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ORIGINAL RESEARCH

Development of gender- and age group-specific equations for estimating body weight from anthropometric measurement in Thai adults

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Video abstract

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Background: Many medical procedures routinely use body weight as a parameter for calculation. However, these measurements are not always available. In addition, the commonly used visual estimation has had high error rates. Therefore, the aim of this study was to develop a predictive equation for body weight using body circumferences.

Methods: A prospective study was performed in healthy volunteers. Body weight, height, and eight circumferential level parameters including neck, arm, chest, waist, umbilical level, hip, thigh, and calf were recorded. Linear regression equations were developed in a modeling sample group divided by sex and age (younger <60 years and older ≥ 60 years). Original regression equations were modified to simple equations by coefficients and intercepts adjustment. These equations were tested in an independent validation sample.

Results: A total of 2000 volunteers were included in this study. These were randomly separated into two groups (1000 in each modeling and validation group). Equations using height and one covariate circumference were developed. After the covariate selection processes, covariate circumference of chest, waist, umbilical level, and hip were selected for single covariate equations (Sco). To reduce the body somatotype difference, the combination covariate circumferences were created by summation between the chest and one torso circumference of waist, umbilical level, or hip and used in the equation development as a combination covariate equation (Cco). Of these equations, Cco had significantly higher 10% threshold error tolerance compared with Sco (mean percentage error tolerance of Cco versus Sco [95% confidence interval; 95% CI]: 76.9 [74.2–79.6] versus 70.3 [68.4–72.3]; $P < 0.01$, respectively). Although simple covariate equations had more evidence errors than the original covariate equations, there was comparable error tolerance between the types of equations (original versus simple: 74.5 [71.9–77.1] versus 71.7 [69.2–74.3]; $P = 0.12$, respectively). The chest containing covariate (C) equation had the most appropriate performance for Sco equations (chest versus nonchest: 73.4 [69.7–77.1] versus 69.3 [67.0–71.6]; $P = 0.03$, respectively). For Cco equations, although there were no differences between covariates using summation of chest and hip (C+Hp) and other Cco but C+Hp had a slightly higher performance validity (C+Hp versus other Cco [95% CI]: 77.8 [73.2–82.3] versus 76.5 [72.7–80.2]; $P = 0.65$, respectively).

Conclusion: Body weight can be predicted by height and circumferential covariate equations. Cco had more Sco error tolerance. Original and simple equations had comparable validity. Chest- and C+Hp-containing covariate equations had more precision within the Sco and Cco equation types, respectively.

Keywords: body weight, anthropometry, circumference, Thai, linear models

Introduction

One of the common important clinical measurement parameters is body weight. Many clinical situations utilize body weight as a variable for the determination of nutrition

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requirements, drug dose administration, resuscitation process, pulmonary tidal volume estimation and hemodynamic assessments.[1–4] However, there are many limitations to obtaining body weight in some clinical practice situations especially in nonambulatory elderly people, and emergency and critically ill patients. A special instrument is required for direct measurement in these patients. Nevertheless, it might be unavailable due to limited resources in developing countries. Although visual estimation is the most common method of estimating weight, the current literature has reported great inaccuracies with this method compared with the actual body weight. In addition, the precision of this method is operator-dependent.[5–8] These errors might lead to adverse and ineffective treatment outcomes.[8,9] To diminish predictive error, one study that was performed in an emergency department (ED) setting demonstrated that anthropometric measurement had greater accuracy of around 20% within a 10% error threshold than visual estimation by ED providers.[10] Although these more scientific anthropometric measurements to estimate body weight have been proposed, ethnic differences and measurement parameter distinctions might impact predicted validity.[11–14] In addition, some parameters used in equations are hard to assess in general practice especially those requiring skinfold thickness.[10,15,16] To our best knowledge, there is no recommended formula to predict body weight with circumferential anthropometric parameters in the Thai or Asian populations. Therefore, the aims of this study were to obtain appropriate and precise methods to estimate actual body weight using circumferential parameters from different parts of the body as well as to propose a simple estimation equation with acceptable validity which could be applied conveniently for general medical practice.

Methods

The authors performed a prospective cross-sectional study which enrolled healthy Thai adult volunteers by an invitation announcement to the Faculty of Medicine, Chiang Mai University via public information posters and the hospital Web site. Four research assistants were trained in the measurement method for each circumferential anthropometric parameter and reliability testing was performed before data collection with kappa agreement with more than 95% with up to 5% error. The authors excluded volunteers whose age was less than 18 years, amputated limb(s), inability of ambulation, inability to lie down, and chronic disease which might interfere with measured parameters such as liver cirrhosis, renal failure, chronic steroid use, and edematous limb(s). This study was approved by the Faculty of Medicine, Chiang Mai University Ethics Committee.

The authors measured and collected body weight and body circumferences as well as demographic data, sex, age, occupation, and habitats. Body circumferences were measured in supine position with a cloth tape measure up to 1 mm width at eight levels including neck, chest, waist, umbilical level, and hip, arm, thigh, and leg circumferences. The measurement method and reference points are described in Table 1. Actual body weight was measured by the same digital weighing apparatus (Zepper TCA-200A-RT; Bangkok, Thailand) and recorded in kilograms with one decimal point. Height was measured by a standard measurement board and all subjects were positioned for height measurement with head, shoulder blades, buttocks, and heels touching the board. This measurement was recorded in centimeters.

The study sample was separated randomly and independently into two groups, a regression modeling group, in whom regression equations were developed to estimate body weight, and a validation group, in whom the equations were tested. The estimated sample size in each group was 250 volunteers based on differences of physiological status and body composition between younger and elderly people as well as each gender distinction.[17] The authors further divided the people by age group and sex. Age was classified into two

Table 1 Methods of anthropometric circumferential parameter measurements

Covariates	Point of measurement method
Neck	Level at cricoid cartilage in anterior and midpoint between external occipital protuberance and tip of spinous process of 7th cervical spine (vertebral prominens at root of neck) in posterior
Arm	Level at midpoint between tip of acromioclavicular eminent to tip of olecranon of elbow of nondominant arm
Chest	At full expiration, measurement at upper chest on the level of junction between the deltopectoral groove and tip of anterior axillary fold
Waist	Narrowest part of abdominal circumference above umbilicus or measurement above umbilicus 1–1.5 inches in cases that could not identify the narrowest part
Umbilical level	Level of umbilicus at anterior and about 1.5–2.0 inches above the superior posterior iliac spine at posterior
Hip	Widest part of hip, level of pubic symphysis at anterior and ischial tuberosity at posterior
Thigh	Level at midpoint between inguinal point and upper border of patella
Calf	Level at midpoint between heel and upper most point of femur condyles (approximately 4 cm proximal to the patella)

groups with a cut-off at 60 years by the official retirement age in the authors' country as well as a previous study background in which there were different body compositions in elderly people.[17] The total estimated population included in this study was 2000 healthy volunteers.

Statistical analysis, parameters selection, modeling, and validation

All of the continuous variable data between age groups and sex were tested for normal distribution with a visual inspection of the histogram and the Shapiro–Wilk W test and reported as mean ± SD. Group differences were calculated using Student's *t*-test for normally distributed continuous variables and Mann–Whitney *U* test for nonparametric continuous variables. The univariable and multivariable linear regression model was used to identify the relationship between independent variable(s) and body weight. A statistical difference was defined as *P* value less than 0.05.

Covariate parameters were decided for the modeling selection by considering correlation values between circumferential variables and body weight. For the equation creation, the authors conformed to the basic theoretical background of alteration of weight depending on the height and volume of an object. Therefore, height was included in the equation covariate in all of the calculated formulas.[11] The authors developed an estimation equation for body weight divided by age group and sex. The formula used was as follows:

$$\text{Body weight (kg)} = b_1\,(\text{Covariate}) + b_2\,(\text{Height}) + a$$

where (b_1) and (b_2) were the regression coefficients and (a) represented the intercept.

