Chapter 3

Height, body weight and body fat prediction by anthropometric measurements

In clinical practice, both height and body weight are the most common parameters used in many aspects as mentioned in the previous chapter. However, some situations cannot be measured due to the unavailability of special equipment. Therefore, both parameters have been neglected. The most common use of visual estimation is substituted. However, errors of estimation are of concern. For body fat, this measurement needs special equipment and cannot be applied in general. Hence, using anthropometric measurements for prediction are proposed for the estimation of height or stature, body weight and body fat prediction. This chapter will discuss and summarize a method of estimation and a prediction model available in literature and a proposed model as well as revealed the external validation of these models in admitted Thai patients.

1. Height prediction by anthropometric measurement

1.1 Rationale of using anthropometric measurements for height prediction

Height is an important clinical parameter along with body mass index and body surface area calculations. These measurements play a significant part in drug dose adjustment, nutrition assessment and requirements as well as for risk stratification.[1-3] Nevertheless, there are some limitations for obtaining this crucial information in special clinical situations such as in immobilized patients, elderly people, emergency and critically ill patients. Of these situations, visual estimation is one of the most common methods for predicting the patient height. However, this method has an unreliable result.[4] A more scientific method was recommended by the prediction of patient stature via the anthropometric measurement model. Although there were many suggested formulas for height prediction with some selected anthropometric measurements such as ulnar length, knee height, hand dimension, demispan and arm span, and an inaccurate prediction may occur due to the relationship between the anthropometric measurement and height depending on ethnic specific differences, gender and age.[5-19] The objective of this section was to summarize models for predicting height by anthropometric measurement in previous literature and the adult Thai population.

1.2 Previous height prediction by anthropometric measurement research

There were numerous studies that investigated the appropriate formula for stature or height prediction. Parameters including age, gender, race and type of anthropometric measurements should be considered for formula selection. Table 3.1 summarized the formulas available in current literature. The anthropometric length measurement of arm span, demispan, knee height, sitting height and ulnar length were used as a covariate parameter in formula predictions. All of formulas used the linear regression model except the Agnihotri et al formula which used the exponential component of hand length for height prediction.[10] Most of the formulas were generated in special populations especially in elderly people. Age is included only in Chumlea and Weinbrenner formulas.[12,20] The Chumlea formula used age as a continuous variable but age was categorized in the latter formula. Although all of the formulas were validated, external validation should be performed before application in different populations.

1.3 Prediction of height in Thai people

The authors performed the study entitled "Height prediction from anthropometric length parameters in Thai people" which was the first article to predict adult Thai people height by length parameters measurement (Appendix B).[23] The philosophical context of this study is detailed in Appendix A.

The following is a description of the study:

Study objectives: the objective of this study was to create an appropriate model to predict height by anthropometric measurement in the adult Thai population.

Study population: The authors enrolled Thai healthy volunteers by an invitation announcement in the Faculty of Medicine, Chiang Mai University via public information posters and the hospital web site.

Exclusion criteria: Volunteers whose age was less than 18 years old, amputated limb(s), inability of ambulation, inability to lie down, chronic disease which might interfere with measured parameters such as liver cirrhosis, renal failure, chronic steroid use and edematous limb(s).

Study settings:Faculty of Medicine, Chiang Mai University.

Data collection: Body lengths of volunteers were measured in the supine position with a cloth tape measure up to one millimeter width in eight levels including demispan, bi-axillary, neck, humeral, forearm, hand, thigh and foot length as well as sitting and knee height. Details of the method of measurement and reference points were described in Chapter 2. Height was measured by a standard measurement board.

Modeling and validation groups: The study sample was separated independently into two groups, a regression modeling group, in whom regression equations were developed to estimate body height, and a validation group, in whom the equations were tested. Age was classified into two groups with cut off at 60 years old 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.[24]

One covariate model Height(cm) = $a + b_1$ (Covariate$_1$)
Two covariates model Height(cm) = $a + b_1$ (Covariate$_1$) + b_2 (Covariate$_2$)
Three covariates model Height(cm) = $a + b_1$ (Covariate$_1$) + b_2 (Covariate$_2$) + b_3 (Covariate$_3$)

Data analyses: Parameters were determined for the modeling selection by correlation value and significant model fitting R square test (F-test), log likelihood, Akaike's information criteria (AIC) and Bayesian's information criteria (BIC). Parameters which had mulitcollinearity property were excluded. Single, double and triple parameters were proposed for the final linear regression models. The coefficient and intercept of the model had been confined to a simple number which was defined as a simple linear regression formula. The proposed formulas were generated in the following models:

Table 3.1 Summary of previous height predicted equations and validation

Author (Year)	Population	Equation		Model	Validation
Joshi (1964)[8]	50 adult M Indian	Male	H(cm)=70.88 + 3.506UL (±9.98)	SE=0.137	N.A.
Bassey (1986)[5]	125 adults H, Europe	Female	H(cm)=60.1+1.35D(cm)	r=0.74 (At all gender)	SD 0.5 cm (At all gender)
		Male	H(cm)=57.8+1.4D(cm)		
Reeves (1996)[6]	553 young adults (M,272; F,281)	Female	H(cm)=66.9+0.57A(cm), Afro-Carribeans	r = 0.73 – 0.89 (in all group); $p<0.05$	Afro-Caribbean's of both sexes and Asian males had significant differences in height ($p<0.01$)
			H(cm)=81.0+0.48A(cm), Asian		
		Male	H(cm)=54.9+0.66A(cm), Afro-Carribeans		
			H(cm)=53.4+0.67A(cm), Asian		
Chumlea (1998)[12]	4750 (Age≥60)				
	White US (M,1369; F,1472)	Female	H(cm)=82.21+1.85K(cm)-0.21Age(yr)	$R^2$0.64; MSE 3.98; SE 3.98	$R^2$0.68; MSE 3.87; CV 2.23
		Male	H(cm)=78.31+1.94K(cm)-0.14Age(yr)	$R^2$0.69; MSE 3.74; SE 3.74	
	Black US (M,474;F, 481)	Female	H(cm)=89.58+1.61K(cm)-0.17Age(yr)	$R^2$0.63; MSE 3.82; SE 3.83	$R^2$0.69; MSE 3.93; CV 2.28
		Male	H(cm)=79.69+1.85K(cm)-0.14Age(yr)	$R^2$0.70; MSE 3.80; SE 3.81	
	Maxican US (M,497; F, 457)	Female	H(cm)=84.25+1.82K(cm)-0.26Age(yr)	$R^2$0.65; MSE 3.77; SE 3.83	$R^2$0.65; MSE 3.77; CV 2.26
		Male	H(cm)=82.77+1.83K(cm)-0.16Age(yr)	$R^2$0.66; MSE 3.68; SE 3.69	
Mohanty (2001)[19]	505 young adult female Indian	Female	SH(cm)=37.6+0.2618A(cm)	r=0.561(0.50-0.62); $p<0.01$	N.A.
			H(cm)=49.57+0.674A(cm)	r=0.816(0.79-0.85); $p<0.01$	
			SH(cm)=60.35+0.245K(cm)	r=0.294(0.21-0.37); $p<0.01$	
			SH(cm)=60.35+1.245K(cm)	r=0.842(0.82-0.87); $p<0.01$	
Kwok (2002)[15]	789 elderly, 885 young Hong Kong	Female	H(cm)=42.99 + 0.677A(cm)	R^2=0.54, SE 4.0	Mean error -1.5±3.1; $p<0.01$
		Male	H(cm)= 45.55 + 0.690A(cm)	R^2=0.59, SE 3.8	Mean error 0.6±4.1; $p>0.05$
Shahar (2003)[21]	200 elderly (F,104; M,96) Malaysian	Female	H(cm)=18.78 + 0.851A(cm)	R^2=0.81, SE 2.66	% difference 1.3
			H(cm)=41.35 + 1.549D(cm)	R^2=0.70, SE 3.41	% difference 2.0
			H(cm)=50.25 + 2.225K(cm)	R^2=0.70, SE 3.40	% difference 3.3
		Male	H(cm)=47.56 + 0.681A(cm)	R^2=0.75, SE 3.04	% difference 1.0
			H(cm)=51.28 + 1.438D(cm)	R^2=0.72, SE 3.18	% difference 1.6
			H(cm)=69.38 + 1.924K (cm)	R^2=0.66, SE 3.51	% difference 2.3
Weinbrenner (2006)[20]	592 elderly (F321, M271)	Female	H(cm)=88.854 + 0.899D(cm)-0.692AC	r=0.625	Mean error -0.02±4.1 cm
		Male	H(cm)=77.821 + 1.132D(cm)-0.215AC	r=0.718	Mean error -0.03±4.6 cm

Table 3.1 (Continue)

Author (Year)	Population	Equation		Model	Validation
Agnihotri (2008)[10]	250 Adults (M 125, F125)	Female Male	H(cm) = 93.876 + exp(0.031HL left) H(cm) = 110.120 + exp(0.024HL left)	R^2=0.542 R^2=0.352	N.A.
Fatmah (2009)[22]	812 H elderly (>55yr; F,517; M,295) Indonesia	Female	H(cm)=62.682+1.889K(cm) H(cm)=28.312+0.784A(cm) H(cm)=46.551+1.309SH(cm)	R^2=0.634 R^2=0.789 R^2=0.599	S86.0-91.0%, Sp 90.6-97.0%[a] S93.4-95.6%, Sp 93.4-93.7%[a] S71.1-90.5%,Sp 88.6-90.5%[a]
		Male	H(cm)=56.343+2.102K(cm) H(cm)=23.247+0.826A(cm) H(cm)=58.047+1.210SH(cm)	R^2=0.732 R^2=0.822 R^2=0.604	S 76.3-91.1%, Sp 94.2-94.7%[a] S 83.9-89.5%, Sp 94.3-95.6%[a] S 78.9-85.7%, Sp 91.4-91.9%[a]
Hirani (2010)[17]	1421 H.25-45 yr. (F,830; M,531) England	Female Male	H(cm)= 64.0 + 1.31D(cm) H(cm) = 65.8 +1.33D(cm)	SE 0.05, Wald test 0.87 SE 0.07, Wald test 0.01	Mean error 0.04±0.2; p>0.05 Mean error -0.29±0.2; p>0.05
Cereda (2010)[18]	635 H 30-55 yr (F,319; M,316) Italy	Both	H(cm)=60.76+2.16K-0.06Age+2.76Sex (Sex: 0=female, 1=male)	R^2= 0.886 , MSE 3.2 cm, agreement -6.1 to 6.5 cm	Female: PE 2.7 cm; CV 1.7% Male: PE 3.1 cm; CV 1.8%
Hirani (2012)[16]	4269 H. elderly (F,873; M,723) England	Female Male:	H(cm) = 85.7+1.12D(cm)–0.15Age(yr) H(cm) = 73.0 + 1.30D(cm) –0.1Age(yr)	SE of D, Age= 0.05, 0.05. Wald test p=0.93 SE of D, Age = 0.04, 0.02.Wald test p=0.43	Mean error -0.01±0.24 cm; p=0.96 Mean error 0.23±0.20 cm; p=0.25

Abbreviation : A, Arm span AC; 5years age categories; CV, coefficient of variance (%); D, Demispan, HL, hand length; K, Knee heigh; MSE, root mean square error; LOA, 95% limits of agreement; PEs, partitioned residual sum of square; SH, Sitting height; UL, Ulnar length; s, sensitivity; sp, specificity, N.A., not available.

