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Original Article

Comparison of four quick and reliable methods of assessing body fat appropriate for clinical settings among young, middle-age, and older healthy male and female adults

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Abstract. [Purpose] Compare four quick (approximately 60 s), reliable methods of assessing %body-fat (%BF) among young (Y, 18–34 years), middle-age (M, 35–59 years), and older (O, 60–88 years) healthy-adults. [Participants and Methods] One-hundred-eighty healthy males-and-females were equally (n=30) divided into Y, M, and O age groups to assess %BF. The %BF methods were: 1) Bioelectrical-impedance-Inbody770 (IB)–criterion reference; 2) Body-mass-index (BMI); 3) Abdominal-and-hip circumferences (CIR); and 4) Skinfold (SF). [Results] %BF were significantly different among the four body-fat methods and among the three age-groups for both males-and-females. %BF among IB,BMI,CIR, and SF were, respectively, 15.7 ± 4.7%, 19.6 ± 3.2%, 17.3 ± 3.5%, and 12.1 ± 4.1% for Y-males; 18.3 ± 5.7%, 22.8 ± 3.6%, 19.6 ± 3.6%, and 15.6 ± 4.5% for M-males; 24.4 ± 6.5%, 25.8 ± 3.3%, 24.0 ± 4.5%, and 20.0 ± 4.1% for O-males; 24.9 ± 6.9%, 28.9 ± 4.1%, 29.4 ± 4.6%, and 22.4 ± 6.3% for Y-females; 25.1 ± 7.0%, 31.4 ± 4.7%, 33.0 ± 4.5%, and 25.0 ± 4.5% for M-females; 35.1 ± 6.3%, 35.5 ± 4.3%, 38.4 ± 4.8%, and 26.4 ± 3.7% for O-females. [Conclusion]The most accurate %BF-methods to use in clinical settings are CIR for Y-and-M-males, CIR and BMI for O-males, SF for Y-and M-females, and BMI for O-females. The least accurate %BF methods are BMI and SF for Y-males, BMI for M-males, SF for O-males, BMI and CIR for Y-and M-females, and SF for O-females. While all 4-methods of assessing %BF can easily and quickly be employed in clinical settings, some methods significantly underestimate or overestimate %BF and yield different results among varying age groups and sex. These findings help identify people at early health risk of cardiometabolic disease, with O-males and O-females at higher risk.

Key words: Percent body fat, Chronic diseases

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INTRODUCTION

Physical Therapy Associations worldwide has published various documents related to physical therapists' role related to health, wellness and fitness. For example, the American Physical Therapy Association (APTA) document titled "Physical Therapists' Role in Prevention, Wellness, Fitness, Health Promotion, and Management of Disease and Disability HOD P06-19-27-12", states that physical therapists "have the expertise and the opportunity to help individuals and populations improve overall health and avoid preventable health conditions". Moreover, the Japanese Physical Therapy Association

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document “Principals of Physical Therapy” states that physical therapists are “experts in the structure of the human body who cooperate with people of all ages in treating a wide variety of health conditions, including sports injuries, musculoskeletal diseases, and chronic poor health conditions, such as diabetes, obesity, osteoarthritis, and stroke”. One such preventable health condition is excess body fat (especially visceral or abdomen fat) which may result in an individual being overweight or obese, which is directly related to many chronic health diseases such as hypertension, metabolic syndrome, type II diabetes mellitus, stroke, cardiovascular disease, and dyslipidemia[1]. A common means by which to quantify being overweight or obese is the body mass index[2, 3]; the ratio of body mass (kg) and body height (m) squared, where overweight is defined as 25 $kg \cdot m^{-2}$ ≤body mass index <30 $kg \cdot m^{-2}$ and obesity is defined as body mass index ≥30 $kg \cdot m^{-2}$. Based on body mass index data, over 2/3 of American adults (compared to approximately 1/3 of Japanese adults) and 1/3 of American children (compared to approximately 5–10% of Japanese children) are considered overweight, and over 1/3 of American adults and children (compared to only 3–5% of Japanese adults and children) are considered obese[4]. Although body mass index is useful in a clinical setting, such as physical therapy, it does not differentiate between lean fat mass and fat free mass, given that only height and weight are measured.

