more than four decades ago and its validity has been questioned in a few studies (Nakadomo, 1991; Tahara et al., 1995), as the physique of the Japanese may have changed since the time it was proposed.

Tahara et al. (1995) measured the body density of 512 females aged between 18 and 66 years of age using the underwater weighing method and anthropometry. From the regression analyses derived they concluded that the equation using two skinfold sites (triceps and subscapular), equivalent to the sites used in the Nagamine and Suzuki equation, was poor, and proposed a new body density prediction equation using the sum of triceps, subscapular and abdominal skinfolds as well as age. This equation is known as Tahara's equation. Later, Tahara et al. (2002) proposed %BF prediction equations based on age and the results obtained from 552 females aged between 18 and 59 years.

However, previous studies by Tahara and his colleagues have a number of limitations, including the fact that the equations were generated from underwater weighing measures. The method was earlier considered a 'gold standard' approach to determine body density. However, the method requires participants to submerge in water and exhale maximally to accurately determine body density. The method is physically inappropriate for many populations, including children and middle-aged and elderly individuals. Further, the method requires a number of prediction equations to estimate %BF and therefore calculation errors may be introduced.

To date, no reported study has compared %BF values estimated from the Nagamine and Suzuki equation and the results obtained from advanced body composition methods such as dual energy x-ray absorptiometry (DXA). DXA has been widely recognised as one of the methods that provides valid estimations of %BF (Wellens et al., 1994; Van Loan, 1998; Glickman et al., 2004; Norcross and Van Loan, 2004). DXA measures human body composition based on a multi-compartment model and is able to differentiate lean body mass, FM, and bone mineral components. The aim of the current study was to compare %BF values estimated from whole-body DXA scans and anthropometry using the Nagamine and Suzuki equation. The study also compared this result with equations proposed by Tahara and his colleagues (Tahara et al., 1995; Tahara et al., 2002). Following a comparison between different methods, new %BF prediction equations for this population were also proposed.

Participants and methods

A convenient sample of 139 healthy Japanese female volunteers aged 18–27 years old were recruited in Saitama Prefecture, Japan. Participants were included in the study if their age was between 18 and 30 years of age and there was no past or current medical history that affected daily lifestyle and body composition. The study was approved by the Human Research Ethics Committees of both Curtin University of Technology and Kagawa Nutrition University. The study adhered to the principles of medical research established by the National Health and Medical Research Council (NHMRC, 1999). Participants were also screened for possible pregnancy prior to DXA assessments using a questionnaire. After obtaining their consent, each participant underwent body composition assessments using whole-body DXA scanning, and anthropometry. All participants completed anthropometry and DXA measurement within one week.

Dual energy x-ray absorptiometry (DXA)

This method uses two simultaneous x-ray beams of different energies to differentiate components of the human body (Heyward, 1998). Whole-body scanning using a DPX-LIQ and DPX-MD X-Ray Bone Densitometer with SmartScan Version 4.7c (Lunar Corporation, Madison, WI, USA) was conducted to determine bone mineral content (BMC), bone density, fat mass (FM), lean mass and %BF of the whole body and different body regions. DXA measurements were completed in approximately 10 min by an accredited technician.

Anthropometry

Anthropometric measurements included stature, body mass, eight skinfold measurements (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf), five girth measurements (relaxed arm, flexed and tensed arm, waist, gluteal and maximum calf), and four bone breadth measurements (biacromial, biiliocristal, biepicondylar humerus and biepicondylar femur). All measurements were taken according the protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (2001) by a Level 3 and a Level 2 anthropometrist accredited by ISAK. Both anthropometrists demonstrated a satisfactory level of inter- and intra-tester technical error of measurements (TEM) using a randomly chosen group of 20 participants (i.e., inter-tester TEM: within 7.5% for skinfolds and within 1.5% for other measurements; intra-tester TEM: within 5.0% for skinfolds and 1.0% for other measurements) as recommended by ISAK (Gore et al., 1996). These TEM values are lower than the levels suggested elsewhere (Wang et al., 2000). All anatomical landmarks were located and marked by the Level 3 anthropometrist (MK).