Note : [a] Sensitivity and specificity of predicted height with nutritional status in different sexes

For external validation, predicted height was calculated and the difference was compared to the actual height in the other equal sized volunteer in each validation subgroup of 250 volunteers. The deviated value was reported in error quantity and relative error to actual height in percent. Original regression formulas and modified simple formulas were compared together with correlation coefficient, error quantity and relative error. The level of error and relative error were divided into four groups, less than 5, 5-10, 10.1-20 and more than 20 centimeters and percent respectively. Agreements of two methods were tested by kappa statistics based on error level.

Results and discussion: Using previous criteria, three parameters (demispan, sitting height and knee height) were chosen for model prediction which was previously mentioned in the selected criteria. Some parameters were not included in the model prediction because there was less correlation coefficient as well as the F test was not significant in every subgroup, the humeral length, forearm length and thigh length had potential trends in some volunteer groups. The proposed five models were demonstrated in Table 3.2. As the formula difficulty was a concern, the original regression formulas were adapted into modified simple formulas (Table 3.2). The coefficient and intercepts were adjusted to the nearest integer number which produced better psychological understanding

Table 3.2 Equations proposed for height prediction

Parameters	Regression formula	Simple formula
Male<60		
D	118.75+0.55(D)	120+0.5(D)
S	88.60+0.90(S)	85+1.0(S)
K	89.44+1.58(K)	90+1.6(K)
S+K	72.75+0.30(S) +1.40(K)	70+0.3(S)+1.4(K)
D+S+K	69.27+0.09(D)+ 0.27(S)+1.35(K)	70+0.1(D)+ 0.3(S)+ 1.3(K)
Male≥60		
D	83.80+0.92(D)	80+1.0(D)
S	79.93+0.99(S)	80+1.0(S)
K	80.31+1.73(K)	80+1.7(K)
S+K	64.90+0.29(S)+1.55(K)	65+0.3(S)+1.5(K)
D+S+K	53.56+0.29(D)+ 0.25(S)+1.33(K)	55+0.3(D)+0.2(S)+1.3(K)
Female<60		
D	101.92+0.67(D)	100+0.7(D)
S	88.4+0.82(S)	90+0.8(S)
K	108.27+1.11(K)	110+1.0(K)
S+K	74.41+0.52(S)+0.92(K)	75+0.5(S)+0.9(K)
D+S+K	60.36+0.30(D)+ 0.45(S)+0.80(K)	60+0.3(D)+ 0.5(S)+ 0.8(K)
Female≥60		
D	96.82+0.70(D)	95+0.7(D)
S	73.5+1.00(S)	75+1.0(S)
K	87.49+1.50(K)	87+1.5(K)
S+K	64.36+0.43(S)+1.25(K)	65+0.4(S)+1.2(K)
D+S+K	52.19+0.24(D)+ 0.41(S)+1.14(K)	50+0.2(D)+ 0.5(S)+1.0(K)

Note: D, Demispan; S, Sitting height; K, Knee height; S+K, Sitting height and knee height; D+S+K, Demispan, sitting height and knee height equations.

In the regression model the correlation co-efficient ranged from 0.46 to 0.92 (Appendix B). Of these, the leg length or knee height model had the highest prediction in the single parameters formula. However, there was a slightly lower and comparable correlation coefficient with the double and triple parameters. Error and relative error in the single parameters were significantly lower in the knee height model except in the demispan model in the younger female group. As a reference in the knee height formula, the double parameter models had a significantly decreased error only in the younger ages in both genders while the triple parameters model had more precision in the younger male group when compared with the knee height model. Error and relative error on increasing age had equal distribution in each subgroup of age and gender in both regression and simple formulas.

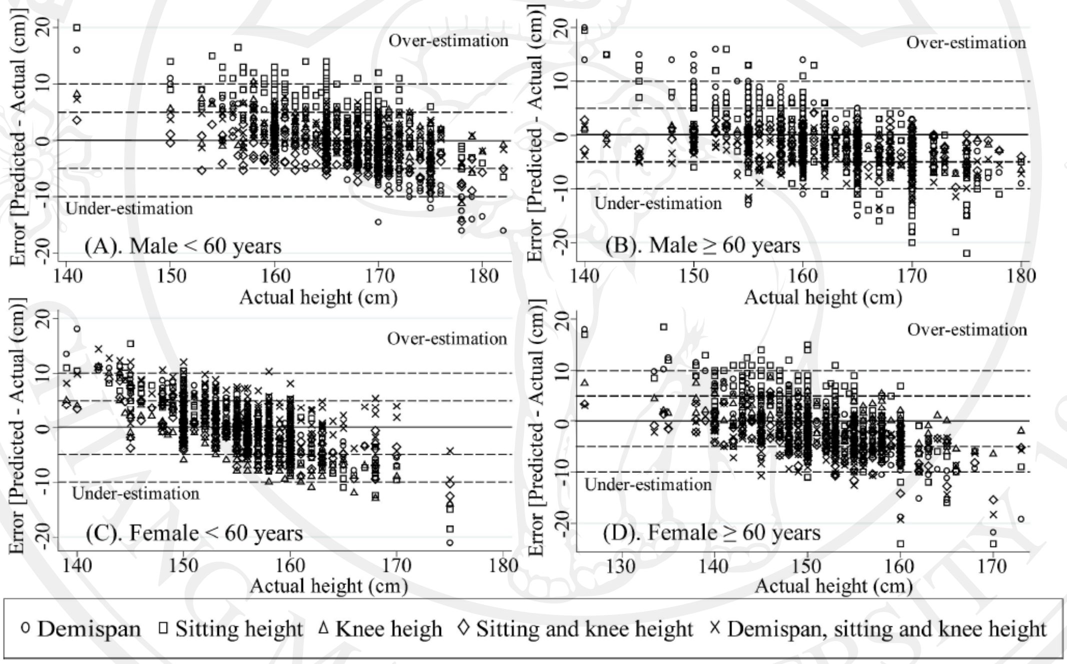

Figure 3.1 Error (Predicted – Actual) and actual height classified by gender and age groups. (A). Male < 60 years. (B). Male ≥ 60 years. (C). Female < 60 years. (D). Female≥ 60 years. (From Chittawatanarat et al. Asia Pac JClin Nutr 2012;21,347-54, with permission of the authors and of Hec Press publisher)

For simple formula validation, the correlation co-efficient in each formula was comparable. Kappa agreements between original and modified formulas were also comparable in all formulas except in the triple parameter model in the older female which had a higher error in the simple formula. Figure 3.1 demonstrated the error quantity over actual height. The error prediction in the validation group of demispan, sitting height, knee height, double and triple modified simple models up to ten percent were 5.7, 9.5, 1.0, 1.1 and 2.6 percent respectively. The authors further stratified actual height into three group as a shorter, normal and taller group which was defined as less than 140, 140 – 160 and more than 160 centimeters respectively. Of these criteria, there were trends of over estimation in the sample that had an actual height of less than 140 centimeters while under-estimations were observed in an actual height of more than 160 centimeters. Most of prediction error of more than ten centimeters occurred in the demispan and sitting model (under-estimation 3.4 and 3.8 percent, over-estimation 2.8 and 6.5 percent respectively) while the other modified simple models had up to 1.7 percent over and under-estimation.

There were some inevitable limitations in this study. (1) Ninety five percent of the volunteers in the present study had census registration in the northern region of Thailand. However, census registration might not reflect the original residence. (2) Although measurement training had been performed before data collection the different body figure might lead to different results because of ill-defined measurement landmarks and these resulted in a measurement bias. (3) Model creations were performed based on healthy subjects; however, external validation into diseased patients should be performed in further studies. (4) There was an unequal distribution of age in the elderly people. Nearly sixty percent of subjects were between 60-70 years old. Therefore, future study for external validation and precision might be over or under estimation in more elderly people.

Study conclusion: Anthropometric parameters with demispan, sitting height, knee height and combination can be applied to height prediction in the adult Thai. Although knee height had the highest precision as a single predictive parameter model, the others were also proposed with acceptable error. A combination of double and triple model might decrease the actual deviation only in younger people. However, over-estimation might be a concern in shorter people and vice versa in taller people. Therefore, formula prediction should be used only in cases of actual unavailable height.

2. Body weight prediction by anthropometrics measurements

2.1 Rational of using anthropometric measurements for body weight prediction

Many clinical situations utilize body weight as a variable for the determination of nutrition requirements, drug dose administration, resuscitation process, pulmonary tidal volume estimation and hemodynamic assessments.[25-28] However, there are many limitations to obtaining body weight in some clinical practice situations especially in non ambulatory elderly people, emergency and critically ill patients. A special instrument is required for direct measurement in these patients. Although visual estimation is the most common method of estimating weight, current literature has reported great inaccuracies of this method compared with the actual body weight. In addition, the precision of this method is operator-dependent.[4,29-31] 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.[32] Although these more scientific anthropometric measurements to estimate body weight have been proposed but ethnic differences and measurement parameter distinctions might impact predicted validity.[33-36] In addition, some parameters used in equations are hard to assess in general practice especially requiring skin fold thickness.[32,37-38] However, there are no recommended formulas suggested to predict body weight with circumferential anthropometric parameters in the Thai or Asian population.

2.2 Previous body weight prediction by anthropometric measurements researches

There were many proposed formulas to estimate body weight. Table 3.3 demonstrated formulas which were reported in previous studies. Of these studies, there were differences in the population involved and different ethnics as well as the anthropometric measurements as predictive covariates.