A reasonably accurate estimate of percent body fat (%BF) can be determined by employing densitometry methods by measuring whole body density (Db), which is the ratio of body mass to body volume. Historically, the densitometry criterion standard of measuring body fat has been hydrodensitometry (underwater) weighing[5] which measures the mass and density of water displaced to help calculate body volume. Plethysmography[6], such as the ‘BodPod®’ can also be used to measure body volume by calculating air displacement instead of water displacement. Plethysmography, like hydrodensitometry, can obtain reasonably accurate estimates of %BF[6]. Once Db is determined, a common prediction equation used to estimate %BF is the two-compartment (which provides estimates of fat mass and fat free mas) ‘Siri’ equation[7]: $((4.95/Db) - 4.50) * 100$. Densitometry methods still remain very popular in many settings (e.g., academia and other research institutions).

More recently, dual-energy X-ray absorptiometry (DEXA)[8], a three-compartment (3-C) model (fat mass, fat free mass, and bone density), and other multicompartmental models[9], such as a four-compartment (4-C) model (eg, fat mass, total body water, protein, minerals), or a five-compartment (5-C) model have been recognized as criterion standard methods in assessing body fat. In general, the more body compartments measured the more accurate the body composition assessment will be. For example, Moon and colleagues[10] reported that %BF using a 3-C DEXA model overestimated %BF by 3.7% when compared to a criterion 5-C model. However, measuring more compartments requires greater time, expertise in testing, and space and money to house relatively expensive equipment, and is therefore not practical in most clinical settings. Nonetheless, DEXA is currently universally recognized as the preferred criterion method in quantifying body fat in academic and research settings[8].

Four major limitations to using DEXA, hydrodensitometry, plethysmography, and 4-C/5C models in clinical settings exist: 1) cost; 2) time intensive (typically 30–60 minutes per assessment); 3) space requirements (most units are large); and 4) specialized training (in some cases, certification is required to operate the equipment and conduct the assessments). In contrast, recent advances in bioelectrical impedance devices, such as the Inbody 770 (Inbody USA, Cerritos, CA, USA), has improved accuracy in calculating %BF, and has been shown to provide similar %BF relative to criterion standard methods such as DEXA and hydrodensitometry[11–17]. Recent studies reported similar %BF between DEXA and Inbody 770; notably, the Inbody 770 underestimated %BF by only 1.2% for men and 2.0% for women, as compared to an overestimation of 3.7%BF by the DEXA[12–17]. Such small differences suggest that employing the Inbody 770 to assess %BF may be reasonable in clinical settings.

The Inbody 770 offers additional advantages in the clinical setting, such as physical therapy: 1) minimal space requirements (it is similar in size to a weigh scale); 2) specialized training or certification is not required; 3) and it is time efficient, requiring approximately 60 seconds to take a body fat measurement. The primary disadvantage is its cost, starting at approximately \$20,000 USD (approximately 3,083,940 Japanese yen), although it is typically cheaper than DEXA (General Electric, Madison, WI, USA), which ranges between \$20,000−\$50,000 USD (approximately 3,083,940–7,709,850 Japanese yen). In addition to the Inbody 770, body mass index[18], abdominal and hip circumferences[19, 20], and skinfold measurements[21, 22] can be employed in the clinic to calculate %BF, and concurrent validity has been established for these three methods employing criterion standards DEXA or hydrodensitometry[18–22] with similar %BF (within 3–5%). Advantageously, these measurements are inexpensive, are quick (60 s or less) and reliable, require virtually no space, and do not require specialized training.

There are no known studies that have compared these four aforementioned %BF methods to each other across age, sex, or ethnicity. Therefore, the purpose of this study was to compare, relative to each other, four quick and reliable methods of assessing %BF in adult young, middle-age, and older healthy males and females with normal or overweight body compositions. In this initial study, Caucasian adults were employed, while other ethnicity groups (eg, Asians) and obese individuals will be studied in the future. The four groups used to calculate %BF were: 1) Bioelectrical impedance Inbody 770 (IB) −criterion reference; 2) Body mass index (BMI)[18]; 3) Abdominal and hip circumferences (CIR)[19, 20]; and 4) Skinfold (SF)[21, 22]. We hypothesized that %BF would be similar among IB, CIR, and BMI but significantly less in SF.