Equations using these single circumferential variables for prediction were determined as single covariate equation or formula (Sco). The authors had concerns that individual disproportion of the body figure in chest and torso might affect the model validation and might result in prediction error. Therefore, the combination of circumference of chest together with hip, waist or umbilical level circumference were performed (Chest + Hip [C+Hp]; Chest + Umbilical level [C+U] and Chest + Waist, [C+W]) and behaved as an independent covariate in the present study equations. These summation-containing variables were determined as combination covariates equation or formula (Cco). The model structure of linearity or violation of linearity between covariates and body weight were verified by residuals versus fitting and predictor plots. To provide the simplest formula, numbers of entered covariates were limited as much as possible in each regression model. Forward and backward stepwise regressions were performed. Multicollinearity covariates in the regression model were separated into independent models. Individual models were selected for further validation based on comparison of adjusted R-square value, Akaike's information criteria (AIC) and Bayesian's information criteria (BIC) in each model prediction. The original regression formulas were modified to simple formulas with adjusted covariate coefficients and constant value to ordinary and memorized number. First, covariate coefficient values were estimated and titrated to the nearest value which could accompany the same value between gender and age group in each covariate equation. Second, mean covariate values were substituted and an intercept value was estimated to the nearest number in each equation. In the case of difference error after modified formula, the coefficient would be adjusted and titrated to minimized error. The final adjusted coefficients and intercept was defined as the modified simple formula.

For external validation, predicted body weight was calculated and the difference was compared to the actual body weight in the other equal-sized volunteer in each validation subgroup. The deviated value was reported in error quantity and relative error to actual body weight in percent. Original regression formulas (original formula) and modified simple formulas (simple formula) were compared together with correlation coefficient, error quantity, and relative error. Absolute errors (predicted weight – actual weight) were compared between equations and stratified by gender and equation types (original or simple formulas) using the paired *t*-test. The performances of equations between type equations were tested by level of relative error which was divided into two groups with error more than 10% or 20% of actual body weight. These cut-points were based on previous studies.[10,11] The agreements of two methods were tested by kappa statistics based on the relative error level. In addition, percentage of error tolerance (100 – percentage of error) in the 10% and 20% thresholds were reported in each covariate equations.

Results

From May 2010 through May 2011, 2000 volunteers were included in this study and divided into four subgroups as mentioned previously. In Table 2, there were no differences between the modeling and validation group of all collected variables. However, almost all volunteers (96.0% to 99.6%) were registered residents in the northern region of Thailand.

Table 2 Characteristics of subjects in model formulation and validation group classified by sex and age groups

Parameters	Age < 60 years		*P*	Age ≥ 60 years		*P*
	Modeling	Validation		Modeling	Validation	
Sex (%)						
Female	250 (50)	250 (50)	1.00	250 (50)	250 (50)	1.00
Male	250 (50)	250 (50)		250 (50)	250 (50)	
Profession (%)						
Female						
Farmer	36 (14.40)	47 (18.80)	0.50	32 (12.80)	31 (12.40)	0.59
Officer	37 (14.80)	39 (15.60)		36 (14.40)	44 (17.60)	
Private	33 (13.20)	39 (15.60)		15 (6.00)	20 (8.00)	
Worker	79 (31.60)	69 (27.60)		18 (7.20)	22 (8.80)	
Others	65 (26.00)	56 (22.40)		149 (59.60)	133 (53.20)	
Male						
Farmer	41 (16.53)	43 (17.34)	0.83	50 (20.00)	37 (14.80)	0.37
Officer	43 (17.34)	47 (18.95)		40 (16.00)	39 (15.60)	
Private	35 (14.11)	28 (11.29)		17 (6.80)	17 (6.80)	
Worker	82 (33.06)	88 (35.48)		28 (11.20)	22 (8.80)	
Others	47 (18.95)	42 (16.94)		115 (46.00)	135 (54.00)	
Habitats (%)						
Female						
Northern	240 (96.0)	242 (96.8)	0.63	247 (98.80)	246 (98.40)	0.70
Others	10 (4.0)	8 (3.2)		3 (1.20)	4 (1.60)	
Male						
Northern	244 (98.39)	248 (99.60)	0.18	248 (99.20)	248 (99.20)	1.00
Other	4 (1.61)	1 (0.40)		2 (0.80)	2 (0.80)	
Age (years)						
Female	46.34 ± 10.21	45.80 ± 9.87	0.61	67.22 ± 6.24	67.43 ± 6.71	0.72
Male	43.63 ± 11.28	43.85 ± 11.10	0.83	69.22 ± 7.41	69.75 ± 7.60	0.43
Body weight (kg)						
Female	57.89 ± 10.41	57.06 ± 10.50	0.38	54.27 ± 10.27	54.51 ± 10.73	0.80
Male	67.55 ± 10.85	67.66 ± 11.52	0.91	60.62 ± 10.84	59.84 ± 11.75	0.44
Height (cm)						
Female	155.62 ± 5.46	154.94 ± 5.61	0.17	152.13 ± 6.60	151.48 ± 6.43	0.26
Male	166.42 ± 6.29	166.09 ± 6.36	0.55	162.65 ± 7.11	161.72 ± 7.02	0.14
BMI (kg/m^2)						
Female	23.74 ± 4.00	23.89 ± 3.95	0.67	23.39 ± 3.90	23.69 ± 4.10	0.41
Male	24.37 ± 3.55	24.50 ± 3.82	0.68	22.84 ± 3.36	22.78 ± 3.65	0.85
Neck (cm)						
Female	33.80 ± 2.82	33.54 ± 2.89	0.31	33.82 ± 2.96	33.95 ± 2.89	0.60
Male	38.50 ± 2.94	38.77 ± 3.09	0.32	37.53 ± 3.03	37.52 ± 3.36	0.99
Chest (cm)						
Female	86.74 ± 8.25	86.20 ± 8.05	0.46	87.47 ± 8.33	87.82 ± 8.67	0.64
Male	92.61 ± 7.20	92.72 ± 7.62	0.87	90.34 ± 7.20	89.82 ± 7.94	0.45
Hip (cm)						
Female	94.32 ± 8.26	93.56 ± 8.41	0.31	94.92 ± 9.22	95.36 ± 9.41	0.60
Male	95.44 ± 7.51	95.26 ± 7.95	0.79	94.76 ± 8.06	94.05 ± 8.68	0.35
Umbilical (cm)						
Female	81.37 ± 10.16	80.47 ± 10.09	0.32	84.30 ± 10.98	84.89 ± 10.97	0.55
Male	84.69 ± 9.64	84.76 ± 9.69	0.93	86.33 ± 9.23	85.44 ± 9.73	0.29
Arm (cm)						
Female	28.13 ± 3.47	27.81 ± 3.34	0.29	27.40 ± 3.55	27.57 ± 3.18	0.56
Male	29.84 ± 3.11	29.86 ± 3.21	0.93	28.28 ± 2.97	27.90 ± 3.20	0.18
Waist (cm)						
Female	77.54 ± 9.65	76.64 ± 9.89	0.31	80.64 ± 9.93	81.26 ± 10.16	0.49
Male	82.25 ± 9.30	82.56 ± 9.57	0.71	83.49 ± 8.74	82.76 ± 9.31	0.37
Thigh (cm)						
Female	46.99 ± 5.64	46.64 ± 5.50	0.48	42.94 ± 5.92	43.53 ± 5.96	0.27
Male	47.85 ± 5.47	47.64 ± 5.94	0.69	42.85 ± 5.01	42.65 ± 5.56	0.67
Calf (cm)						
Female	33.46 ± 3.51	33.40 ± 3.55	0.86	32.51 ± 4.37	32.32 ± 4.15	0.61
Male	35.16 ± 4.54	35.07 ± 4.71	0.82	33.37 ± 4.54	33.14 ± 4.60	0.58

Abbreviation: BMI, body mass index.

At the variables selection process after forward and backward stepwise linear regression, the authors found that the torso circumferences of waist, hip, and umbilical level had multicollinearity properties with each other in the model-creating covariates and these were the major reason to enter these variables separately in each model.

In Table 3, although there were significant correlations of all circumference parameters, only chest, hip, umbilical level, waist, arm, and thigh circumference had a correlation coefficient of more than 70% in at least three quarters of all subgroups in each covariate equation. However, the authors selected only chest, hip, umbilical level, and waist circumference for further validation and performance assessments after consideration of R-square, AIC, and BIC values (Table 3). Cco equations of C+Hp, C+U, and C+W showed increased correlation coefficients and R-square value as well as decreases in the AIC and BIC values when they were compared to the same level of the Sco (Table 3). Therefore, the authors finally decided to select equations comprised of chest, hip, umbilicus, and waist, C+Hp, C+U, and C+W to validate the processes (Table 4).