Covariates parameters used in these formulas could be divided into three groups which were circumferences, skin fold thickness and length measurements. All of proposed circumference covariates in these studies were extremities measurements including mid arm circumference (MAC)[32-33,37-40] and calf circumference (CC)[37-39] except for the waist circumference in Miyatake et al study.[35] Subscapular (SST)[38-39] and triceps skin fold thickness (TSF)[37] were two of measurements involved in proposed predictive covariates. Height[33], knee height[32,37-40] and Left foot breadth at ball (measured by foot print method)[34] were length measurement parameters used in body weight prediction in various formulas in these studies. All of proposed equations were divided by gender. Only the formula for body weight prediction in elderly males proposed by Donini et al utilized a logarithm of measurement parameters in the covariates parameter.[39]

2.3 Prediction of body weight in Thai people

"Development of gender- and age group-specific equations for estimating body weight from anthropometric measurement in Thai adults." was the pioneer report to propose equations for body weight prediction using body circumference in Thai adults (Appendix C).[41] The philosophical context of this study is detailed in Appendix A.

The following is a short communication of the study.

Study objectives: 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.

Study population, exclusion criteria: and study settings: previously mentioned in height prediction in section 1.3.

Data collection: Body circumferences were measured in volunteer supine position with a cloth tape measure up to one millimeter width in eight levels including neck, chest, and waist, umbilical level of abdomen, hip, arm, thigh and leg circumferences. Details of the method of measurement and reference points were described in Chapter 2. Actual body weight was measured by the same digital weighing apparatus and recorded in kilograms with one decimal point. Height was measured by a standard measurement board as mention in section 1.3

Modeling and validation groups: using the same modeling and validation method as section 1.3

Data analyses: 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.[33] The authors developed an estimation equation for body weight divided by age group and gender. The prototype model was demonstrated as follow:

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

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 criteria as in section 1.3. 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. Detailing of absolute and relative errors, kappa agreement and performance tolerance were described in Appendix C.

Results and discussion: During the variables selection process, 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.

Using selection criteria, the authors' selected only chest, hip, umbilical level, waist, C+ Hp, C+ U and C+ W circumference for further validation and performance assessments. (Table 3.4). 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 3.4.

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, the Cco equations had more correlation coefficient and adjusted R-square as well as less AIC and BIC than the Sco equations. 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 vs. single (SS), combination vs. combination (CC) and combination vs. single covariate (CS) formulas these were demonstrated in Appendix C. Of these, the Cco equations had more precision and error tolerance than the Sco equations.

Regarding the second question, the authors demonstrated these performance errors into two aspects. First, using critical error levels, which were determined into two thresholds of error and error tolerance at 10% and 20%. Second, quantitative errors of equation were demonstrated by Bland-Altman plot, in which each error value was located on their actual body weight (Figure 3.2 and 3.3). All of Kappa agreement correlations of error occurrence between the original and simple formulas had higher than 50 percent in all paired formulas except the C+U older female (0.43), the C+W older male (0.47) in 10% threshold and waist of the younger male (0.33) in the 20% threshold. However, these entire pair error occurrences between original and simple formula had significant agreement with *p* value of less than 0.01. Quantitative error over actual body weight using Bland – Altman plots were demonstrated in Figure 3.2 (Sco equations) and Figure 3.3 (Cco equations). Of these figures, although most of prediction error was contained in two standard deviations but 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 Figure 3.2 and 3.3, we could observe that both prediction formulas had the tendency to over estimation in lower body weights (less than 40 kg) and under estimation 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 10% error threshold. At the overall aspect (see detail in Appendix C), the appropriate Sco in both genders and age groups was the chest containing equation which had higher accuracy than other Sco in term

Table 3.3 Summary of previous body weight predicted equation and validation[41]

Author (Year)	Population	Equation	Model	Validation
Chumlea (1988)[38]	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 singed differences 0.1 - 1.8 kg.
Donini (1998)[39]	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: ± 4.9kg
Jung (2004)[40]	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 (2007)[35]	2635 adults (H,Japan)	Female: ↓3kg ≈↓2.85 waist(cm) Male: ↓3kg ≈↓3.45 waist(cm)	N.A.	N.A.
Crandall (2009)[33]	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 (2009)[32]	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 (2010)[34]	50 young male (H,Egypt)	Male: WT=9.05(FBBL) +11.53	R^2=0.27	N.A.
Bernal-Orozco (2010)[37]	95 elderly female (P, Maxico)	Female: WT= 1.599(KH)+1.135(MAC) +0.735(CC) +0.621(TSF) -83.123	R^2=0.90	Difference error in 3 samples: -0.02±4.3; -0.7 ± 4.2; 1.9±3.2

Abbreviation: 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 skin fold thickness; SST, Subscapular skinfold thickness; ln, Natural logarithm; N.A., Not available.

Note: [a]Study used Ross Laboratories equation (Columbus, Ohio) for body weight prediction. These formulas were generated based on Caucasian population. [b] calculated from error tolerance

Table 3.4 Gender 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

Abbreviation: C+Hp, Chest + Hip circumference; C+U, Chest + Umbilical level circumference; C+W, Chest + Waist circumference

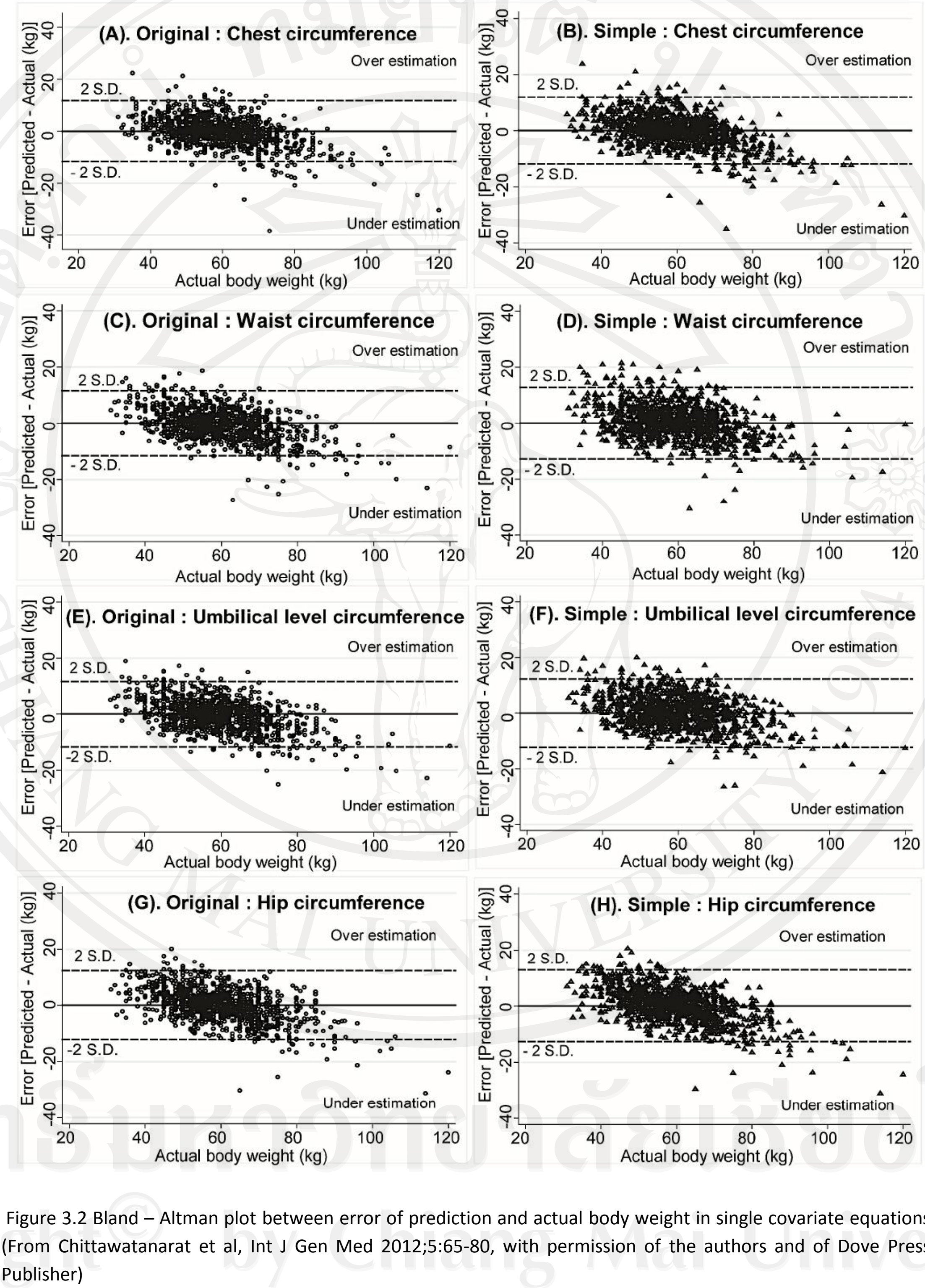

Figure 3.2 Bland – Altman plot between error of prediction and actual body weight in single covariate equations (From Chittawatanarat et al, Int J Gen Med 2012;5:65-80, with permission of the authors and of Dove Press Publisher)