Because waist circumference (WC), waist-to-hip ratio (WHpR), and waist-to-height ratio (WHtR) have previously been shown to be independent predictors and proxies of central obesity and a screening risk assessment tool that identifies people at early health risk of cardiometabolic disease (eg, cardiovascular disease, type II diabetes)[23–31], a secondary purpose was to compare WC, WHpR and WHtR among the three different age groups for males and females. No additional data collection was needed because these variables were obtained when BMI and CIR were assessed. Because people tend to become more sedentary as they age, it was hypothesized that older males and females would have significantly greater WC, WHpR and WHtR compared to younger and middle-aged males and females.

PARTICIPANTS AND METHODS

One-hundred-eighty healthy Caucasian males and females between 22–88 years old were equally (n=30) divided into three groups of both males and females: 1) younger 18–34 years old (Y); 2) middle-age 35–59 years old (M); 3) older 60–88 years old (O). Inclusion criteria included heathy (no history of cardiovascular, metabolic, or neuromuscular disease) adult Caucasian males and females between 18–88 years old with a BMI between 18.5 kg/m^2 (lower limit of normal weight) and 29.9 kg/m^2 (upper limit of overweight). Underweight (BMI<18.5 kg/m^2), obese (BMI ≥30 kg/m^2), or non-Caucasian individuals were excluded in this initial study because non-homogeneity has been shown to affect the accuracy in calculating %BF[15, 31–35]. In addition, using bioelectrical impedance to assess %BF in obese individuals is limited and may be inaccurate secondary to differences in body water distribution compared to those of more normal weight. The accuracy of skinfold measurements also decreases in obese individuals[35]. All participants provided written informed consent in accordance with the Institutional Review Board at California State University, Sacramento (protocol number AG2374).

To help ensure consistent conditions, all participants were instructed to abstain from exercise, food intake, caloric beverages, caffeine, and tobacco for eight hours prior to testing (no alcohol or excess caffeine for 24 hours), but remain euhydrated. Subsequently, participants reported to the Human Performance Lab for body composition testing. A single tester assessed body weight and body height for all participants, and an assistant recorded all measurements from the tester. Body weight was assessed using a calibrated professional digital column weigh scale (Medical Device Depot, Inc., Fairview, PA, USA) with participants wearing only shorts and shirt, while height was assessed without shoes or socks using a custom wall mounted stadiometer. Db and %BF were assessed using appropriate software, traditional and modified Siri equations[21, 22, 32, 33], and regression equations for the following four methods: 1) IB; 2) BMI; 3) CIR; and 4) SF.

For the IB (Inbody USA, Cerritos, CA, USA) method, recommended procedures from the manufacturer were employed. Each participant stood upright on the footplate of the IB grasping the handles, with two electrodes in contact with each forefoot, two electrodes in contact with each hindfoot, two electrodes in contact with each palm, and two electrodes in contact with each thumb. Each participant was instructed to remain motionless and upright during the test, and a tester ensured this command was followed. The IB estimated body composition across 5 segments (right leg, left leg, right arm, left arm, and trunk), using six frequencies: 1, 5, 50, 250, 500, and 1,000 kHz. Body composition results were calculated using proprietary prediction algorithms built into the firmware of the IB. The total testing time once the participant stepped onto the IB was approximately 60 s. For the BMI[18] method, body mass (kg) and height (m) were first measured (performed in <60 s) and then BMI was calculated (kg/m^2) and entered into the following equation[18] to assess %BF: %BF = 63.7 − 864*(1/BMI) − 12.1*SEX + 0.12*AGE + 129* (ASIAN) * (1/BMI) – 0.091* (ASIAN) * (AGE) – 0.030* (AFRICAN AMERICAN) *AGE), where BMI was in kg/m^2, SEX=0 for females and 1 for males; Asian=1 for Asians and 0 for all other races; and African American=1 for African Americans and 0 for all other races. SEE=3.97%