The coefficients of the equation were confined to a simple number and the intercept of the equation was also adjusted using the average of the covariates values. These modified simple formulas were demonstrated in Table 4. Although correlation coefficients were lower in some simple formulas, most of them were comparable and all had a statistically significant relation with a *P* value of less than 0.01 (Table 5). While the simple equations of weight prediction could be switched between sex in elderly volunteers except waist-containing covariate equations (Waist and C+W equations) in younger volunteers, only

Table 3 Correlation coefficient (*r*), adjusted R-square (R^2), Akaike's information criteria (AIC), and Bayesian's information (BIC) of single and combination covariates classified by sex and age groups

Covariate	<60 years				≥60 years			
	r	R^2	AIC	BIC	*r*	R^2	AIC	BIC
Neck								
Female	0.70	0.54	1689.00	1699.56	0.69	0.58	1660.84	1671.41
Male	0.65	0.55	1704.94	1715.50	0.72	0.64	1649.64	1660.20
Chest								
Female	0.84	0.75	1535.90	1546.46	0.81	0.73	1553.37	1563.94
Male	0.80	0.69	1615.30	1625.86	0.81	0.70	1605.35	1615.92
Hip								
Female	0.84	0.72	1560.60	1571.17	0.76	0.67	1602.66	1613.22
Male	0.82	0.71	1592.28	1602.84	0.74	0.62	1661.14	1671.70
Umbilical								
Female	0.84	0.78	1509.53	1520.09	0.66	0.62	1636.88	1647.44
Male	0.81	0.73	1578.45	1589.02	0.78	0.72	1587.35	1597.91
Arm								
Female	0.77	0.69	1594.11	1604.68	0.78	0.68	1589.01	1599.58
Male	0.70	0.58	1687.81	1698.38	0.71	0.62	1660.59	1671.15
Waist								
Female	0.87	0.82	1457.49	1468.05	0.68	0.62	1635.62	1646.19
Male	0.82	0.75	1560.49	1571.05	0.79	0.73	1573.42	1583.98
Thigh								
Female	0.74	0.59	1661.03	1671.60	0.74	0.62	1637.98	1648.54
Male	0.61	0.48	1741.29	1751.86	0.80	0.69	1613.92	1624.49
Calf								
Female	0.61	0.44	1739.78	1750.3	0.68	0.54	1680.49	1691.05
Male	0.53	0.40	1776.26	1786.82	0.64	0.55	1704.52	1715.08
C+Hp								
Female	0.90	0.83	1438.54	1449.11	0.83	0.76	1521.05	1531.62
Male	0.88	0.79	1509.10	1519.67	0.84	0.74	1569.06	1579.62
C+U								
Female	0.88	0.82	1451.23	1461.79	0.78	0.72	1555.27	1565.83
Male	0.86	0.79	1512.09	1522.66	0.85	0.77	1531.95	1542.51
C+W								
Female	0.89	0.83	1434.26	1444.83	0.79	0.72	1554.79	1565.35
Male	0.86	0.79	1511.31	1521.88	0.85	0.78	1522.96	1533.53

Abbreviations: C+Hp, chest + hip circumference; C+U, chest + umbilical level circumference; C+W, chest + waist circumference.

Table 4 Sex- and age group-specific original regression and modified simple formula derived from modeling formulation group

Age	<60 years		≥60 years	
Type	**Original equation**	**Simple equation**	**Original equation**	**Simple equation**
Chest				
Female	1.01 (C) + 0.39 (H) – 90.33	1 (C) + (H/3) – 80	0.90 (C) + 0.43 (H) – 90.72	1 (C) + (H/3) – 85
Male	1.12 (C) + 0.39 (H) – 100.4	1 (C) + (H/3) – 80	1.05 (C) + 0.35 (H) – 91.95	1 (C) + (H/3) – 85
Hip				
Female	1.00 (Hp) +0.32 (H) – 87.37	1 (Hp) + (H/3) – 90	0.76 (Hp) + 0.50 (H) – 93.08	0.8 (Hp) + (H/2) – 95
Male	1.10 (Hp) +0.36 (H) – 97.38	1 (Hp) + (H/3) – 85	0.81 (Hp) + 0.49 (H) – 94.72	0.8 (Hp) + (H/2) – 95
Umbilical				
Female	0.83 (U) + 0.49 (H) – 86.46	0.8 (U) + (H/2) – 85	0.58 (U) + 0.67 (H) – 97.00	0.8 (U) + (H/2) – 90
Male	0.85 (U) + 0.49 (H) – 85.42	0.8 (U) + (H/2) – 80	0.77 (U) + 0.55 (H) – 96.20	0.8 (U) + (H/2) – 90
Waist				
Female	0.90 (W) + 0.48 (H) – 86.44	1 (W) + (H/2) – 95	0.65 (W) + 0.62 (H) – 92.69	1 (W) + (H/2) – 100
Male	0.89 (W) + 0.50 (H) – 89.08	1 (W) + (H/2) – 100	0.83 (W) + 0.55 (H) – 98.93	1 (W) + (H/2) – 105
C+Hp				
Female	0.58 (C+Hp) + 0.31 (H) – 94.82	0.6 (C+Hp) + (H/3) – 100	0.47 (C+Hp) + 0.43 (H) – 96.47	0.6 (C+Hp) + (H/3) – 105
Male	0.65 (C+Hp) + 0.31 (H) – 107.05	0.6 (C+Hp) + (H/3) – 100	0.57 (C+Hp) + 0.31 (H) – 96.34	0.6 (C+Hp) + (H/3) – 105
C+U				
Female	0.50 (C+U) + 0.42 (H) – 91.70	0.5 (C+U) + (H/2) – 105	0.41 (C+U) + 0.55 (H) – 99.59	0.5 (C+U) + (H/2) – 110
Male	0.56 (C+U) + 0.40 (H) – 97.75	0.5 (C+U) + (H/2) – 105	0.52 (C+U) + 0.40 (H) – 96.42	0.5 (C+U) + (H/2) – 110
C+W				
Female	0.51 (C+W) + 0.42 (H) – 91.06	0.6 (C+W) + (H/3) – 90	0.43 (C+W) + 0.51 (H) – 96.24	0.5 (C+W) + (H/2) – 105
Male	0.56 (C+W) + 0.41 (H) – 99.51	0.6 (C+W) + (H/3) – 95	0.54 (C+W) + 0.40 (H) – 98.07	0.5 (C+W) + (H/2) – 110

Abbreviations: C+Hp, chest + hip circumference; C+U, chest + umbilical level circumference; C+W, chest + waist circumference.

three formulas using chest, C+Hp, and C+U had these properties (Table 4).

Model validity was tested in three aspect questions. First, which models between Sco and Cco were appropriate equations in term of precision? Second, do simple formulas have the similar prediction value comparing with original regression model? Third, which covariate equation should be recommended in Sco and Cco? For the first question, in addition to each formula, fittings were compared and verified using correlation coefficient (r), adjusted R-square, AIC, and BIC which were demonstrated in Table 3. They also were tested by absolute error difference (Table 5 and Figure 1). We observed that the Cco equations had more correlation coefficient and adjusted R-square as well as less AIC and BIC than the Sco equations which could be interpreted that Cco have had better model fitting than the Sco. In addition, performance of equations with each covariate prediction was tested. Absolute errors were compared and demonstrated as the differences of them within formula types comparing between single versus single (SS), combination versus combination (CC), and combination versus single covariate (CS) formulas; these were demonstrated in Figure 1 as varying shade colors of green (SS), blue (CC), and red (CS) bars, respectively. In Figure 1, SS and CC had comparable total evidence of significant comparison pairs to total pairs (SS versus CC: 33.33% [16/48] versus 37.5% [9/24]; $P = 0.73$). However, there was significantly higher evidence of distinctly CS pairs than non-CS (CC and SS) pairs (CS versus non-CS: 69.79% [67/96] versus 34.72% [25/72]; $P < 0.001$, respectively). These could be interpreted that comparison within the same type of Sco or Cco equations were comparable, but comparison between the different types of equation had significant difference errors. In addition, at the error threshold at 10% and 20% (Table 7 and Figure 4), the tolerance threshold of error in Cco had more accuracy than Sco (mean percentage error tolerance of Cco versus Sco [95% confidence interval (95% CI); P value]: 10%; 76.9 versus 70.3 [74.2–79.6 versus 68.4–72.3; $P < 0.01$] and 20%; 96.8 versus 94.5 [95.7–97.7 versus 93.2–95.8; $P < 0.01$]). The subgroup analyses on sex, age group, and type of equations (Figure 4) also had corresponding results. Therefore, the Cco equations had more precision and error tolerance than Sco equations.