To estimate %BF from anthropometry, the body density of each participant was first estimated using the following body density prediction equations:

1) Body density $= 1.0897 - 0.00133 \cdot (X_1)$

where $X_1 = \Sigma$(triceps and subscapular skinfolds in mm). (Nagamine and Suzuki, 1964) − (NS)

2) Body density $= 1.07931 - 0.00059 \cdot (X_1) - 0.00015 \cdot (X_2)$

where $X_1 = \Sigma$(triceps, subscapular and abdominal skinfolds in mm) and $X_2 =$ Age. (Tahara et al., 1995) − (T1)

3) Body density $= 1.0330 + 0.00010 \cdot (X) - 0.00002 \cdot (X)^2$

where $X =$ Age. (Tahara et al., 2002) − (T2)

Estimated body density values were then converted into %BF values using the equation by Siri (1961) [%BF $= (4.95/\text{Body density} - 4.50) \cdot 100$)]. In addition, the following %BF prediction equation was used to compare with the DXA results:

4) $\%BF = 28.282 - 0.425 \cdot (X) + 0.00877 \cdot (X)^2$

where X=Age. (Tahara et al., 2002)−(T3)

Finally, body mass index (BMI; body mass (kg)/stature $(m)^2$), waist to height ratio (WHtR; waist girth (cm)/stature (cm)), sum of two skinfolds (∑2 using triceps and subscapular in mm), sum of three skinfolds (∑3 using triceps, subscapular and abdominal in mm), sum of eight skinfolds (∑8 in mm) and height-corrected sum of eight skinfolds (Ht∑8; sum of skinfolds·(170.18/stature)) were calculated using the anthropometric results.

Statistical analyses were conducted using the SPSS statistical package (version 14.0.0, 2005, Chicago, USA). Using the results from DXA as the criterion, inter-method differences in %BF values estimated from different equations were assessed using the limits of agreement method (Bland and Altman, 1986). The results of differences were expressed as mean±2·standard deviations (SD) and the Bland and Altman plot was presented in each comparison. Regression analyses using a forward stepwise model were also conducted to develop %BF prediction equations using anthropometric variables. Independent variables used in regression analysis were age, individual skinfold sites, ∑2, ∑3, ∑8 and Ht∑8. The %BF values obtained from DXA scans were used as the dependent variable. The developed equations were presented with adjusted r^2 ($R^2_{(adj)}$) and standard error of estimate (SEE). In addition, a magnitude of “best fit” for each developed equation was determined by the Akaike Information Criterion (AIC) using the following formula:

$$AIC = 2 \cdot k + n \cdot Ln(RSS/n)$$

where k is the number of estimated parameters in the equation, n is the number of participants, and RSS is the residual sum of squares for each equation. The “best fitting” equation has the smallest AIC value.

Results

Descriptive characteristics of the Japanese female participants are shown in Table 1. Table 2 shows correlations between selected anthropometric variables and %BF estimated from DXA. Among skinfold variables, triceps skinfold had the highest correlation with DXA (r=0.854), followed by supraspinale (r=0.848) and biceps skinfold (r=0.824), suggesting Japanese females may have higher fat deposition in the upper limb and trunk region. In addition, the correlation between %BF from DXA and the sum of eight skinfolds was also very high (r=0.908). This indicates a strong and directly proportional relationship between %BF and skinfold measurement in young Japanese females.

Table 3 illustrates differences in estimated %BF values between the methods included in the study. Using the DXA assessment as the criterion method, %BF values estimated by the Nagamine and Suzuki equation and Tahara’s equation using the sum of skinfolds (triceps, subscapular and abdominal) were highly correlated with the DXA results ($r_{(NS)}$=0.859 and $r_{(T1)}$=0.870 respectively). However, both equations significantly (p<0.01) underestimated %BF compared to results obtained from DXA (5.4% by the Nagamine and Suzuki equation and 4.8% by Tahara’s equation). The prediction equations for body density and %BF using age as an independent variable (e.g., T2 and T3) did not correlate with the DXA results and also significantly over- or underestimated the %BF of young Japanese females.