For the CIR[19, 20, 33] method, a single experienced (32 years experience) tester measured abdominal and hip circumferences using a spring-load Gulick measuring tape to ensure consistent and accurate measurements, and an assistant recorded all measurements from the tester. The measurement sites for men and women have been reported previously[19, 20] and are as follows: 1) Abdomen 1 - laterally, midway between lowest portion of the rib cage and iliac crest and anteriorly, midway between the xiphoid process of the sternum and the umbilicus; 2) Abdomen 2 - laterally at the level of the iliac crest and anteriorly at the umbilicus; and 3) Hips (buttocks) - anteriorly, at the level of the symphysis pubis and posteriorly, at the maximal protrusion of the gluteal muscle. One additional site that was measured for men only was the 1) Iliac - measured anteriorly at the anterior superior iliac spine. Each abdominal, iliac, and hip site was measured a second time, and the values were averaged. The total time needed to twice take abdominal, iliac, and hip measurements was approximately 60–90 s. Modified Siri equations[21, 22, 32, 33] were used for women as follows: %BF = ((4.96/Db) – 4.51)*100 for younger and middle-aged women, and %BF = ((5.02/Db) – 4.57)*100 for older women. Abdominal, iliac, and hip measurements, as well as age, body mass and body height, were then entered into appropriate body density equations[21, 22], and with adjustments for ethnicity, age, and sex %BF was calculated as follows[32, 33]: Men:[19] %BF = −47.371817 + 0.57914807*(ABDOMINAL 1_{cm} + ABDOMINAL 2_{cm})/2 + 0.25189114*(HIP_{cm}) + 0.21366088*($ILIAC_{cm}$) - 0.35595404*($BODYMASS_{kg}$); SEE = 3.6%. Young and Middle-Age Women:[20, 32, 33] %BF = ((4.96/(1.168297 − 0.002824*(ABDOMINAL 1_{cm} + ABDOMINAL 2_{cm})/2 + 0.0000122098*((ABDOMINAL 1_{cm} + ABDOMINAL 2_{cm})/2)^2 − 0.000733128*(HIP_{cm}) + 0.000510477*($HEIGHT_{CM}$) - 0.000216161*AGE) - 4.51)*100); SEE = 4.2%. Older Women[20, 32, 33]: %BF = ((5.02/(1.168297 − 0.002824* (ABDOMINAL 1_{cm} + ABDOMINAL 2_{cm})/2 + 0.0000122098*((ABDOMINAL 1_{cm} + ABDOMINAL 2_{cm})/2)^2 − 0.000733128*(HIP_{cm}) + 0.000510477*($HEIGHT_{CM}$) − 0.000216161*AGE) − 4.57)*100); SEE = 4.2%.

For the SF[7, 8, 21, 22, 32, 33] method, Lange skinfold calipers (Beta Technology Inc., Cambridge, MA, USA) calibrated with an accuracy of ± 1 mm were employed by a single experienced (32 years experience) tester who measured all participants, and an assistant recorded all measurements from the tester. Standardized procedures for all SF measurements were employed and have been previously described[8, 33]. %BF was assessed by using both 7-site and 3-site equations and averaging calculated values. The seven sites used for both males and females were chest, midaxillary, triceps, subscapular, abdomen, suprailiac, and thigh, and each site measured a second time and then recorded values were averaged[8, 33]. Three of the 7 sites were also used in the 3-site equations and were chest, abdomen, and thigh for men, and triceps, suprailiac, and thigh for women[8, 33]. The total time needed to twice take 7 SF measurements was approximately 60–90 s. Modified Siri equations[21, 22, 32, 33] were employed as follows: %BF = ((4.95/Db) – 4.50)*100 for younger and middle-age men, %BF = ((4.97/Db) – 4.52)*100 for older men, %BF = ((4.96/Db) – 4.51)*100 for younger and middle-aged women, and %BF = ((5.02/Db) – 4.57)*100 for older women. The recorded SF measurements, as well as adjustments for ethnicity, age, and sex, were then entered below into the following equations to calculate %BF: Young and Middle-Age Men using 7 Site method[21, 32, 33]: %BF = (4.95/(1.112 − 0.00043499*(SUM OF 7 SITES) + (0.00000055*(SUM OF 7 SITES)^2 − 0.00028826*AGE) − 4.50)*100, SEE = approximately 3.5% body fat; Young and Middle-Age Men using 3 Site method[21, 32, 33]: %BF = (4.95/(1.10938 − 0.0008267*(SUM OF 3 SITES) + 0.0000016*(SUM OF 3 SITES)^2 − 0.0002574*AGE) − 4.50))*100, SEE = approximately 3.4% body fat; Older Men using 7 Site method[21, 32, 33]: %BF = (4.97/(1.112 − 0.00043499*(SUM OF 7 SITES) + (0.00000055*(SUM OF 7 SITES)^2 − 0.00028826*AGE) − 4.52)*100, SEE = approximately 3.5% body fat; Older Men using 3 Site method[21, 32, 33]: %BF = (4.97/(1.10938 − 0.0008267*(SUM OF 3 SITES) + 0.0000016*(SUM OF 3 SITES)^2 − 0.0002574*AGE) − 4.52)*100, SEE = approximately 3.4% body fat; Young and Middle-Age Women using 7 Site method[22, 32, 33]: %BF = (4.96/(1.097 − 0.00046971*(SUM OF 7 SITES) + 0.00000056*(SUM OF 7 SITES)^2 − 0.00012828*AGE) − 4.51)*100, SEE = approximately 3.8% body fat; Young and Middle-Age Women using 3 Site method[22, 32, 33]: %BF = (4.96/(1.0994921 − 0.0009929*(SUM OF 3 SITES) + 0.0000023*(SUM OF 3 SITES)^2 − 0.0001392*AGE) − 4.51)*100), SEE = approximately 3.9% body fat; Older Women using 7 Site method[22, 32, 33]: %BF = (5.02/(1.097 − 0.00046971*(SUM OF 7 SITES) + 0.00000056*(SUM OF 7 SITES)^2 − 0.00012828*AGE) − 4.57)*100, SEE = approximately 3.8% body fat; Older Women using 3 Site method[22, 32, 33]: %BF = (5.02/(1.0994921 − 0.0009929*(SUM OF 3 SITES) + 0.0000023*(SUM OF 3 SITES)^2 − 0.0001392*AGE) − 4.57)*100), SEE = approximately 3.9% body fat.