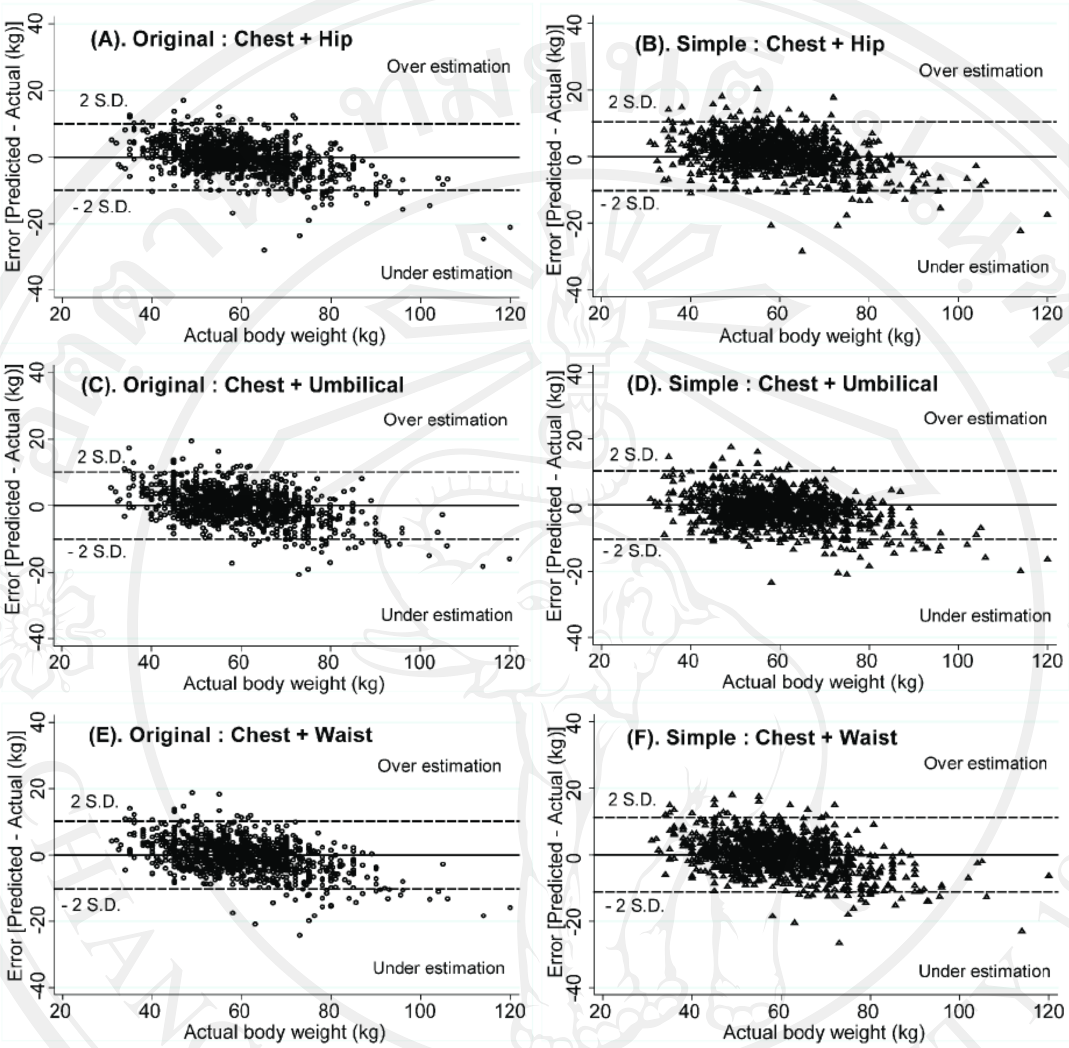

Figure 3.3 Bland – Altman plot between error and actual body weight in combination covariate equations (From Chittawatanarat et al, Int J Gen Med 2012;5:65-80, with permission of the authors and of Dove Press Publisher)

of error tolerance (Chest vs. Non-Chest [95%CI]. 10%: 73.4 [69.7/77.1] vs. 69.3 [67.0/71.6]; p=0.03. 20%: 95.3 [93.2/95.8] vs. 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, although there were no differences of error tolerance between the C+Hp and other Cco equation (C+Hp vs. Non-C+Hp [95%CI]. 10%: 77.8[73.2/ 82.3] vs. 76.5[72.7/80.2]; p=0.65. 20%: 96.9 [95.5/98.2] vs. 96.8[95.6/ 98.0]; p0.96) but C+Hp had more error tolerance. In addition, we observed that C+Hp had more precision and slightly higher mean error tolerance comparing with other Cco in all subgroups (Figure 3.4).

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

3. Body fat prediction by anthropometrics measurements

3.1 Rational of using anthropometric measurements for body fat prediction

As previously discussed in Chapter 2, body composition evaluation needs special tools to measure and some of these tools are unavailable and expensive. In addition, they cannot be used in general clinical application and clinical epidemiological fields. For body fat and fat free mass, although BMI is a crude determinant for defining weight classification but they have some limitations populations such as athletes or body builders. In addition, A large retrospective study in critically ill patients demonstrated that only underweight patients are associated with poor outcomes in contrast with overweight and obese patients.[42] These results had the same direction in a large prospective study of non bariatric surgical patients.[43] This difference might be explained by the fat mass (FM) and fat free mass (FFM) proportions. The decrease of FFM and increase of FM had a negative impact to the overall mortality in an epidemiologic study especially in males.[44-45] Therefore, a combination both of BMI and FM might be clinical prognostic indicators as well as obesity diagnostic criteria.[24] Of these reasons, using anthropometric measurement for body composition prediction is widely used. This section will summarize the prediction equations which are currently used.

3.2 Previous body fat prediction by anthropometric measurements research

3.2.1 Calculation of body fat from skinfolds via body density

Calculation of body fat from skinfold thickness via body density is the most widely used and pioneer methods for estimating body fat. Skinfold thickness measurements from multiple anatomical sites are also used to estimate body density, the percentage of body fat. The method involves the following process.[46] (1) Determination of appropriate skinfolds and other anthropometric measurements for the prediction of body density; the selection of the sites depends on the age, sex, race and population group under investigation. (2) Calculation of body density, using an appropriate regression equation. (3) Calculation of the percentage of body fat from body density, using population specific or generalized regression equations and (4) Calculation of total body fat and/or the fat free mass using following equations.

$$\text{Total body fat (kg)} = \frac{\text{body weight (kg)} \times \text{\% body fat}}{100}$$

$$\text{Fat free mass(kg)} = \text{body weight (kg)} - \text{body fat (kg)}$$

1. Choice of appropriate skinfold sites

There are numerous studies to investigate using the combination of skinfolds and other anthropometric measurements for body fat prediction. In general, a combination of skinfold, such as triceps, subscapular, Suprailiac, thigh or abdomen, are used for young adult male and female. For the elderly, the biceps, triceps, Suprailiac and subscapular skinfolds are preferred sites which are more closely associated with body density.[47-48]

2. Calculation of body density using population-specific regression equation

The specific regression equation should be selected that is compatible with the individual anthropometric measurement population. These include age, sex, race and body fatness. Moreover, a criterion or reference method for determining body density (such as underwater weighing, dual energy x ray absorptiometry, and four compartment model) should be considered. Other selection factors that must be considered with caution including the experience of the anthropometrist, the type of skinfold caliper used, and hydration status of the subject.

3. Calculation of body density using generalized regression equations

Generalized regression equations have been developed based on large heterogeneous samples, varying in age and degree of body fatness. Two equations given below are commonly used. Both of them are based on the two compartment model and fat free mass in each age was assumed to have constant density. However, these equations have been validated for use in adult Caucasian populations. The first equation is proposed by Durnin and Womersley which calculates the body density as equation (1).[49]

$$\mathrm{Density(kg/m^3)} = 1.1631 - (0.0632\ \times\ \log_{10}(\mathrm{SK_4[mm]})\ldots\ldots\ldots\ldots(1)$$

SK_4 represents the sum (in mm) of the skinfold measurement for the biceps, triceps, subscapular and Suprailiac skinfolds. The second equation is valid for adult male subjects 18-61 years of varying fatness and is taken form Jackson and Pollock as equation (2)[50]

$$\mathrm{Density(kg/m^3)} = 1.10938 - (8.267 \times 10^{-4} \times \mathrm{SK_3}) + (1.6 \times 10^{-6}\ \times (\mathrm{SK_3})^2) - (2.574 \times 10^{-4} \times \mathrm{Age})\ldots(2)$$

SK_3 is the sum (in mm) of the chest, abdomen, and thigh skinfolds and the age in years to calculate the body density.

4. Calculation of percentage body fat

The final stage in the calculation of the percentage of body fat mass (PFM) from multiple skinfold measurement is the selection of an empirical equation relating fat content to body density as previous mention density. Most of equations have been developed based on the classic two compartment model for body composition. However, there are some underlying assumptions of the calculated formula (1) the density of the fat free mass is relatively constant, (2) the density of fat for normal persons does not vary among individuals, (3) the water content of fat free mass is constant and (4) the proportion of bone mineral to muscle in the fat free body mass is constant. There were difference used values for density of fat and the fat free mass coefficient in equations as follows (3-5).[51-53]

Table 3.5 Summary of predicted percent body fat mass formula

Author	Demographic	Criterion	Subgroups	Equations	R^2 (%)	SEE(%)
Lean	Caucasian (UK)	DNM	Male	PFM= 0.567 (W) + 0.101 (A) - 31.8	77.8	4.1
(1996)[55]	M 63; F 84	RV		PFM= 1.31 (TF) + 0.430 (A) - 9.16	76.9	4.3
	Age 16-65 yr.			PFM= 1.33 (BMI) + 0.236 (A) - 20.2	67.0	5.0
				PFM= 0.353 (W) + 0.756 (TF) + 0.235 (A) - 26.4	86.6	3.2
				PFM= 0.742 (BMI) + 0.950 (TF) + 0.335 (A) - 20.0	84.5	3.4
				PFM= 30.9 (1ogSK$_4$) + 0.271 (A) - 39.9	80.1	4.0
				PFM= 76.7 (MAR) + 0.237 (A) - 20.4	69.1	4.9
				PFM= 24.2 (MLR) + 0.256 (A) - 22.6	67.7	5.0
				PFM= 1.52 (MUAC) + 0.336 (A) - 38.7	57.3	5.8
				PFM= 42.6 (MAR) + 0.917 (TF) + 0.334 (A) - 19.6	84.4	3.4
				PFM= 13.0 (MLR) + 0.933 (TF) + 0.348 (A) - 20.4	83.5	3.4
				PFM= 0.757 (MUAC) + 1.07 TF) + 0.398 (A) - 29.0	80.7	3.8
			Female	PFM= 0.439 (W) + 0.221 (A) - 9.4	70.4	4.7
				PFM= 0.944 (TF) + 0.279 (A) + 4.6	75.1	4.3
				PFM= 1.21 (BMI) + 0.262 (A) - 6.7	74.5	4.4
				PFM= 0.232 (W) + 0.657 (TF) + 0.215 (A) - 5.5	79.0	4.0
				PFM= 0.730 (BMI) + 0.548 (TF) + 0.270 (A) - 5.9	80.2	3.9
				PFM= 30.8 (logSK$_4$) + 0.274 (A) - 31.7	76.4	4.2
				PFM= 73.6 (MAR) + 0.287 (A) - 7.6	73.0	4.5
				PFM= 22.0 (MLR) + 0.300 (A) - 7.2	72.2	4.6
				PFM= 1.38 (MUAC) + 0.243 (A) - 16.7	73.3	4.5
				PFM= 41.3 (MAR) + 0.607 (TF) + 0.253 (A) -4.7	79.7	3.9
				PFM= 12.0 (MLR) + 0.626 (TF + 0.260 (A) - 4.3	79.3	4.0
				PFM= 0.676 (MUAC) + 0.582 (TF) + 0.246 (A)- 7.1	77.0	4.2
Wang et al	China	DXA	Female	PFM= 0.899(BMI)+0.029(A)+0.279(TF)-0.117(SC)+0.172(I) + 0.188(T) -0.57	54.0	4.4
(1994)[58]			Male	PFM= 0.471(BMI)+0.082(A)+0.327(TF)+0.132(AB)+0.289(T)-4.40	39.0	4.9
Deurenberg	Dutch(1229)	DNM	Children	PFM = 1.51(BMI) – 0.7(A) -3.6(Sex) + 1.4	38.0	4.4
(1991)[59]	M,521; F 708		Adult	PFM = 1.20(BMI) + 0.23(A) – 10.8(Sex) – 5.4	79.0	4.1
				(Male ,sex=1; Female, sex=0)		