Figure 1 shows the inter-method differences in estimated %BF using DXA as a criterion. In comparison with DXA, the Nagamine and Suzuki equation which was developed specifically from young Japanese females had relatively wide limits of agreement (mean±2SD) of 5.4%±6.2%. This suggests application of the equation may underestimate %BF

Table 1 Physical characteristics of Japanese females included in the study (n=139)

Variable	Mean	SD	Range
Age (Years)	20.4	1.3	18.0–27.0
Stature (cm)	158.8	5.0	147.6–170.7
Body mass (kg)	52.5	6.1	37.8–70.7
Body Mass Index (kg/m^2)	20.8	2.2	15.1–29.1
Waist girth (cm)	66.3	4.9	57.3–82.3
Sum of two skinfolds (mm)*	31.1	9.7	12.6–63.4
Sum of three skinfolds (mm)**	49.9	15.6	17.7–95.4
Sum of eight skinfolds (mm)***	124.5	35.5	50.1–233.7
Height-corrected sum of skinfolds (mm) ****	126.9	38.3	53.9–260.6

* Sum of two skinfolds=∑(triceps and subscapular) in mm
** Sum of three skinfolds=∑(triceps, subscapular and abdominal) in mm
*** Sum of eight skinfolds=∑(triceps, subscapular, biceps, iliac crest, supraspinale, front thigh, medial calf skinfolds) in mm
**** Height-corrected sum of eight skinfolds=Sum of eight skinfolds·(170.18/stature)

Table 2 Correlations with percentage body fat (%BF) estimated from DXA and selected anthropometric variables in 139 Japanese females

Anthropometric variables	Correlation with %BF obtained from DXA (r)
Triceps skinfold	0.854**
Subscapular skinfold	0.781**
Biceps skinfold	0.824**
Iliac crest skinfold	0.816**
Supraspinale skinfold	0.848**
Abdominal skinfold	0.760**
Front thigh skinfold	0.585**
Medial calf skinfold	0.689**
Sum of eight skinfolds	0.908**
Arm (relaxed) girth	0.789**
Arm (flexed and tensed) girth	0.743**
Waist (minimum) girth	0.738**
Gluteal girth	0.712**
Calf (maximum) girth	0.536**

** Spearman’s correlation is significant at the 0.01 level.

Table 3 Differences in estimated %BF values obtained from DXA and prediction equations using anthropometry in Japanese females (n=139)

Variable	Percent body fat (%)		Mean %BF difference	Correlation with DXA
	Mean	SD		
$\%BF_{(DXA)}$	27.6	5.9	—	—
$\%BF_{(NS)}$	22.2	5.9	−5.4*	0.862**
$\%BF_{(T1)}$	22.9	4.2	−4.8*	0.878**
$\%BF_{(T2)}$	34.0	0.6	6.4*	0.077
$\%BF_{(T3)}$	23.3	0.1	−4.4*	−0.085

* Mean %BF differences significantly different at the 0.01 level.
** Spearman's correlation is significant at the 0.01 level.