A repeated measures 2-way ANOVA ($p<0.01$) with post hoc tests was employed to assess differences among four body fat methods and three age groups, while a 1-way ANOVA was employed to assess differences in WC, WHpR and WHtR among the three age groups. The significance level was set at $p<0.01$.

RESULTS

Participant age, mass, height and BMI data for males and females are shown in Table 1. There were no significant differences among young, middle-age, and older age groups for mass, height, and BMI for both males and for females.

Participant WC, WHpR and WHtR data for males and females are shown in Table 2. For both males and females, WC, WHpR and WHtR were all significantly greater in O compared to Y and M, while there were no significant differences found between Y and M.

%BF among the four body fat methods and three age groups for males and females are shown in Table 3. Significant differences were found among the four body fat methods and among the three age groups for both males and females. There was also a significant interaction between age groups and body fat methods for both males and females.

Within Y and M males, BMI was significantly greater than IB, CIR, and SF, IB and CIR were significantly greater than S, and there was no significant difference between IB and CIR. Within O males, IB, BMI, and CIR were significantly greater than I, and there were no significant differences found among IB, BMI, and CIR.

Within Y and M females, BMI and CIR were significantly greater than IB and SF, and there was no significant difference between BMI and CIR. Within Y Females, IB was significantly greater than S. Within M Females, there was no significant difference between IB and S. Within O females, CIR was significantly greater than IB and S, BMI was significantly greater than S, and there were no significant differences between IB and BMI.

Within IB and CIR, O was significantly greater than Y and M for males and females. Within BMI, O and M was significantly greater than Y for males, and O was significantly greater than Y and M for females. Within SF, O was significantly

Table 1. Participants mean ± standard deviation age, mass, height and body mass index (BMI) data for sex and age group

Sex	Age group	Age (years)*	Mass (kg)**	Height (cm)**	BMI (kg·m^{-2})**
Male	Younger	25.9 ± 3.4	79.1 ± 10.1	178.5 ± 7.7	24.8 ± 2.3
Male	Middle-age	46.4 ± 6.9	79.5 ± 9.1	176.8 ± 6.0	25.4 ± 2.6
Male	Older	69.8 ± 7.7	77.9 ± 11.0	174.3 ± 8.4	25.5 ± 2.3
Female	Younger	26.7 ± 3.7	63.6 ± 8.6	166.3 ± 8.1	23.0 ± 2.5
Female	Middle-age	46.0 ± 7.2	65.4 ± 8.7	167.6 ± 6.9	23.2 ± 2.1
Female	Older	70.7 ± 6.4	61.1 ± 7.7	160.9 ± 5.6	23.8 ± 2.6

*Significant differences ($p<0.01$) in age between younger and middle-age, younger and older, and middle-age and older age groups for males and for females.
**No significant differences ($p<0.01$) among younger, middle-age, and older age groups for mass, height, and BMI for males and for females.