The second question aimed to compare the performance of original and modified simple formulas. The authors demonstrated these performance errors in two aspects. First, using critical error levels, which were determined into two thresholds of error and error tolerance at 10% and 20% (Tables 6, 7, and Figure 4). Second, quantitative errors of equation were demonstrated by Bland–Altman plot, in which each error value was located on their actual body weight (Figures 2 and 3). By

Table 5 Validation of original regression and modified simple formula from validation group classified by sex and age groups

Parameter	Original formula			Simple formula		
	*r**	Error (kg)†	RE (%)†	*r**	Error (kg)†	RE (%)†
Age < 60 years						
Chest						
Female	0.87	3.65 ± 3.71	6.49 ± 6.58	0.87	3.73 ± 3.72	6.71 ± 6.87
Male	0.84	4.69 ± 4.16	7.12 ± 6.54	0.84	4.87 ± 4.15	7.38 ± 6.51
Hip						
Female	0.86	4.27 ± 3.50	7.45 ± 5.74	0.86	4.38 ± 3.63	7.58 ± 5.85
Male	0.86	4.58 ± 3.70	6.75 ± 5.22	0.86	4.83 ± 4.05	6.95 ± 5.18
Umbilical						
Female	0.87	4.11 ± 3.22	7.32 ± 5.82	0.87	4.07 ± 3.18	7.30 ± 5.87
Male	0.87	4.57 ± 3.48	6.90 ± 5.36	0.87	5.37 ± 3.90	8.46 ± 6.90
Waist						
Female	0.88	3.84 ± 3.05	6.87 ± 5.65	0.89	4.30 ± 3.42	7.83 ± 6.67
Male	0.87	4.46 ± 3.42	6.67 ± 5.09	0.87	4.68 ± 3.71	6.88 ± 5.23
C+Hp						
Female	0.92	3.13 ± 2.76	5.59 ± 4.99	0.92	3.72 ± 3.10	6.78 ± 5.97
Male	0.90	3.91 ± 3.18	5.77 ± 4.53	0.90	3.91 ± 3.18	5.92 ± 4.89
C+U						
Female	0.91	3.37 ± 2.82	6.00 ± 4.98	0.91	3.56 ± 2.91	6.27 ± 4.89
Male	0.89	4.05 ± 3.29	6.10 ± 5.16	0.89	4.09 ± 3.49	6.05 ± 5.09
C+W						
Female	0.91	3.34 ± 2.80	5.94 ± 4.94	0.91	4.01 ± 3.16	7.25 ± 6.01
Male	0.89	4.07 ± 3.39	6.02 ± 4.99	0.89	4.44 ± 3.56	6.51 ± 5.07
Age ≥ 60 yrs						
Chest						
Female	0.84	4.40 ± 3.96	7.98 ± 6.47	0.83	4.53 ± 4.01	8.24 ± 6.68
Male	0.86	4.46 ± 4.01	7.58 ± 6.67	0.86	4.52 ± 4.07	7.63 ± 6.66
Hip						
Female	0.84	4.55 ± 3.74	8.74 ± 7.40	0.84	4.92 ± 4.03	9.73 ± 8.66
Male	0.81	5.32 ± 4.56	9.31 ± 8.26	0.81	5.38 ± 4.57	9.49 ± 8.45
Umbilical						
Female	0.80	4.97 ± 4.29	9.34 ± 8.17	0.78	5.36 ± 4.37	10.17 ± 8.74
Male	0.88	4.47 ± 3.61	7.54 ± 5.94	0.88	4.40 ± 3.49	7.52 ± 6.03
Waist						
Female	0.78	4.99 ± 4.53	9.41 ± 8.57	0.76	5.90 ± 5.39	11.50 ± 11.17
Male	0.88	4.52 ± 3.55	7.67 ± 6.06	0.88	4.71 ± 3.45	8.10 ± 6.16
C+Hp						
Female	0.88	3.91 ± 3.23	7.38 ± 6.10	0.88	4.19 ± 3.50	7.98 ± 6.84
Male	0.88	4.28 ± 3.79	7.28 ± 6.26	0.88	4.17 ± 3.74	7.22 ± 6.45
C+U						
Female	0.85	4.34 ± 3.58	8.21 ± 7.06	0.85	5.01 ± 3.83	9.30 ± 7.06
Male	0.91	3.75 ± 3.13	6.41 ± 5.47	0.91	3.87 ± 3.31	6.51 ± 5.52
C+W						
Female	0.84	4.44 ± 3.85	8.25 ± 6.94	0.84	4.62 ± 3.85	8.76 ± 7.59
Male	0.91	3.75 ± 3.16	6.49 ± 5.73	0.91	4.41 ± 3.54	7.29 ± 5.54

Notes: *$P < 0.01$ all; †mean ± SD.
Abbreviations: *r*, correlation coefficient; RE, relative error; C+Hp, chest + hip circumference; C+U, chest + umbilical level circumference; C+W, chest + waist circumference; SD, standard deviation.

critical error threshold of 10% and 20%, almost all simple equations had a higher error than the original formula (Table 6). However, there were no differences between the types of equations in term of error tolerance in both critical levels (Table 7 and Figure 4C). All kappa agreement (Table 6) correlations of error occurrence between the original and simple formulas had higher than 50% in all paired formulas except the C+U older female (0.43), C+W older male (0.47) in 10% threshold, and waist of the younger male (0.33) in the 20% threshold. However, these pair error occurrences between original and

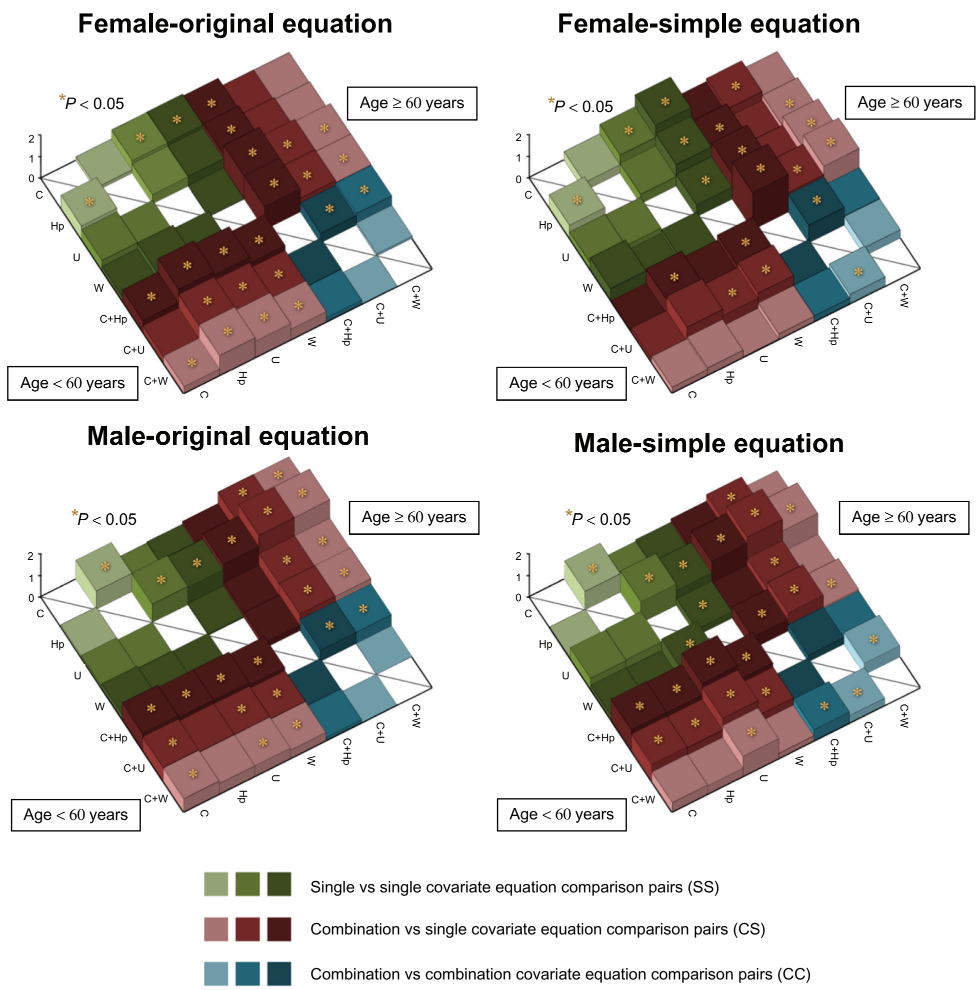

Figure 1 Absolute error difference between each covariate equation classified by type of formula, sex, and age groups.
Notes: Three-dimensional graphs show the comparison pattern of mean error difference between difference equation classified by equation type and sex. The diagonal line in each three-dimensional graph separates comparison performance within age group (above, ≥60 years; below, <60 years). Green, red, and blue colors are the comparisons between single versus single (SS), combination versus single (CS), and combination versus combination covariate equation, respectively (CC). *Significant difference between models, $P < 0.05$.