Table 3.5 (Continue)

Author	Demographic	Criterion	Subgroups	Equations	R^2 (%)	SEE(%)
Deurenberg (1997)[60]	China (n 205)	DNM	Dutch	PFM = 1.38(BMI) + 0.25(Age in year) – 12.1(Sex) -8.1	89.0	4.3
	Dutch (n 189)		Chinese	PFM = 1.45(BMI) + 0.11(Age in year) – 10.4(Sex) -5.9	83.0	4.2
				(Male ,sex=1; Female, sex=0)		
Teran (1991)[56]	White (18-50 yr)	DNM	With RV	PFM = 43.427(ln CIRC) + 10.906(ln SKF) – 0.694 (FOR) – 4.045(RV) – 236.298	69.0	4.3
	Female		Without RV	PFM = 42.515(ln CIRC) + 11.662(ln SKF) – 0.653(FOR) – 241.677	65.0	4.6
Gallagher (2000)[61]	International African(M 155,F 99)	DXA	All	PFM= 76.0-1097.8 -(1/BMI) -20.6(sex) + 0.053(A) + 95.0(Asian) (1/BMI) - 0.044(Asian)(A)+ 154 (sex)(1/BMI) + 0.034 (sex)(A)	90.0	4.31
	Asian(M 633,F 322) White(M 225,F 192)	4C	All	PFM= 63.7-864(1/BMI)-12.1(sex)+ 0.12 (Age in year) + 129 (Asian)(1/BMI) - 0.091(Asian)(Age in year)- 0.030 (African)(A)	89.0	3.97
			Asian (F)	PFM= 64.8 -752(1/BMI)+ 0.016 (Age in year)	88.0	2.91
			Asian (M)	PFM =51.9-740(1/BMI)+ 0.029(Age in year)	77.0	3.49
Pongchaiyakul (2005)[57]	Thai	DXA	Male	PFM=0.42(SC) + 0.62(BMI) – 0.28(Bi)+0.17(W) – 18.47	68.0	N.A.
	Model(M98,F 125)		Female	PFM = 0.42(Hp) + 0.17(I)+0.46(BMI) – 23.75	68.0	N.A.
	Valid(M83,F130)		Both	PFM= 1.65(BMI) + 0.06(Age in year) – 15.3(Sex) – 10.67	83.0	N.A.
				(Male ,sex=1; Female, sex=0)		

Abbreviation: TF,triceps skinfold; AB, abdominal; Bi, Biceps skinfolds(mm); BMI, body mass index; 4C,four compartment model; DNM,Densitometry; FOR, forearm circumference (cm); F,Female; Hp=Hip circumference(cm); I, Suprailiac skinfold (mm); ln (CIRC),natural logarithm of the sum of five circumferences in cm (upperarm, upper abdomen, lower abdomen, thigh and calf); ln (SKF), the natural logarithm of the sum of the triceps and thigh skinfolds (mm); log SK_4, logarithm of sum of four skinfold thickness(mm); M, Male; MAR, Ratio of body mass to arm span(kg/cm); MLR, Ratio of body mass to lower leg length(kg/cm); MUAC, mid upper arm circumference (cm); PFM, Percent body fat mass(%); RV, residual lung volume in liters; SC,subscapular skinfolds (mm); T,thigh skinfold (mm);. W,waist circumference(cm)

$$\text{PFM} = \left(\left(\frac{4.950}{\text{D}}\right) - 4.500\right) \times 100\%.....(3)^{51}$$

$$\text{PFM} = \left(\left(\frac{4.570}{\text{D}}\right) - 4.142\right) \times 100\%.....(4)^{52}$$

$$\text{PFM} = \left(\left(\frac{5.548}{\text{D}}\right) - 5.044\right) \times 100\%.....(5)^{53}$$

Equation (3) was proposed by Siri et al which assumed that the densities of fat and the fat free mass are 0.90 and 1.10 kg/L respectively.[51] Equation (4) and (5) were created by Brozek et al and Rathburn et al respectively.[52-53] Both equations used the concept of a reference man of a specified density and composition. These equations avoid the requirement of estimating the density of fat free mass. They were developed from the chemical analysis of cadavers. However, in the high prevalence of overweight and obesity population, the equation of Siri et al equation yields increasingly higher estimates of PFM and using of Brozek et al equation may now be preferable.[54]

3.2.2 Other predictive equations

With the limitation of complicated steps for body fat prediction, therefore, many formulas using difference criterion and reference methods or application of body density have been proposed. Using the different parts of anthropometric measurement for body fat prediction is included in the formula. Table 3.5 summarized the formula available in current literature. Of these, age, race and gender are the parameters that should be considered before formula selection. Lean et al proposed twelve formulas in each gender. The authors suggested that a predicted equation containing waist circumference as a covariate parameter had more power prediction. Power of prediction would be increased when triceps skinfold thickness was added.[55] More difficult methods using a logarithm form to modify anthropometric measurement were suggested by Teran et al formula.[56] In addition, the addition of residual lung volume to the formula could increase the power of prediction. For Gallagher et al formula, interestingly, these formulas were generated based on two standard measurements, dual energy X ray absorptiometry (DEXA) and the four compartment model (4C). These formulas considered ethnic differences by international collected data and integrated ethic parameters to the formula. In addition, the formula considered the interaction between the parameters involved. As previously discussed, external validation in different populations should be performed before the selection of formula in clinical practice.

3.3 Prediction of body fat in Thai people

To our best knowledge, only Pongchaiyakul et al suggested an anthropometric measurement formula in Thai people.[57] The authors performed the study in rural Thai people in north east region of Thailand using DEXA as reference tools. Their proposed formulas were demonstrated in Table 3.5. The suggested formulas were divided into two groups. First, a simple formula predicted body fat using only BMI, age and sex. Second, a more complex formula, these formulas were further categorized into two groups by gender. Both genders used BMI as a covariate. However, there were differences in the anthropometric measurement parameter. While the formula in male used two skinfold thickness (subscapular and biceps skinfold) and waist circumference in prediction parameters but female formula used only one skinfold thickness of suprailiac skinfold and one circumference of hip in equation. However, both formulas had less power than the simple formula (Table 3.5). The study concluded that a simple formula may provide an accurate estimate of PFM and could potentially aid in the diagnosis of obesity in rural Thai people.[57]

4. External validation of height and body weight prediction in clinical situations

As previous describes of height and body weight prediction studies in Thai adult (Appendix B and C), although the formulas were validated but the population in the studies have been performed in healthy volunteer. The application of these might be distorted and be uncertain accuracy in the clinical situations.

Study objectives: The aims of this study were to external validate and verify the accuracy of the height and body weight prediction formulas in the admitted patient.

Study population: The selected Thai adult patients who were admitted in hospital and consented for anthropometric measurement were enrolled in this study.

Exclusion criteria: The patients, whose age was less than 18 years old, amputated limb, pitting edema, cirrhosis with markedly ascites and chronic renal failure needed dialysis, were excluded in this study.

Study settings: To decease geographic bias and population different in distinct part of Thailand, the data collected sites were performed in two large hospitals where locates in different region of Thailand, Bhumibol Adulyadej hospital locates in Bangkok (central region) and Surin regional hospital in Surin province (southern part of north-east region).

Data collection: Nutrition specialist nurses who familiar with anthropometric measurement were assigned for data collection after understanding study protocol and measurement landmark. For decrease data collection parameters, the authors selected only some anthropometric measurement parameters based on the most accurate results in the previous healthy volunteer study (Appendix B and C). This included knee height, demispan and sitting height for height predicted formulas and chest and hip circumference for body weight predicted formula. Patient demographic data was also collected including age, gender, principle diseases, admitted wards, underlying disease. Actual height was measured with standard method and actual weight was measured with standard available tool in each hospital.

Predicted formula: Described simple formulas in previous study (Appendix B and C) were used in this study. The authors selected these formulas due to bedside clinical application concern. The details of formula using in this study were summarized as Table 3.6.

Table 3.6 Summary of simple predicted formula using in external validation study

	<60 years	≥60 years
Body weight		
Chest		
Female	1(C)+(H/3)-80	1(C)+(H/3)-85
Male	1(C)+(H/3)-80	1(C)+(H/3)-85
Hip		
Female	1(Hp)+ (H/3) -90	0.8(Hp)+(H/2)-95
Male	1(Hp)+ (H/3)-85	0.8(Hp)+(H/2)-95
Chest +Hip		
Female	0.6(C+Hp)+(H/3)-100	0.6(C+Hp)+(H/3)-105
Male	0.6(C+Hp)+(H/3)-100	0.6(C+Hp)+(H/3)-105
Height		
Demispan		
Female	100+0.7(D)	95+0.7(D)
Male	120+0.5(D)	80+1.0(D)
Sitting height		
Female	90+0.8(S)	75+1.0(S)
Male	85+1.0(S)	80+1.0(S)
Knee height		
Female	110+1.0(K)	87+1.5(K)
Male	90+1.6(K)	80+1.7(K)

Abbreviation: K, Knee height (cm); D, Demispan(cm); S, Sitting height(cm); C,Chest circumference (cm); H, body height (cm); Hp, Hip circumference (cm); C+Hp, combination of chest and hip circumference (cm)

Data analysis

Predicted height and weight in different age group and gender were calculated and compared to actual height and body weight. The validation and accuracy were reported as quantitative absolute error and percentage of error on actual height and weight.