Table 2. Participants mean ± standard deviation waist, waist-to-hip ratio, and waist-to-height ratio data for males and females

Sex	Age group*	Waist (cm)	Waist-to-hip ratio	Waist-to-height ratio
Male	Younger	83.6 ± 6.6[O]	0.83 ± 0.05[O]	0.47 ± 0.04[O]
Male	Middle-age	86.4 ± 6.9[O]	0.86 ± 0.05[O]	0.49 ± 0.04[O]
Male	Older	92.3 ± 8.4[Y, M]	0.92 ± 0.07[Y, M]	0.53 ± 0.05[Y, M]
Female	Younger	72.4 ± 5.8[O]	0.75 ± 0.03[O]	0.44 ± 0.04[O]
Female	Middle-age	75.3 ± 6.2[O]	0.76 ± 0.04[O]	0.45 ± 0.04[O]
Female	Older	79.4 ± 7.0[Y, M]	0.82 ± 0.07[Y, M]	0.50 ± 0.05[Y, M]

*Significant difference ($p<0.01$) among the three age groups.
[O]Significantly different ($p<0.01$) than older age group.
[M]Significantly different ($p<0.01$) than middle-age group.
[Y]Significantly different ($p<0.01$) than younger age group.

Table 3. Participants mean ± standard deviation percent body fat (%BF) among four body fat methods and three age groups[INT] for males and females

Sex	Age groups**	Body fat methods*			
		Inbody 770 (IB) (%BF)	Body mass index (BMI) (%BF)	Circumference (CIR) (%BF)	Skinfold (SF) (%BF)
Male	Younger	15.7 ± 4.7[B, S, O]	19.6 ± 3.2[I, C, S, O, M]	17.3 ± 3.5[B, S, O]	12.1 ± 4.1[I, B, C, M, O]
Male	Middle-age	18.3 ± 5.7[B, S, O]	22.8 ± 3.6[I, C, S, Y]	19.6 ± 3.6[B, S, O]	15.6 ± 4.5[I, B, C, Y, O]
Male	Older	24.4 ± 6.5[S, Y, M]	25.8 ± 3.3[S, Y]	24.0 ± 4.5[S, Y, M]	20.1 ± 4.1[I, B, C, Y, M]
Female	Younger	24.9 ± 6.9[B, C, S, O]	28.9 ± 4.1[I, S, O]	29.4 ± 4.6[I, S, O]	22.4 ± 6.3[I, B, C, O]
Female	Middle-age	25.1 ± 7.0[B, C, O]	31.4 ± 4.7[I, S, O]	33.0 ± 4.5[I, S, O]	25.0 ± 4.5[B, C]
Female	Older	35.1 ± 6.3[C, S, M, Y]	35.5 ± 4.3[S, Y, M]	38.4 ± 4.8[I, S, Y, M]	26.4 ± 3.7[I, B, C, Y]

*Significant difference ($p<0.01$) among the four body fat methods.
** Significant difference ($p<0.01$) among the three age groups.
[INT]Significant interaction ($p<0.01$) between age groups and body fat methods.
[O]Significantly different ($p<0.01$) than older age group.
[M]Significantly different ($p<0.01$) than middle-age group.
[Y]Significantly different ($p<0.01$) than younger age group.
[I]Significantly different ($p<0.01$) than IB.
[B]Significantly different ($p<0.01$) than BMI.
[C]Significantly different ($p<0.01$) than CIR.
[S]Significantly different ($p<0.01$) than SF.

greater than Y and M for males, M was significantly greater than Y for males, and O was significantly greater than Y for females.

DISCUSSION

This is the first known study to compare several %BF methods over multiple age, sex, and ethnicity groups for males and females that may be appropriate in clinical settings, are valid and reliable (validated by multiple studies using a gold standard method), and that require minimal time (approximately 60 s), training, cost (except for the IB), and space. This initial study was limited to male and female Caucasian adults with either normal weight or overweight. Therefore, additional studies should be conducted in Asian and other ethnicities, as well as in obese individuals, although as previously mentioned, the reliability and validity of using IB, BMI, CIR, and SF in obese individuals may be diminished and problematic, especially using IB and SF.