simple formulas had significant agreement with a P value of less than 0.01 (Table 6). Of these agreements between original and simple equations, median agreement in the Sco equations was slightly higher than the Cco equations but there were no statistical differences (Median [interquartile range; IQR] Sco versus Cco: 10%; 0.79 [0.24] versus 0.66 [0.20]; $P = 0.14$ and 20%; 0.74 [0.13] versus 0.66 [0.25]; $P = 0.13$). Subgroup analyses on sex and age group also had accorded results (female versus male: 10%; 0.66 [0.19] versus 0.79 [0.24]; $P = 0.24$ and 20%; 0.72 [0.14] versus 0.77 [0.30]; $P = 0.34$. Younger versus older: 10%; 0.72 [0.21] versus 0.74 [0.24]; $P = 0.82$ and 20%; 0.74 [0.24] versus 0.74 [0.18]; $P = 0.57$). Quantitative error over actual body weight using Bland–Altman plots was demonstrated in Figure 2 (Sco equations) and Figure 3 (Cco equations). Of these figures, although most of prediction error was contained in two standard deviations, a negative correlation of error over actual body weight could be observed especially in the Sco equations and these correlations had more conversions to the baseline in Cco equations. However, in Figures 2 and 3, we could observe that both prediction formulas had the tendency to overestimation in lower body weights (less than 40 kg) and underestimation in higher body weights (more than 90 kg).

The third question was to select the appropriate equation by the anthropometric validation result criteria in a previous study which had around one-third occurrence on the total population of anthropometric body weight predicted formula at the 10% error threshold.[10] With this criterion, acceptable performance equations were observed and selected depending on age group and sex as follows: first, in males, all Sco in both age groups could be included with this criterion, second, in females, selected equations were dependent on age groups. While all Sco could be selected in the younger female, only both chest Sco (original and simple; 31.2% and

Table 6 Performance and error agreement between original regression and modified simple formula divided by sex and age group

Parameters	Error ≥ 10%			Error ≥ 20%		
	Original[a]	Simple[a]	Kappa*	Original[a]	Simple[a]	Kappa*
Age < 60 years						
Chest						
Female	51 (20.4)	54 (21.6)	0.89	7 (2.8)	12 (4.8)	0.73
Male	62 (24.8)	66 (26.4)	0.85	10 (4.0)	12 (4.8)	0.81
Hip						
Female	77 (30.8)	77 (30.8)	0.85	5 (2.0)	8 (3.2)	0.61
Male	63 (25.2)	66 (26.4)	0.78	7 (2.8)	4 (1.6)	0.72
Umbilical						
Female	72 (28.8)	68 (27.2)	0.80	6 (2.4)	8 (3.2)	0.85
Male	60 (24.0)	83 (33.2)	0.53	8 (3.2)	14 (5.6)	0.72
Waist						
Female	52 (20.8)	65 (26.0)	0.61	9 (3.6)	12 (4.8)	0.85
Male	60 (24.0)	69 (27.6)	0.53	4 (1.6)	2 (0.8)	0.33
C+Hp						
Female	39 (15.6)	56 (22.4)	0.63	4 (1.6)	8 (3.2)	0.66
Male	38 (15.2)	45 (18.0)	0.61	3 (1.2)	4 (1.6)	0.57
C+U						
Female	42 (16.8)	44 (17.6)	0.72	5 (2.0)	5 (2.0)	0.59
Male	47 (18.8)	47 (18.8)	0.82	3 (1.2)	3 (1.2)	1.00
C+W						
Female	43 (17.2)	65 (26.0)	0.53	4 (1.6)	10 (4.0)	0.42
Male	46 (18.4)	52 (20.8)	0.72	2 (0.8)	2 (0.8)	1.00
Age ≥ 60 years						
Chest						
Female	78 (31.2)	83 (33.2)	0.84	12 (4.8)	12 (4.8)	0.91
Male	69 (27.6)	69 (27.6)	0.88	15 (6.0)	15 (6.0)	1.00
Hip						
Female	82 (32.8)	98 (39.2)	0.76	21 (8.4)	32 (12.8)	0.73
Male	84 (33.6)	82 (32.8)	0.95	27 (10.8)	27 (10.8)	0.96
Umbilical						
Female	96 (38.4)	98 (39.2)	0.61	24 (9.6)	25 (10.0)	0.75
Male	75 (30.0)	70 (28.0)	0.85	3 (3.6)	10 (4.0)	0.84
Waist						
Female	91 (36.4)	103 (41.2)	0.50	22 (8.8)	38 (15.2)	0.66
Male	74 (29.6)	77 (30.8)	0.71	10 (4.0)	12 (4.8)	0.71
C+Hp						
Female	64 (25.6)	76 (30.4)	0.64	10 (4.0)	15 (6.0)	0.71
Male	62 (24.8)	65 (26.0)	0.88	9 (3.6)	10 (4.0)	0.84
C+U						
Female	78 (31.2)	97 (38.8)	0.43	15 (6.0)	18 (7.2)	0.51
Male	48 (19.2)	56 (22.4)	0.81	7 (2.8)	5 (2.0)	0.66
C+W						
Female	83 (33.2)	82 (32.8)	0.67	14 (5.6)	20 (8.0)	0.75
Male	47 (18.8)	65 (26.0)	0.47	9 (3.6)	6 (2.4)	0.52

Notes: [a]Number of error (%), *kappa agreement *P* value <0.001 all of parameters.
Abbreviations: Kappa, kappa agreement probability; C+Hp, chest + hip circumference; C+U, chest + umbilical level circumference; C+W, chest + waist circumference.

33.2%) and original hip Sco (32.8%) in the older female could be included. Third, for Cco, all predicted formulas had this acceptable performance except in the C+U simple equation in the elderly female (38.8%). Of these results and quantitative error to actual body weight in Table 6 as well as error tolerance in Table 7, at the overall aspect, the appropriate chest containing equations of Sco in both sex and age groups had higher accuracy than other Sco in terms of error tolerance. (Chest versus non-Chest [95% CI] 10%: 73.4 [69.7–77.1] versus 69.3 [67.0–71.6]; $P = 0.03$. 20%: 95.3 [93.2–95.8] versus 94.3 [92.6–96.0]; $P = 0.25$). In addition, the Sco using chest covariate equations had the highest kappa agreement between the original and simple formula. For the Cco equation, error and error tolerance were comparable (Tables 6, 7, and

Table 7 Mean error tolerance threshold with 95% confidence interval classified by sex, age groups, and types of equations