Results and discussion

The total of 101 patients was included in this external validation study during 1 July to 31 July 2012. Of these, younger (<60 years) and older patient (≥60 years) were 49 and 52 respectively. Male patients had slightly higher proportion than female but there were no statistically difference (Table 3.7). Nearly half of patients were non-ambulation. More than fifty percent of patients' occupations were farmer or employee but 46.15 percent of older patients have been retired while 44.90 percent of younger patients were employee. About 80 percent of patients were included in surgical patients in both age groups. Three common diseases were gastrointestinal, soft tissue disease and hepatobiliary diseases respectively. More than 60 percent in younger patient had no underlying but only 36 percent in older had at least one underlying diseases. Hypertension and diabetics mellitus were the two most common underlying diseases (Table 3.7). Detail of anthropometric measurement parameters in both age group patients have been demonstrated in Table 3.8. Of these parameters, all anthropometric measurement in male had higher than female. However, there were no statistical different all of these parameters between age group in each gender.

Table 3.7 Demographic data of patients

Patient demographic data	Age < 60 yrs (n=49)	Age ≥ 60 yrs (n=52)	All (n=101)	P value
Age [Mean(S.D.)] (yrs)				
1. Male	41.81(11.95)	71.54(9.45)	55.95(18.43)	<0.01
2. Female	41.67(12.68)	67.79(7.13)	56.60(16.32)	<0.01
Gender				
1. Male	31(63.27)	28(53.85)	59(58.42)	0.337
2. Female	18(36.73)	24(46.15)	42(41.58)	
Status				
1. Non- Ambulatory	20(40.82)	29(55.77)	49(48.51)	0.13
2. Ambulatory	29(59.18)	23(44.23)	52(51.49)	
Occupation				
1. Farmer	9(18.37)	23(44.23)	32(31.68)	<0.01
2. Employee	22(44.90)	5(9.62)	27(26.73)	
3. Officer	5(10.20)	0(0)	5(4.95)	
4. Other include retired	13(26.53)	24(46.15)	37(36.63)	
Ward				
1.Surgery	39(79.59)	44(84.62)	83(82.18)	0.104
2. Medicine	1(2.04)	5(9.62)	6(5.94)	
3. ENT	8(16.33)	3(5.77)	11(10.89)	
4.Orthopedics	1(2.04)	0(0)	1(0.99)	
Principle diseases				
1. Gastrointestine	14(28.57)	13(25.00)	27(26.73)	0.11
2.Hepato-biliary-pancreas	3(6.12)	9(17.31)	12(11.88)	
3.Neurological diseases	7(14.29)	9(5.77)	10(9.90)	
4.Head-neck-brease	2(4.08)	2(3.85)	4(3.96)	
5.Soft tissue disease	3(6.12)	12(23.08)	15(14.85)	
6.Cardio-vascular-thoracic	4(8.16)	6(11.54)	10(9.90)	
7.Trauma	5(10.20)	2(3.85)	7(6.93)	
8.Urology	1(2.04)	1(1.92)	2(1.98)	
9.Orthopedics	2(4.08)	1(1.92)	3(2.97)	
10.Ear-Nose-Throat	8(16.33)	3(5.77)	11(10.89)	
Underlying disease				
1. No underlying	32(65.31)	19(36.54)	51(50.50)	0.159
2. Diabetics	3(6.12)	9(17.31)	12(11.88)	
3.Hypertension	9(18.37)	10(19.23)	19(18.81)	
4.Coronary heart disease	0(0)	1(1.92)	1(0.99)	
5.Renal insufficiency	0(0)	2(3.85)	2(1.98)	
6.Chronic respiratory	1(2.04)	2(3.85)	3(2.97)	
7. Cirrhosis (Mild)	2(4.08)	3(5.77)	5(4.95)	
8.Malignancy	1(2.04)	3(5.77)	4(3.96)	
9. Other	1(2.04)	3(5.77)	4(3.96)	

Table 3.8 Anthropometric measurement parameters categorized by age group and gender

Anthropometric data	Age < 60 yrs (n=49)	Age ≥ 60 yrs (n=52)	All (n=101)	P value
Height				
Male	164.66(5.38)	164.83(4.18)	164.75(4.81)	0.56
Female	153.61(4.53)	153.67(5.10)	154.07(4.83)	0.54
Body weight (kg)				
Male	59.5(15.67)	54(8.50)	56.89(12.97)	0.10
Female	51.81(9.88)	53.81(12.73)	52.95(11.51)	0.58
Circumference				
Chest				
Male	86.94(8.17)	84.43(7.03)	85.74(7.69)	0.21
Female	80.81(8.55)	80.94(9.81)	80.88(9.18)	0.96
Hip				
Male	86.61(8.63)	84.71(7.65)	85.71(8.17)	0.38
Female	89.53(9.62)	91.17(10.34)	90.46(9.95)	0.60
Length				
Knee height				
Male	49.82(2.71)	51.03(4.30)	50.39(3.57)	0.19
Female	45.14(2.87)	45.85(2.85)	45.55(2.82)	0.42
Demispan				
Male	78.28(2.98)	78.69(4.36)	78.51(3.79)	0.73
Female	86.80(4.82)	85.18(3.97)	86.03(4.48)	0.17
Sitting height				
Male	86.80(4.82)	85.18(3.97)	86.18(4.48)	0.17
Female	81.11(4.37)	81.07(3.69)	81.08(3.95)	0.97

Table 3.9 and 3.10, Figure 3.4 – 5 and Figure 3.8 – 9 demonstrated about of height and body weight prediction accuracy on actual measurement categorized by gender and age group. For height prediction, all of predictive results had comparable error with in age group and gender which mean absolute error range around 3 – 4 cm (range of S.D. between 1.51 to 4.13 cm) and percent error up to 3 percent (range of S.D. between 1.01 to 2.61 percent) except predominant higher error using sitting and knee height in younger male patient (Table 3.9, Figure 3.8). In addition, demispan had trend to under estimation while sitting and knee height had tendency to over estimation both on patient actual height and age (Figure 3.4 and 3.6). However, there was less error tendency of prediction in older patient (Figure 3.4).

For body weight prediction accuracy (Table 3.10, Figure 3.5, 3.7 and 3.9), the predicted body weight assessed by chest(C), hip (Hp) and combination of chest and hip (C+Hp) had tendency to underestimation in patient who had body weight more than 90 (Figure 3.5). This finding was similar to previous healthy study in Appendix C. The results of these might be occurred from modeling and validation group in the study included overweight and obese patient less than 20%. Therefore, using of this formula to body weight prediction might be underestimated and limited application in these group patients. However, utilizing of these formulas in clinical situations frequently used in normal or malnourished patients for nutritional status screening and assessment. In addition, formulas accuracy (range of S.D. between 1.54 to 12.05%) could be used in each age group with average error less than 8 kg or (range of S.D. between 2.19 to 7.06 kg) 10% error except chest (C) containing formula in younger male and older female patient (Table 3.10 and Figure 3.9). In Figure 3.7, Hip(Hp) containing formula had tendency to slightly over estimation in elderly patient but there were contrary directions in C and C+Hp containing formula.

Table 3.9 Estimation method of height

Height parameter	**Age < 60 yrs (n=49)** [Mean (S.D.)/ Median(IQR)]	**Age ≥ 60 yrs (n=52)** [Mean (S.D.)/ Median(IQR)]
Actual height		
Male	164.66(5.38)/165(10)	164.83(4.18)/ 165(7.25)
Female	153.61(4.53)/155(8)	153.67(5.10)/154(5)
Estimation height		
Knee height formula		
Male	**Ht(E) = 90+1.6(K)**	**Ht(E) = 80+1.7(K)**
Predicted height(cm)	169.71(4.33)/170.00(4.00)	166.76(7.31)/ 165.52(5.52)
Absolute error(cm)	5.90(3.05)/ 6.20(3.80)	3.98(4.26)/ 3.40(3.53)
Percent error(%)	3.62(1.94)/ 3.76(2.27)	2.41(2.52)/ 2.06(2.19)
Female	**Ht(E) = 110+1.0(K)**	**Ht(E) = 87+1.5(K)**
Predicted height(cm)	155.14(2.82)/155.00(3.00)	155.78(4.28)/155.25(4.87)
Absolute error(cm)	3.14(1.51)/ 3.25(2.00)	3.99(2.60)/3.63(4.13)
Percent error(%)	2.04(1.01)/ 2.02(1.38)	2.63(1.77)/ 2.34(2.83)
Demispan formula		
Male	**Ht(E) = 120+0.5(D)**	**Ht(E) = 80+1.0(D)**
Predicted height(cm)	162.51(1.92)/ 162.25(2.50)	165.41(3.86)/ 165.5(5.25)
Absolute error(cm)	3.64(3.05)/ 2.5(3.55)	3.37(2.77)/ 3(4.25)
Percent error(%)	2.17(1.75)/ 1.60(2.09)	2.06(1.71)/ 1.88(2.54)
Female	**Ht(E) = 100+0.7(D)**	**Ht(E) = 95+0.7(D)**
Predicted height(cm)	154.79(2.09)/ 155.65(3.50)	150.08(3.05)/ 149.78(4.20)
Absolute error(cm)	3.08(2.89)/ 1.90(3.30)	4.12(2.93)/ 3.34(4.10)
Percent error(%)	2.01(1.96)/ 1.23(2.02)	2.63(1.82)/ 2.13(2.52)
Sitting height formula		
Male	**Ht(E) = 85+1.0(S)**	**Ht(E) = 80+1.0(S)**
Predicted height(cm)	171.80(4.82)/ 171.50(5.30)	165.18(3.97)/ 165.5(6.25)
Absolute error(cm)	7.86(4.13)/ 7.10(4.50)	3.89(2.35)/ 3.75(2.40)
Percent error(%)	4.84(2.61)/ 4.48(3.01)	2.35(1.40)/ 2.23(1.45)
Female	**Ht(E) = 90+0.8(S)**	**Ht(E) = 75+1.0(S)**
Predicted height(cm)	154.89(3.50)/ 154.80(4.80)	156.07(3.69)/ 156.25(4.50)
Absolute error(cm)	3.14(2.49)/2.80(2.60)	4.03(2.65)/ 3.25(4.30)
Percent error(%)	2.04(1.60)/ 1.83(1.88)	2.64(1.77)/ 2.08(2.70)

Note:Absolute error = |Predicted height – Actual height|, Mean(S.D.)/ Median(IQR); Percent error = (Absolute error/ Actual height)x100, Mean (S.D.)/ Median(IQR)
Abbreviation: S.D., Standard deviation; Ht(E), height estimation (cm); K, Knee height (cm); D, Demispan(cm); S, Sitting height(cm)