In contrast to the cost of estimating %BF with BMI, CIR, and SF, both DEXA and IB are relatively expensive, approximately $20,000 USD (approximately 3,083,940 Japanese yen) for the IB and $20,000−$50,000 USD (approximately 3,083,940–7,709,850 Japanese yen) for DEXA. Although DEXA is considered the gold standard for estimating body composition, it has been reported to overestimate %BF by 3–4% when compared to a criterion 5-C model[10]. Several studies have demonstrated that the IB produces results very similar to the DEXA with reported %BF values that were underestimated by only 1.2% for men and 2.0% for women[12–17] Therefore, the IB may possibly be a closer representation of an individual's actual %BF than DEXA. Moreover, compared to DEXA, the IB requires less space, requires less time to assess %BF (only about 60 s for the IB compared to 30–60 min for the DEXA), and does not require specialized training. Consequently, the IB may be well suited for clinical settings if cost is not an issue.

One of the most interesting findings in the current study was understanding how BMI, CIR, and SF underestimate or overestimate %BF, and by how much, compared to the criterion reference IB, and how these measurements vary among different age groups and sex. Compared to the reference criterion IB, %BF was overestimated 0.4% to 6.3% by BMI, generally overestimated 1.3% to 7.9% by CIR, and underestimated 0.1% to 8.7% by SF. The most and least accurate % BF methods as a function of age and sex are summarized in Table 4. A comparison of %BF assessment in the current study to %BF assessment by similar studies, are summarized in Table 5.

Both Gallagher and colleagues[18] and Tran and Weltman[20] used a similar Caucasian population, age groups, and body mass indices as the current study. Notably, Tran and Weltman[19] did not divide males into Y, M, and O groups, but used instead a single group of males between 22–78 years old (Y + M + O) in calculating %BF utilizing CIR. Their findings revealed an average body mass index for males of 27.4 kg/m^2 as compared to a 24.8–25.5 kg/m^2 body mass index for males in the current study. Jackson and colleagues[21, 22] also did not divide males and females into Y, M, and O groups in calculating %BF, but rather used a single group of males between 18–61 years old (Y + M) and a single group of females between 18–55 years old (Y + M). Average %BF across this age range was estimated at 17.7%. Consequently, their findings are unable to discriminate %BF assessment accuracy by age group.

It is known that individuals whose %BF lie beyond healthy ranges are at risk of cardiometabolic disease. Healthy %BF ranges have been reported to be 10–22% in males and 20–32% in females at various ages[36]. Younger individuals are at the lower half of these %BF ranges and older individuals are at the upper half of these %BF ranges. Therefore, accurate assessment of %BF by age group is paramount in identifying at-risk individuals. Risk of cardiometabolic disease can also be further assessed using body mass index, WC, WHpR and WHtR. Using data already collected when estimating %BF via BMI and CIR allows for the calculations of all these measurements without the need for additional data. WC, WHpR and WHtR are proxies of central obesity and in addition to %BF they can easily and quickly be used as a screening risk assessment that can identify people at early health risk of cardiometabolic disease[23–31].

As hypothesized, O males and females had significantly greater WC, WHpR and WHtR compared to Y and M males and females, which implies that O males and females may be at higher risk of cardiometabolic disease than Y and M males and females, especially if they are obese. Obesity can be assessed using body mass index values, and risk of cardiometabolic disease progressively increases as body mass index increases as follows[37]: 1) ≥25 kg/m^2 and <30 kg/m2=over weight (increased risk); 2) ≥30 kg/m^2 and <35 kg/m^2=Class I obesity (high risk); 3) ≥35 kg/m^2 and <40 kg/m^2=Class II obesity (very

Table 4. Most and least accurate percent body fat (% BF) methods, as a function of age and sex, compared to the reference criterion IB

% BF method	Age group and sex most accurate for	Age group and sex least accurate for
CIR	Y, M, and O males	Y and M females
SF	Y and M females	O males and females; Y males
BMI	O males and females	Y and M males and females

IB: Inbody 770; CIR: circumference; SF: skinfold; BMI: body mass index; Y: younger; M: middle-age; O: older.