Parameters Mean (95% CI)	Sex			Age group			Type			All
	Female	Male	*P*	Younger	Older	*P*	Original	Simple		
10% threshold										
Chest	73.4 (63.0–83.8)	73.4 (71.3–75.5)	1.00	76.7 (72.3–81.1)	70.1 (65.7–74.5)	0.02	74 (66.7–81.3)	72.8 (65.2–80.4)	0.73	73.4 (69.7–77.1)
Hip	66.6 (60.3–72.9)	70.5 (63.6–77.4)	0.23	71.7 (67.0–76.4)	65.4 (60.5–70.3)	0.03	69.4 (63.4–75.4)	67.7 (59.2–76.2)	0.62	68.55 (64.9–72.2)
Umbilical	66.6 (56.6–76.6)	71.2 (65.1–77.3)	0.26	71.7 (65.6–77.8)	66.1 (57.0–75.2)	0.16	69.7 (60.2–79.2)	68.1 (59.3–76.9)	0.71	68.9 (64.4–73.4)
Waist	68.9 (54.0–83.8)	72.0 (67.3–76.7)	0.55	75.4 (70.7–80.1)	65.5 (57.0–74.0)	0.02	72.3 (61.4–83.2)	68.6 (57.7–79.5)	0.47	70.4 (64.9–76.0)
C+Hp	76.5 (66.6–86.4)	79.0 (70.7–87.3)	0.56	82.2 (76.9–87.5)	73.3 (69.3–77.3)	$<$0.01	79.7 (70.7–88.7)	75.8 (67.4–84.2)	0.35	77.6 (73.2–82.3)
C+U	73.9 (56.8–91.0)	80.2 (77.4–83.0)	0.29	82.0 (80.4–83.6)	72.1 (58.0–86.2)	0.07	78.5 (68.1–88.9)	75.6 (60.0–91.2)	0.64	77.0 (70.5–83.6)
C+W	72.7 (60.8–84.6)	79.0 (73.4–84.6)	0.18	79.4 (73.2–85.6)	72.3 (61.5–83.1)	0.12	78.1 (66.1–90.1)	73.6 (65.8–81.4)	0.36	75.9 (70.5–81.2)
All	71.2 (68.3–74.2)	75.0 (73.1–77.0)	0.03	77.0 (75.1–78.9)	69.3 (67.0–71.5)	$<$0.01	74.5 (71.9–77.1)	71.7 (69.2–74.3)	0.12	73.1 (71.4–74.9)
20% threshold										
Chest	95.7 (94.1–97.3)	94.8 (93.2–96.5)	0.25	95.9 (94.4–97.4)	94.6 (93.5–95.7)	0.07	95.6 (93.5–97.7)	94.9 (93.9–95.8)	0.38	95.3 (94.4–96.1)
Hip	93.4 (85.5–100)	93.5 (85.6–100)	0.98	97.6 (96.4–98.8)	89.3 (86.4–92.2)	$<$0.01	94.0 (87.2–100)	92.9 (84.1–100)	0.76	93.45 (89.6–97.3)
Umbilical	93.7 (87.2–100)	95.9 (94.2–97.6)	0.33	96.4 (94.2–98.6)	93.2 (87.7–98.7)	0.14	95.3 (90.0–100)	94.3 (89.5–99.1)	0.67	94.8 (92.3–97.3)
Waist	91.9 (83.6–100)	97.2 (94.2–100)	0.11	97.3 (94.4–100)	91.8 (83.7–99.9)	0.09	95.5 (90.6–100)	93.6 (83.8–100)	0.60	94.6 (90.7–98.4)
C+Hp	96.3 (93.4–99.2)	97.4 (95.2–99.6)	0.38	98.1 (96.7–99.5)	95.6 (93.9–97.3)	0.01	97.4 (95.2–99.6)	96.3 (93.4–99.2)	0.38	96.8 (95.5–98.2)
C+U	95.7 (91.4–100)	98.2 (97.0–99.4)	0.13	98.4 (97.7–99.1)	95.5 (91.5–99.5)	0.06	97.0 (93.7–100)	96.9 (92.5–100)	0.96	96.9 (95.0–98.8)
C+W	95.2 (90.9–99.5)	98.1 (95.9–100)	0.10	98.2 (95.8–100)	95.1 (91.2–99.0)	0.08	97.1 (93.7–100)	96.2 (91.3–100)	0.65	96.6 (94.5–98.7)
All	94.6 (93.2–95.9)	96.4 (95.4–97.4)	0.02	97.4 (96.9–98.0)	93.6 (92.3–94.9)	$<$0.01	96.0 (95.0–97.0)	93.6 (94.6–96.4)	0.26	95.5 (94.7–96.3)

Note: Error tolerance (%) = 100 − error (%).
Abbreviations: C+Hp, chest + hip; C+U, chest + umbilical; C+W, chest + waist circumference.

Figure 4). Although there were no differences of error tolerance between the C+Hp and other Cco equations (C+Hp versus Non-C+Hp [95% CI] 10%: 77.8 [73.2–82.3] versus 76.5 [72.7–80.2]; $P = 0.65$. 20%: 96.9 [95.5–98.2] versus 96.8 [95.6–98.0]; $P = 0.96$), but C+Hp had more error tolerance. In addition, we observed that C+Hp had more precision and slightly higher mean error tolerance compared with other Cco in all subgroups (Figure 4, Table 7).

Discussion

Although weight scales are highly available, there were some limitations in special groups of people and many previous studies have suggested equations using anthropometric measurement to predict these parameters (Table 7).[10–12,14–16,18] However, all of the population studies were collected and generated formulas based on the Western population and there were no suggested equations in the Asian population. Therefore, the present study was a pioneering endeavor to develop equations to predict body weight by anthropometric circumferential measurements. The present study separated equations divided by age groups and sex due to previous reports of variations of body composition depending on the age spectrum and sex difference and possibly interference to equation validity.[17] These were demonstrated by differences of coefficient and intercepts at the same covariate equations in different age spectrums in the present study (Table 4). No differences were found in all of the measuring parameters between the modeling and validation groups (Table 1). In the selection process, stepwise regression analysis revealed multicollinearity between hip, umbilical level, and waist

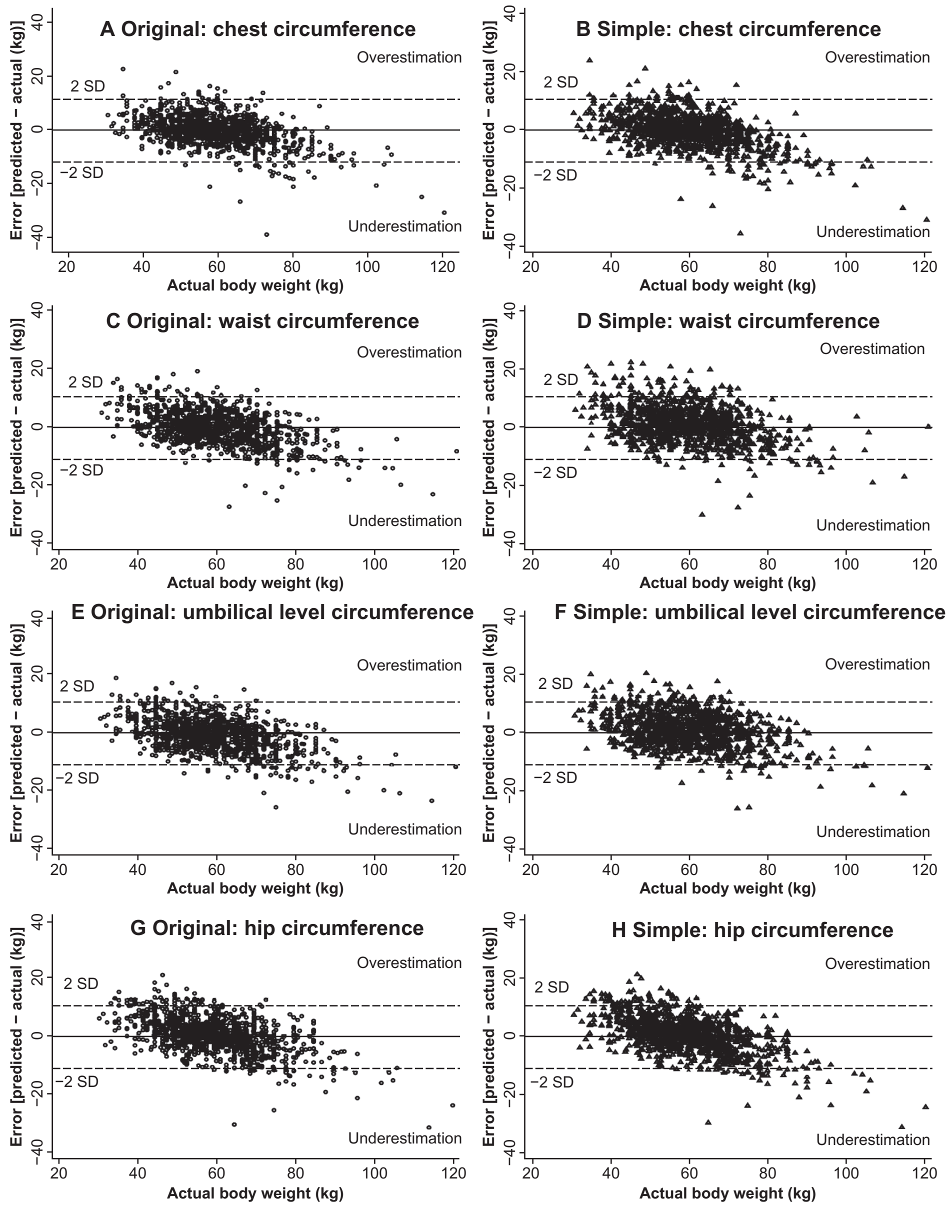

Figure 2 Bland–Altman plot between error of prediction and actual body weight in single covariate equations.
Abbreviation: SD, standard deviation.

variables. Therefore, these covariates were separated into individual equations in the present study and the fixed covariate parameter of the individual equations was body height. Differences of body somatotype effect and body shape might affect the predictive validity.[19–21] Although the authors did not detail body somatotype classifications due to the complexity of measurement, simple combinations between chest and one torso region were initiated by summation between the chest and abdominal region circumference (Cco) and these equations were tested for validation.