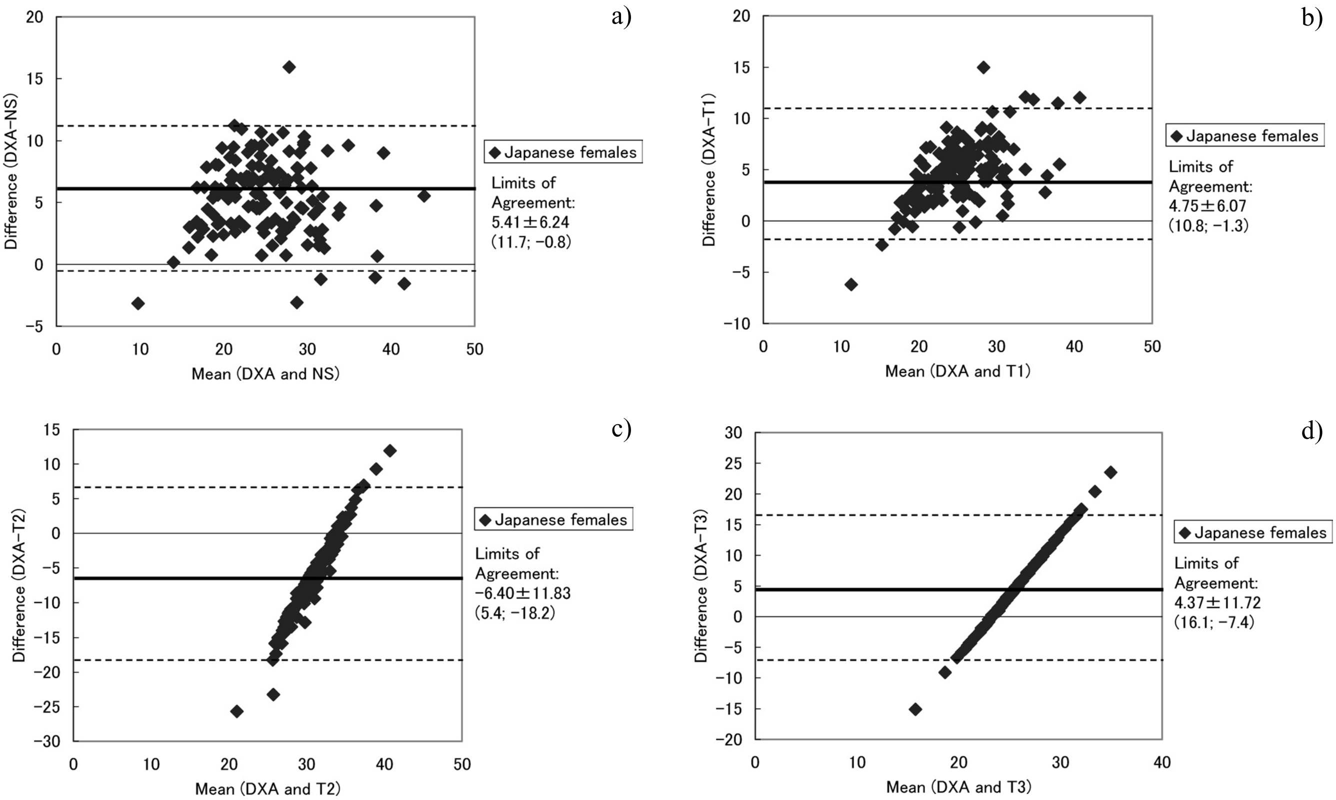

Fig. 1 Inter-method differences in estimated %BF of a) the Nagamine and Suzuki equation (NS), b) Tahara's equation (T1), c) the new Tahara equation using age to predict body density (T2), and d) the new Tahara equation using age to predict %BF (T3) compared with the DXA results.
Estimated %BF values using different prediction equations were compared with the values obtained from DXA and presented as Bland and Altman plots (mean±2*SD). In comparison with DXA, both the Nagamine and Suzuki equation (NS) and Tahara's equation (T1) significantly underestimated and indicated a possible underestimation as high as 11–12% in young Japanese females (a and b). The other equations using age as an independent variable (T2 and T3) clearly showed an underestimation pattern as an increase in measured %BF using DXA.

of participants by up to 12%. In addition, Japanese females with a very small or large amount of body fat as measured by DXA were likely to be overestimated by anthropometry using this equation. Similarly Tahara's equation showed possible underestimation by as much as 11% compared to the DXA result. This equation however, showed a different pattern in over- and underestimation compared to the Nagamine and Suzuki equation and it showed a trend of underestimation as the actual %BF estimated by DXA increased. This underestimation pattern is more prominent in the two equations that used age as the dependent variables (T2 and T3).

From regression analyses using DXA and anthropometric variables, %BF prediction equations were developed (Table 4). Although age was entered as an independent variable, it was excluded from the final equations. Using a forward

Table 4 Percent body fat prediction equations proposed from the study using anthropometric variables

Dependent variable	Regression equation	$R^2_{(adj)}$	SEE	AIC
All anthropometric variables	%BF=−4.054+0.16·(Triceps)+0.154·(Iliac crest) +0.281·(Biceps)+0.263·(Gluteal girth)+0.229·(Medial calf) −3.249·(Humerus bone breadth)+0.517·(Relaxed arm girth) +0.125·(Abdominal)	0.875	2.070	215.2
Individual skinfold sites	%BF=9.452+0.286·(Triceps)+0.255·(Iliac crest) +0.569·(Biceps)+0.190·(Medial calf)+0.123·(Abdominal)	0.844	2.311	236.8
Three skinfolds sites equivalent to Tahara's equation	%BF=9.981+0.673·(Triceps)+0.228·(Abdominal) +0.165·(Subscapular)	0.786	2.712	285.0
Sum of two skinfolds*	%BF=11.55+0.518·(Sum of 2 skinfolds)	0.739	2.990	306.8
Sum of three skinfolds**	%BF=11.294+0.328·(Sum of 3 skinfolds)	0.758	2.879	296.1
Sum of eight skinfolds***	%BF=8.848+0.151·(Sum of 8 skinfolds)	0.835	2.378	242.2
Height-corrected sum of eight skinfolds****	%BF=9.043+0.139·(Ht-corrected sum of skinfolds)	0.830	2.415	246.6