Table 5. Percent body fat (%BF) in the current study compared to %BF from comparable studies in the literature

%BF method	Age group and sex	%BF					
		Current study	Gallagher et al.[18]	Tran and Weltman[20]	Tran and Weltman[19]	Jackson and Pollock[21]	Jackson et al.[22]
BMI	Y Female	28.9%	33%	-	-	-	-
BMI	M Female	31.4%	35%	-	-	-	-
BMI	O Female	35.5%	38%	-	-	-	-
BMI	Y Male	19.6%	21%	-	-	-	-
BMI	M Male	22.8%	23%	-	-	-	-
BMI	O Male	25.8%	25%	-	-	-	-
CIR	Y Female	29.4%	-	32%	-	-	-
CIR	M Female	33.0%	-	37%	-	-	-
CIR	O Female	38.4%	-	41%	-	-	-
CIR	Y + M + O Male	20.3%			26.0%		
SF	Y + M Male	13.9%	-	-	-	17.7%	
SF	Y + M Female	23.7%	-	-	-		24.1%

BMI: body mass index; CIR: circumference; SF: skinfold; Y: younger; M: middle-age; O: older.

high risk); and 4) ≥40 kg/m^2=Class III obesity (extremely high risk). Because the participants in the current study had body mass indices that were between normal weight to overweight, they were either not at risk or at increased risk, respectively, for cardiometabolic disease.

Because WC is an independent predictor of cardiometabolic disease, a recent consensus statement recommended that it be considered a vital sign in clinical practice and routinely performed to assess risk of cardiometabolic disease[28)]. Risk of cardiometabolic disease for WC is as follows for females[27, 28, 37)]: 1) ≥90 cm WC <105 cm =increased risk; 2) ≥105 cm WC <115 cm =high risk; and 3) WC ≥115=very high risk. Risk of cardiometabolic disease for WC is as follows for males[27, 28, 37)]: 1) ≥100 cm WC <110 cm =increased risk; 2) ≥110 cm WC <125 cm =high risk; and 3) WC ≥125=very high risk. The participants in the current study did not have a WC that increased their risk of cardiometabolic disease.

Risk of cardiometabolic disease increases with WHpR >0.95 for young men, >1.03 for men 60–69 years old, >0.86 for young women, and >0.90 for women 60–69 years old[38)]. The participants in the current study did not have a WHpR that increased their risk of cardiometabolic disease.

A systematic review and meta-analysis demonstrated that WHtR may be a better screening tool than waist circumference and BMI in assessing cardiometabolic risk, and reported that a WHtR ≥0.5 increases risk of cardiometabolic disease[29, 30)]. Therefore, keeping waist circumference to less than half body height decreases risk of cardiometabolic disease. Notably, only the O males and females in the current study had a WHtR ≥0.5 and thus were at increased risk of cardiometabolic disease. These findings align with previous studies that suggest older populations have a tendency toward being overweight or obese.

In conclusion, the results from this study provide a tool that can easily and quickly assess risk of cardiometabolic disease by estimating %BF, body mass index, WC, WHpR and WHtR. Compared to the reference criterion IB, %BF was:

1) overestimated by BMI in Y and M males and Y females by ~4% to 4.5%, O males by 1.4%, M females by 6.3%, and O females by 0.4%

2) overestimated by CIR in Y and M males by ~1.5%, Y females by 4.5%, M females by 7.9%, and O females by 3.3%, and underestimated by CIR in O males by 0.4%

3) underestimated by SF in Y and M males by ~3% to 3.5%, in O males by 4.3%, Y females by 2.5%, M females by 0.1%, and O females by 8.7%

When using BMI, CIR, or SF in clinical settings, the most accurate methods to use are CIR for Y and M males, CIR and BMI for O males, SF for Y and M females, and BMI for O females. Similarly, the least accurate methods to use are BMI and SF for Y males, BMI for M males, SF for O males, BMI and CIR for Y and M females, and SF for O females. WC, WHpR and WHtR were greater in O compared to Y and M, and can easily be used in clinical settings to help identify people at early health risk of cardiometabolic disease.

Conflicts of interest

The authors have no conflicts of interest to declare.

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