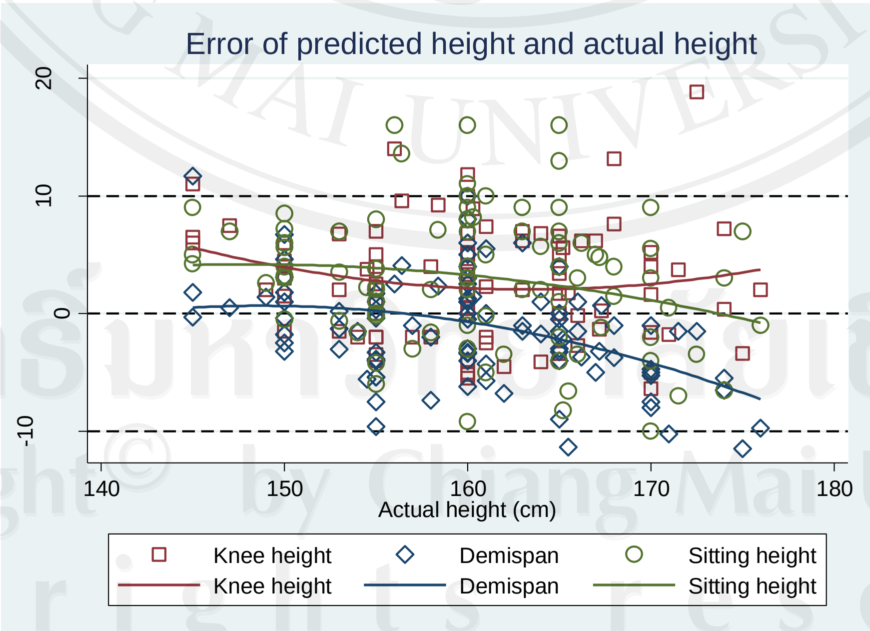

Figure 3.4 Bland – Altman plot and fitted line between error of prediction and actual height

Table 3.10 Estimation method of body weight

	Age < 60 yrs (n=49) [Mean (S.D.)/ Median(IQR)]	Age ≥ 60 yrs (n=52) [Mean (S.D.)/ Median(IQR)]
Actual body weight		
Male	59.5(15.67)/57.6(18)	54.00(8.50)/54.25(13.75)
Female	51.81(9.88)/47.5(9)	53.81(12.73)/49.5(14)
Estimation body weight		
Chest circumfernce		
Male	**Wt(E) = 1(C)+(H/3)-80**	**Wt(E) = 1(C)+(H/3)-85**
Predicted weight (kg)	61.82(9.06)/ 62.67(10.00)	54.37(7.78)/ 52.50(13.17)
Absolute error(kg)	7.71(6.19)/ 7.00(7.17)	3.24(2.19)/ 2.67(2.92)
Percent error(%)	13.28(9.03)/ 11.86(12.70)	6.25(4.65)/ 5.09(6.88)
Female	**Wt(E) = 1(C)+(H/3)-80**	**Wt(E) = 1(C)+(H/3)-85**
Predicted weight (kg)	52.34(9.15)/ 49.67(9.50)	47.16(10.38)/ 45.33(12.33)
Absolute error(kg)	4.57(5.09)/3.17(4.67)	6.91(4.53)/6.50(5.83)
Percent error(%)	9.21(11.54)/6.30(5.59)	12.45(7.15)/ 12.99(11.82)
Hip circumferrence		
Male	**Wt(E) = 1(Hp)+ (H/3)-85**	**Wt(E) = 0.8(Hp)+(H/2)-95**
Predicted weight (kg)	56.50(9.60)/ 56.30(10.33)	55.19(7.16)/ 54.45(10.95)
Absolute error(kg)	6.11(7.06)/ 4.00(4.67)	3.51(3.51)/ 2.78(4.60)
Percent error(%)	9.60(8.23)/6.56(10.83)	6.89(7.10)/ 4.75(8.85)
Female	**Wt(E) = 1(Hp)+ (H/3) -90**	**Wt(E) = 0.8(Hp)+(H/2)-95**
Mean (S.D.)	51.06(10.29)/ 48.50(12.33)	54.77(9.00)/ 53.00(8.82)
Absolute error(kg)	4.06(4.02)/ 2.67(4.67)	4.98(3.29)/ 3.80(4.85)
Percent error(%)	8.14(8.82)/ 5.07(4.71)	9.50(6.91)/ 7.47(8.69)
Chest + hip circumference		
Male	**Wt(E)=0.6(C+Hp)+(H/3)-100**	**Wt(E)=0.6(C+Hp)+(H/3)-105**
Predicted weight (kg)	59.01(10.69)/ 57.20(12.03)	51.43(8.71)/49.9(15.55)
Absolute error(kg)	5.70(5.97)/3.70(4.60)	3.39(2.57)/3.10(2.50)
Percent error(%)	9.12(7.01)/7.63(10.00)	6.43(4.77)/ 5.36(6.13)
Female	**Wt(E)=0.6(C+Hp)+(H/3)-100**	**Wt(E) = 0.6(C+Hp)+(H/3)-105**
Predicted weight (kg)	53.74(11.11)/ 49.73(11.40)	49.48(12.14)/ 47.77(11.63)
Absolute error (kg)	3.95(5.30)/3.70(4.60)	5.03(3.61)/ 3.1(2.50)
Percent error(%)	8.29(12.05)/ 7.63(10.00)	9.48(6.85)/5.36(6.13)

Note : Absolute error = |Predicted weight – Actual weight|, Mean(S.D.)/ Median(IQR); Percent error = (Absolute error/ Actual weight)x100, Mean (S.D.)/ Median(IQR)

Abbreviation: S.D., Standard deviation; Wt(E),estimation body weight; C,Chest circumference (cm); H, body height (cm); Hp, Hip circumference (cm); C+Hp, combination of chest and hip circumference (cm)

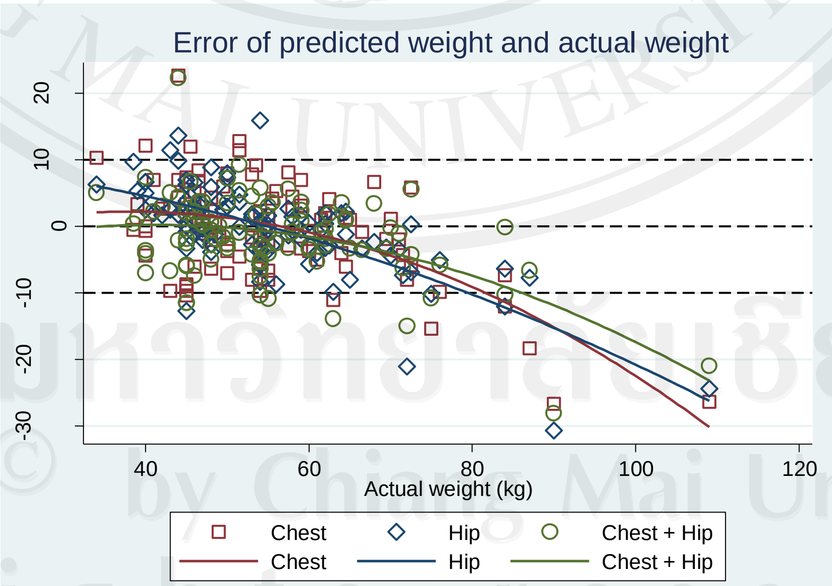

Figure 3.5 Bland – Altman plot and fitted line between error of prediction and actual body weight

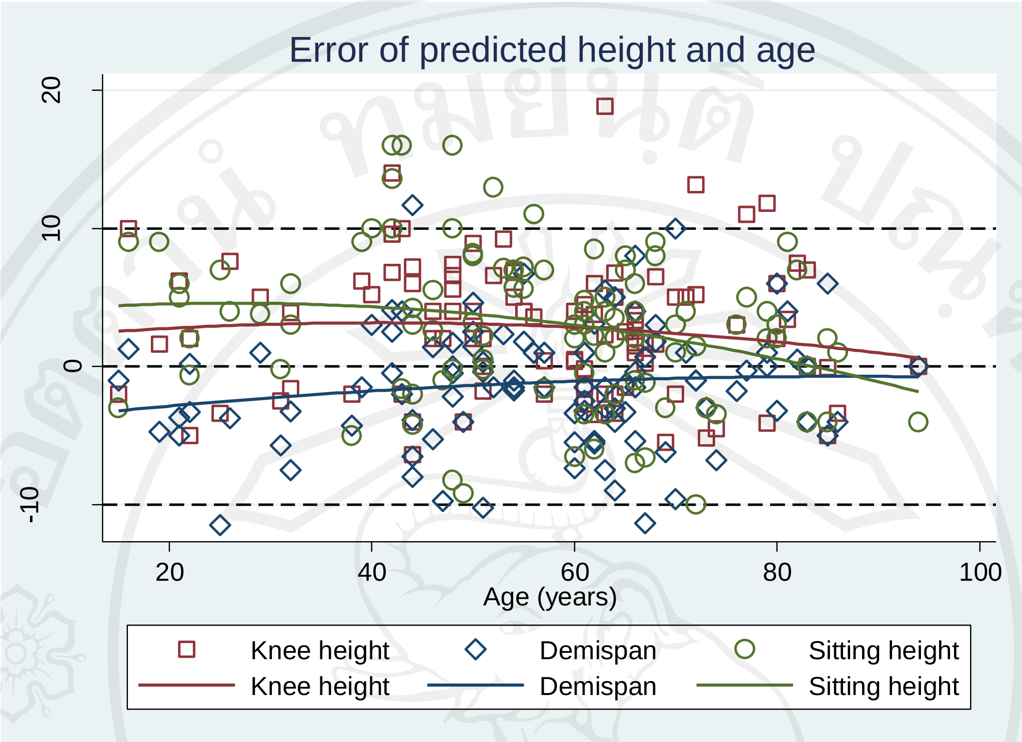

Figure 3.6 Bland – Altman plot between error and fitted line of prediction of height and patient age