* Sum of two skinfolds=∑(triceps and subscapular) in mm
** Sum of three skinfolds=∑(triceps, subscapular and abdominal) in mm
*** Sum of eight skinfolds=∑(triceps, subscapular, biceps, iliac crest, supraspinale, front thigh, medial calf skinfolds) in mm
**** Height-corrected sum of eight skinfolds=Sum of eight skinfolds·(170.18/stature)

stepwise analysis, the equation using five individual skinfold measurements (triceps, iliac crest, biceps, medial calf and abdominal), two girth measurements (gluteal and relaxed arm) and humerus bone breadth had the highest correlation (R^2_{adj}=0.875, SEE=2.070) with the %BF value obtained from the whole-body DXA scan and also had the lowest AIC value (215.2). The equation that only used five skinfold sites retained a high correlation (R^2_{adj}=0.844, SEE=2.311, AIC=236.8) with the DXA results, indicating that an application of equations using skinfolds alone is also acceptable in total body fat prediction. The equation using the sum of two skinfolds (i.e., triceps and subscapular) had the lowest correlation with the %BF results obtained from DXA (R^2_{adj}=0.739, SEE=2.990, AIC=306.8). The equation using the sum of three skinfolds (i.e., triceps, subscapular and abdominal), which was used in Tahara's equation, showed a higher correlation of 0.758. However, the analysis also showed that the equation using individual skinfold values correlated more highly with the DXA result than using the sum of skinfolds (R^2_{adj}=0.786, SEE=2.717, AIC=285.0).

Furthermore, the analysis also proposed the following equations using two or three skinfolds to estimate %BF in young Japanese females:

$$\%BF = 9.531 + 0.712 \cdot (\text{Triceps}) + 0.350 \cdot (\text{Iliac crest}) \quad (R^2_{adj}=0.788,\ SEE=2.695,\ AIC=280.4)$$

$$\%BF = 10.091 + 0.410 \cdot (\text{Triceps}) + 0.316 \cdot (\text{Iliac crest}) + 0.750 \cdot (\text{Biceps}) \quad (R^2_{adj}=0.827,\ SEE=2.436,\ AIC=254.0)$$

The proposed equations did not include subscapular or abdominal skinfold sites that have been included in previously proposed equations and showed higher correlations and lower AIC values compared to the equations using the sum of skinfolds (Table 4). The results suggest that equations using individuals skinfold sites have better precision in %BF prediction compared to the equations using the sum of skinfold values.

Discussion

The equations proposed by Nagamine and Suzuki have been widely used in Japan for more than four decades to estimate the body composition of the Japanese population. However, despite being developed from young Japanese males (18 to 27 years of age) and females (18 to 23 years of age), they were often misinterpreted and introduced as equations for the adult population in general (Toyokawa and Saeki, 1985) in later years.

Using young Japanese females, the current study showed a significant underestimation of %BF using the Nagamine and Suzuki equation compared to the results obtained from whole-body DXA scans. Considering a comparable stature and weight between the participants in the current study and two large surveys conducted in Japan (JARD, 2002; Kenkou Eiyou Jouhou Kenkyuukai (The Society for the Study of Health), 2004), it is reasonable to suggest that the Nagamine and Suzuki equation is no longer appropriate for young Japanese females. This result is consistent with the results obtained from young Japanese males (Kagawa et al., 2006). Potential reasons may include the technical error of measurements in both underwater weighing and anthropometry during the development process, problems in the formation of the equation (as the relationship between body density and skinfolds has been suggested to be quadratic) (Jackson and Pollock, 1978), and also a possible secular trend in body proportion, body composition and also fat distribution changes in the Japanese population.