Previous studies using mid-arm and calf circumference together with skinfold thickness parameters in elderly people or using only arm circumference and height in obese people were proposed for body weight prediction.[11,14–16,18] However, with our criteria for covariate selection, the authors found that mid-arm, mid-thigh, and mid-calf circumference had fewer fitting properties using correlation coefficient, adjusted R-square, AIC, and BIC than the other covariates (Table 2). Therefore, these variables were not selected for our model creation and validation processes. The probable reasons of these differences might be explained by different ethnic groups having different body composition as well as weight distribution.[22] In addition, there were no comparisons between different circumferences of anthropometric measurements in previous studies.[11,14–16,18] There were some concerns about the measurement difficulties of these torso

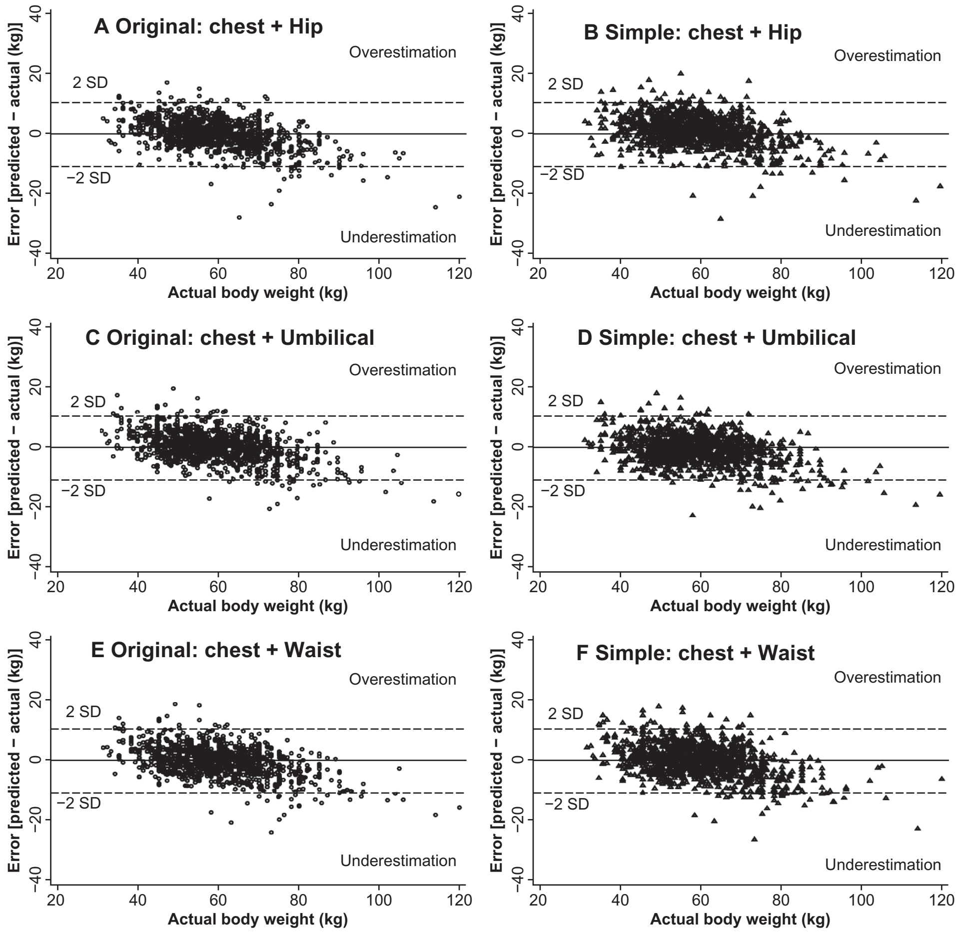

Figure 3 Bland–Altman plot between error and actual body weight in combination covariate equations.
Abbreviation: SD, standard deviation.

parameters, but these parameters might be collected and are feasible to perform during health care processes. The author divided the proposed models into two groups as mentioned previously: Sco equations and Cco equations. To simplify our equation for the purpose of bedside use, the covariate coefficients and constant intercepts were adjusted to simple numbers (Table 4). Both original and simple models were verified for validity to the other samples in the validation groups.

For the validation results in Table 5, both original and simple formulas had significant correlation coefficients of more than 0.75 ($P < 0.01$). Of these, the original and simple equations were comparable in correlation coefficients. Although there were comparable numbers of significant differences when comparing between CC and SS pairs, CS pairs had significant differences (Figure 1). When considered together with Tables 5 and 6, these findings demonstrated that combination covariate equations had more precision than the single covariate equation. These might be explained by different somatotypes in volunteers. Somatotype patterns of endomorphic, mesomorphic, or ectomorphic body types are the important factor to determine different body circumference proportions and body stature. Different gender, age, and lifestyles lead to these somatotype distinctions.[19,21] In the authors' opinion, summation of chest and one of torso circumference might simply be a method to decline the somatotype effect and these resulted in higher error tolerance in combination covariate equations. For the Sco equation (Tables 5, 6, and Figure 2) and Cco equation (Tables 5, 6, and Figure 3), even though chest-containing equations and the summation of chest and hip did not have the least predictive error in all age groups and sex, they had acceptable performance compared with all of the others. In addition, both equations had the better error tolerance when comparing the same type of equation in Figure 4. Therefore, the authors proposed these two equations to predict the actual body weight. The background reason to explain these findings was unknown, but the authors suspected that these variables had less variation and conformed alterations to body weight, body composition, and stature throughout life span.[17,19]

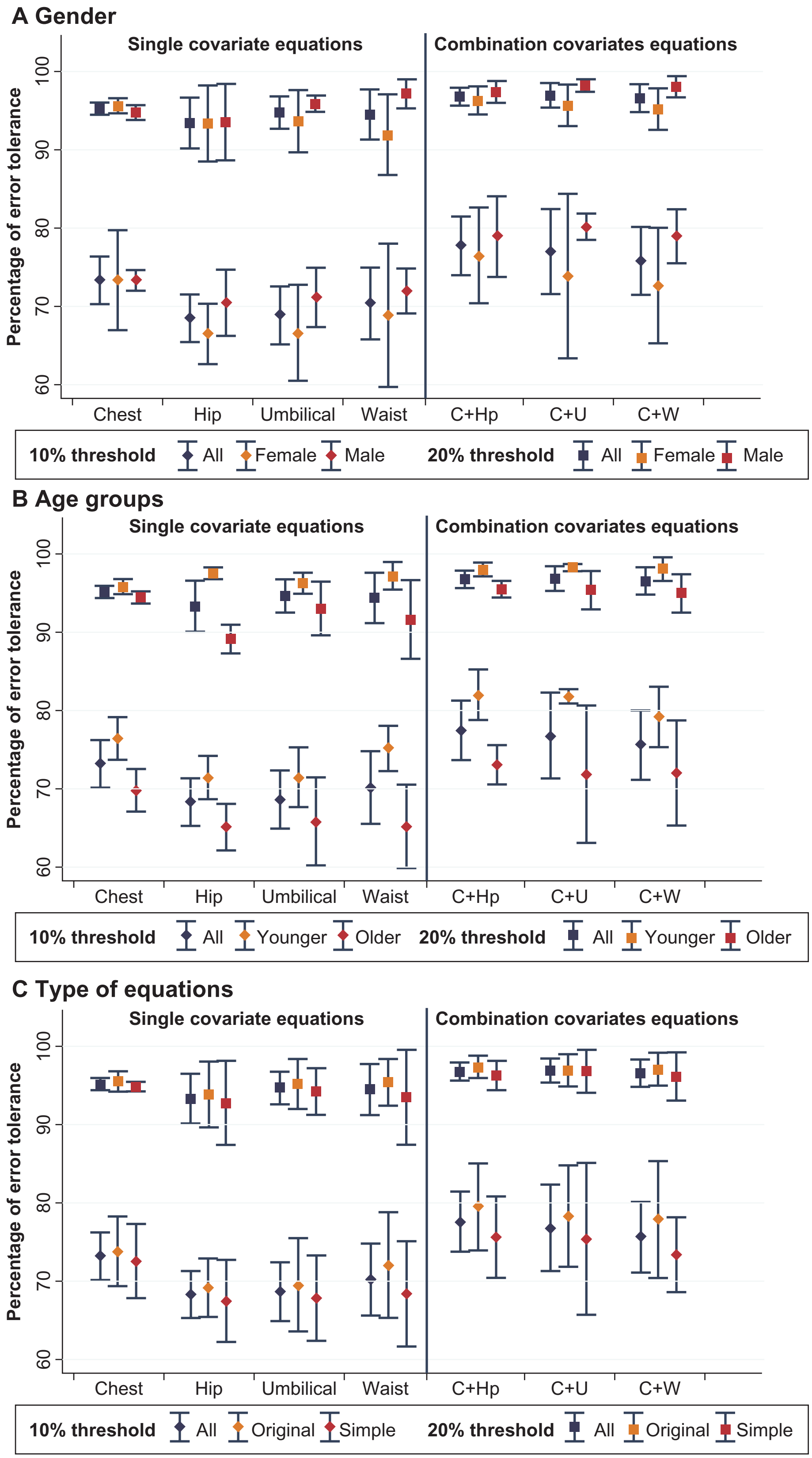

Figure 4 Percentage of error tolerance comparison in 10% and 20% error threshold in each covariate equation classified by the subgroups (**A**) sex (**B**) age groups, and (**C**) type of equations.

Note: Error tolerance (%) = 100 – error (%).

Abbreviations: C+Hp, chest + hip; C+U, chest + umbilical; C+W, chest + waist.

Table 8 Summary of previous body weight predicted equation and validation

Author	Population	Equation	Model	Validation
Chumlea[16]	228 elderly (P, USA)	Female: WT = 0.98 (MAC) + 1.27 (CC) + 0.40 (SST) + 0.87 (KH) – 62.35 Male: WT = 1.73 (MAC) + 0.98 (CC) + 0.37 (SST) + 1.16 (KH) – 81.69	Female $R^2 = 0.85$ Male $R^2 = 0.90$	Mean signed differences 0.1 – 1.8 kg
Donini[14]	285 elderly (H, Italy)	Female: WT = 1.41 (MAC) + 1.11 (CC) + 0.47 (SST) + 1.0 (KH) – 67.37 Male: WT = 36.2 (ln MAC) + 42.47 (ln CC) + 6.91 (ln SST) + 0.8 (KH) – 253.7	Female $R^2 = 0.83$ Male $R^2 = 0.89$	95% error range Woman: ±6.1 kg Male: ±4.9 kg
Jung[18]	300 elderly (P+H, Hong Kong)	Female: WT = 1.01 (KH) + 2.81 (MAC) – 66.04 Male: WT = 1.10 (KH) + 3.07 (MAC) – 75.81	See note[a]	Difference (95% CI) Female: 2.7 (2.3/3.6) Male: 0.4 (–0.5/1.4)
Miyatake[13]	2635 adults (H, Japan)	Female: ↓3 kg ≈ ↓2.85 waist (cm) Male: ↓3 kg ≈ ↓3.45 waist (cm)	NA	NA
Crandall[11]	1471 Obese (P+H, USA)	Female: WT = 2.15 (MAC) + 0.54 (HT) – 64.6 Male: WT = 3.29 (MAC) + 0.43 (HT) – 93.2	$R^2 = 0.55$ $R^2 = 0.59$	Error 10%: 30%–35% Error 20%: 8%–10%
Lin[10]	235 adults (P, USA)	Female: WT = 1.01 (KH) +2.81 (MAC) – 66.04 Male: WT = 1.10 (KH) + 3.07 (MAC) – 75.81	See note[a]	Error 10%: 31% (95% CI: 25%/37%)[b]
Fawzy[12]	50 young male (H, Egypt)	Male: WT = 9.05 (FBBL) + 11.53	$R^2 = 0.27$	NA
Bernal-Orozco[15]	95 elderly female (P, Mexico)	Female: WT = 1.599 (KH) + 1.135 (MAC) + 0.735 (CC) + 0.621 (TSF) – 83.123	$R^2 = 0.90$	Difference error in three samples: –0.02 ± 4.3; –0.7 ± 4.2; 1.9 ± 3.2

Notes: [a]Study used Ross Laboratories equation (Columbus, OH) for body weight prediction. These formulas were generated based on Caucasian population; [b]calculated from error tolerance.
Abbreviations: H, healthy volunteers; P, patients; WT, predicted body weight; HT, height; FBBL, left foot breadth at ball (measured by foot print method); KH, knee height; MAC, mid arm circumference; CC, calf circumference; TSF, triceps skinfold thickness; SST, subscapular skinfold thickness; ln, natural logarithm; NA, not available.

The most common body weight prediction method is visual estimation. However, many previous studies demonstrated that this was a poor estimation method and it was estimator-dependent.[6,7,23] One prospective study in an intensive care unit demonstrated that body weight errors estimation of ≥10% and ≥20% of actual body weight were as much as 47% and 19%, respectively.[23] Although there were differences in the setting and population in the previous study, the single (Chest) and combination (C+Hp) proposed equations in this present study could decrease evidence errors predictions compared to a previous study (≥10% and ≥20% error [95% CI]: Chest 26.6 [22.9–35.1] and 4.7 [3.9–5.6]. C+Hp 22.4 [17.7–29.5] and 3.2 [1.8–4.5], respectively; Table 6).

There were a number of potential strengths and weakness in the present study. The major strengths in the present study were a large sample size which was divided by gender and age groups. In addition, the modeling or development of the equation and validation groups were comparable in all basic demographics and measured data and different circumferences have been compared and demonstrate model fitting in the present study. However, there were a number of inevitable limitations for the study weakness. First, almost all of the participants in the present sample resided in the northern region of Thailand. Although all were the same ethnic background, the differences in lifestyle and living patterns between regions and Asian countries might affect the average body composition resulting in a validity distortion. However, the mixed ethnicity in the northern region of Thailand results from its geographic location between multiple nationalities. This might be the supportive factor to reduce ethnic differences when prediction results are extrapolated to other Asian countries. Second, nearly 80% of the volunteers had a body mass index of less than 25 kg/m^2, which is the criterion threshold of obesity diagnosis. Violations of linearity were performed before the model creation, but the authors found that underestimation might have occurred in volunteers with an actual body weight of more than 90 kg (Figures 2 and 3). Therefore, using the proposed prediction equation on this special population might include a caution for underestimating body weight. However, the present study demonstrated that using a combination covariate equation might alleviate these effects. The mathematic method to take the logarithm of covariate parameters before substitution of these values in the equations might diminish these effects and these methods have been proposed in a previous report (Table 7).[14]

However; simple formulation and general clinical bedside calculation were our primary aims. Therefore, logarithm-based models were not proposed in the present study. Third, although the authors attempted to decrease the somatotype effect by a simplifying method using the summation of chest and one torso circumference as one covariate in the equations, the actual somatotype-detailing anthropometric measurement data was not collected in the present study. Therefore, the correlation between these simplified methods and actual somatotype could not be demonstrated. However, the authors observed that these methods could reduce performance error when comparing individual covariate-predicted equations and further study might be performed to reveal the relationship between combination covariate and somatotypes. Fourth, because of internal validity concerns, the study population was collected only in healthy volunteers. Therefore, the equation results might be distorted when equations are extrapolated to diseased patients. However, there were inconsistent population recruitments in the previous studies of body weight prediction (Table 7). In addition, the actual body weight in diseased patients might deviate from functional body weight in healthy volunteers by body composition alternations.[24,25] However, most phase I clinical trials were performed in healthy volunteers to determine the metabolic and pharmacological actions and the maximally tolerated dose. Of these backgrounds, in the authors' opinions, functional body weight from healthy volunteers might be applied to general clinical practice. Because of these limitations, further validation studies should be performed using these equations in the special clinical situations of the emergency department, intensive care units, or with immobilized patients. Finally, the authors proposed simple formulas which could be used in both sexes in the same age group. Although the authors endeavored to titrate the regression coefficient and intercept by substitution covariates with the mean value of the modeling sample as well as comparable correlation coefficients, the performance error of these equations was higher than the original ones. However, error tolerances of simple and original equations had comparable evidences of accuracy in the 10% error threshold range from one-fourth to one-third of the total sample. Therefore, these methods should be used only in situations in which a direct measurement is unavailable.

Conclusion

Body weight might be predicted by height and circumferential covariates equations. Cco had more error tolerance than Sco. Original and simple equations had comparable validity. Chest- and C+Hp-containing covariate equations had more precision between Sco and Cco equations, respectively.

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Disclosure

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