The current study also examined the predictability of other equations proposed for adult females aged above 18 years of age (Tahara et al., 1995; Tahara et al., 2002). Tahara's equation (using the sum of skinfolds) showed slightly better prediction than the Nagamine and Suzuki equation but nonetheless a significant underestimation of approximately 5% was still evident. The limits of agreement indicated that it may underestimate by as much as 11%, with little difference from the Nagamine and Suzuki equation (with a maximum underestimation of 11.7%). A possible reason for this is that both equations used the sum of skinfolds rather than individual skinfold values. The current study has compared correlations between the DXA results and equations using individual skinfold sites and the sum of two, three and eight skinfolds. The results indicate that the equation using individual skinfold values was more highly correlated ($R^2_{(adj)}=0.844$) and also had lower AIC value (236.8) than the equation using the sum of skinfolds ($R^2_{(adj)}$ for the sum of eight, three and two skinfolds were 0.835, 0.758 and 0.739 respectively and AIC values were 242.2, 296.1 and 306.8 respectively). Similarly, the equation including triceps, subscapular and abdominal skinfolds individually showed a higher correlation with the DXA results ($R^2_{(adj)}=0.786$, AIC=285.0) compared to the equation using the sum of the same skinfold sites ($R^2_{(adj)}=0.758$, AIC=296.1). In fact, the correlation obtained from the equation using the sum of three skinfolds was even lower than the results obtained from the equation using two skinfold sites ($R^2_{(adj)}=0.788$, AIC=280.4). While the previous prediction equations have used the sum of skinfolds, these results suggest higher precision in %BF estimation in the equations using individual skinfold values compared to the sum of skinfold values. The use of individual values in future prediction equations is therefore recommended.

In order to reduce participant burden and time-efficiency, it is important to propose an equation that is sufficient to predict the body composition of participants with a minimum number of measurement sites. The current study showed that the equation using three skinfolds had an R^2_{adj} of 0.827 with the DXA results, which was comparable to the equations using a greater number of anthropometric variables and appeared sufficient to estimate %BF in young Japanese females. The finding was consistent with an earlier study (Tahara et al., 1995). However, the current study observed that different skinfold sites (i.e., triceps, iliac crest and biceps) than those from the previous studies (i.e., triceps, subscapular and abdominal) were more closely associated with %BF in young Japanese females. This difference may be the result of methodological differences. The previous study used a sample of 512 females whose age ranged from 18 to 66 years of age and there may be a change in subcutaneous fat distribution depending on the ages of the participants. Also, the previous study measured skinfolds based on the standard of Behnke and Wilmore (1974), which does not include biceps skinfold and iliac crest skinfold measurements. These differences in measurement protocol are also evident when compared with the Nagamine and Suzuki study (1964), which only measured chest, abdominal, triceps, subscapular and knee skinfolds. Because previous studies did not measure biceps skinfold, a skinfold which was found to be useful to estimate %BF in Japanese females in the current study, the equations proposed from the previous studies might have been insufficient to estimate %BF in Japanese females.

Furthermore, the current study compared the results obtained from DXA with the values estimated from recently proposed equations using age as an independent variable. The results clearly indicate that both equations do not estimate body fat of participants accurately and also showed a strong trend to underestimation of %BF of participants as %BF estimated from DXA increases. This may be simply due to a bias of the equations that is a result of using age alone to estimate the body composition of individuals. While the authors of the earlier study suggested that fat mass accumulation increases with aging, there is a need to consider variability in fat mass accumulation within each age group. Consequently, even though these equations may be convenient for a rough estimate in an epidemiological setting, they are not useful for individuals.

Conclusion

When compared with values obtained from DXA, the current study showed that the traditionally employed prediction equations for anthropometry significantly underestimate %BF of young Japanese females and therefore are not valid for a precise estimation of their body composition. The proposed equations using individual skinfold sites may improve %BF estimation using anthropometry for this specific age group. The current study indicated that equations using individual skinfolds have higher correlations to the DXA results compared to the equations using the sum of skinfolds. Considering participant burden and time-efficiency, the application of prediction equations using at least three skinfold sites is recommended for a precise %BF prediction for this specific age group. Future research should focus on increased sample size, including participants from a wider age range in order to establish more generalizable prediction equations.

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Correspondence to: Masaharu Kagawa, Postdoctoral Research Fellow, ATN Centre for Metabolic Fitness, Institute of Health and Biomedical Innovation, Queensland University of Technology, Corner of Blamey Street and Musk Avenue, Kelvin Grove QLD 4059 Australia
Phone: +61–7–3138–6091
Fax: +61–7–3138–6030
e-mail: m.kagawa@qut.edu.au