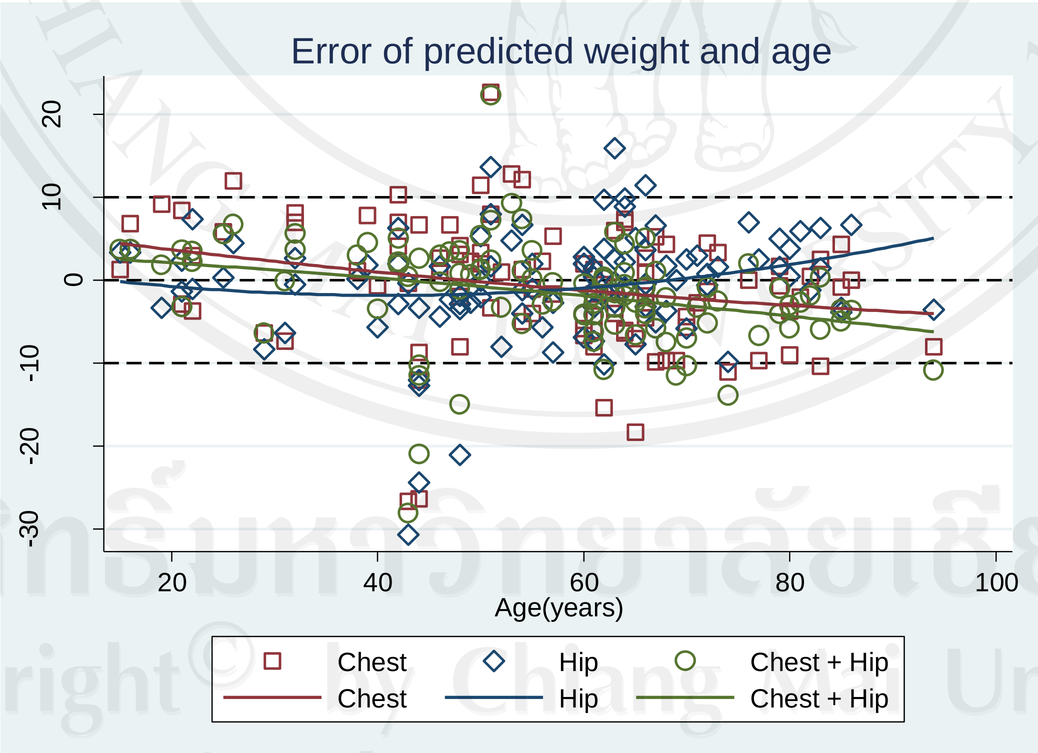

Figure 3.7 Bland – Altman plot and fitted line between error of prediction of body weight and patient age

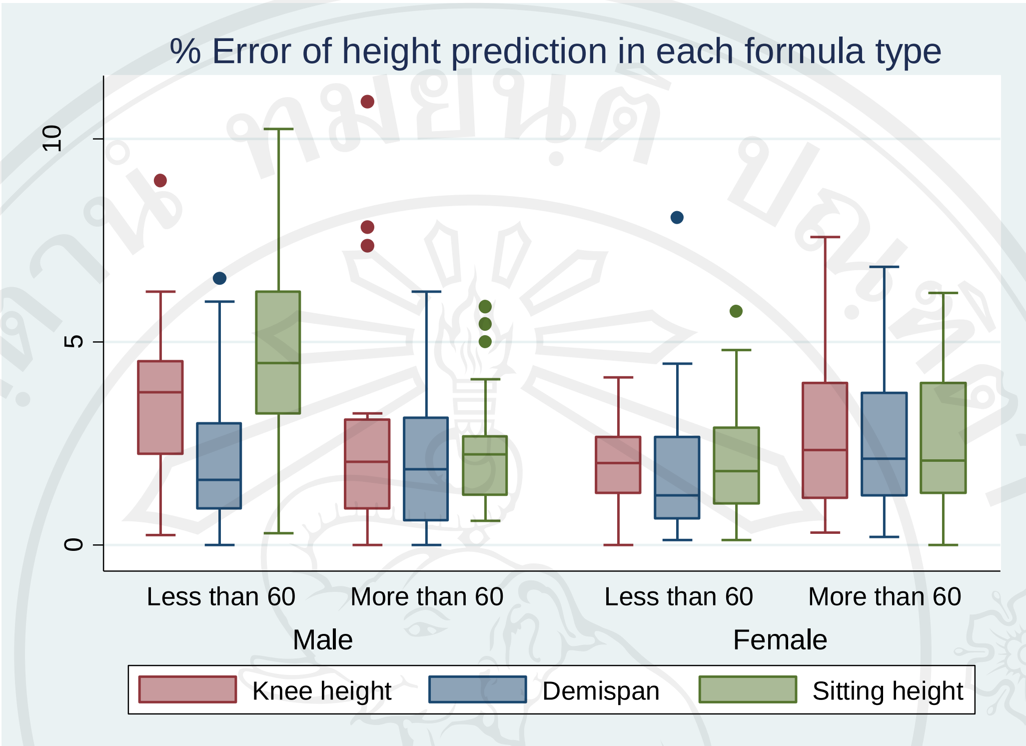

Figure 3.8 box plot between absolute error of height and patient subgroups divided by gender and age group
Note: “Less than 60” was the patient age less than 60 year and “More than 60” was the patients age more than or equal 60 years

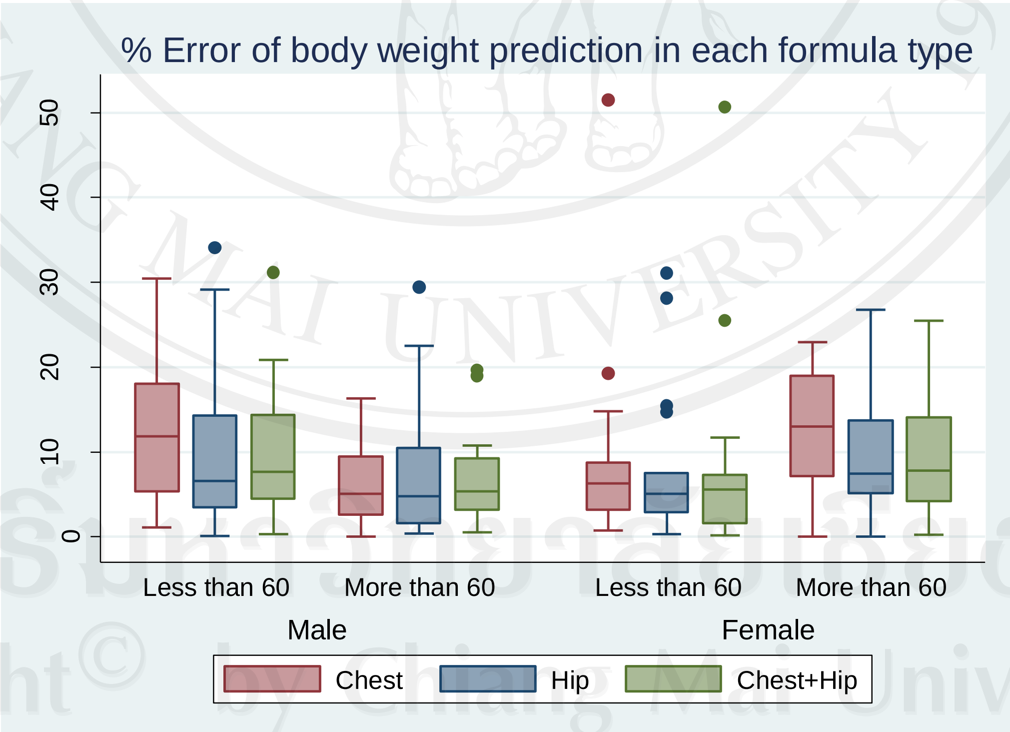

Figure 3.9 box plot between absolute error of body weight prediction and patient subgroups divided by gender and age group
Note: “Less than 60” was the patient age less than 60 year and “More than 60” was the patients age more than or equal 60 years

Table 3.11 accuracy comparison in term of absolute error and percent error between patient and healthy volunteer in previous study in Appendix A and B

	Age < 60 yrs [Mean(S.D.)]			Age ≥ 60 yrs [Mean(S.D.)]		
	Patient	**Healthy**	**P value**	**Patient**	**Healthy**	**P value**
Estimation height						
Knee height formula						
Male	*n=31*	*n=250*		*n=28*	*n=250*	
Absolute error	5.90(3.05)	2.80(2.0)	<0.01	3.98(4.26)	2.40(1.90)	<0.01
Percent error	3.62(1.94)	1.68(1.30)	<0.01	2.41(2.52)	1.50(1.20)	<0.01
Female	*n=18*	*n=250*		*n=24*	*n=250*	
Absolute error	3.14(1.51)	4.20(2.90)	0.13	3.99(2.60)	2.70(1.90)	<0.01
Percent error	2.04(1.01)	2.70(1.80)	0.13	2.63(1.77)	1.78(1.31)	<0.01
Demispan formula						
Male	*n=31*	*n=250*		*n=28*	*n=250*	
Absolute error	3.64(3.05)	4.40(3.30)	0.22	3.37(2.77)	5.10(4.10)	0.03
Percent error	2.17(1.75)	2.50(1.90)	0.36	2.06(1.71)	3.20(2.70)	0.03
Female	*n=18*	*n=250*		*n=24*	*n=250*	
Absolute error	3.08(2.89)	3.60(3.10)	0.49	4.12(2.93)	4.50(3.50)	0.61
Percent error	2.01(1.96)	2.40(2.10)	0.03	2.63(1.82)	2.90(2.30)	0.58
Sitting height formula						
Male	*n=31*	*n=250*		*n=28*	*n=250*	
Absolute error	7.86(4.13)	5.90(3.90)	<0.01	3.89(2.35)	5.20(4.20)	0.11
Percent error	4.84(2.61)	2.50(1.70)	<0.01	2.35(1.40)	3.20(2.60)	0.09
Female	*n=18*	*n=250*		*n=24*	*n=250*	
Absolute error	3.14(2.49)	3.70(3.10)	0.45	4.03(2.65)	5.10(4.00)	0.20
Percent error	2.04(1.60)	2.40(2.00)	0.46	2.64(1.77)	3.40(2.70)	0.18
Estimation body weight						
Chest circumfernce						
Male	*n=31*	*n=250*		*n=28*	*n=250*	
Absolute error	7.71(6.19)	4.87(4.15)	<0.01	3.24(2.19)	4.52(4.07)	0.10
Percent error	13.28(9.03)	7.38(6.51)	<0.01	6.25(4.65)	7.63(6.66)	0.29
Female	*n=18*	*n=250*		*n=24*	*n=250*	
Absolute error	4.57(5.09)	3.73(3.72)	0.37	6.91(4.53)	4.53(4.01)	<0.01
Percent error	9.21(11.54)	6.71(6.87)	0.16	12.45(7.15)	8.24(6.68)	<0.01
Hip circumferrence						
Male	*n=31*	*n=250*		*n=28*	*n=250*	
Absolute error	6.11(7.06)	4.83(4.05)	0.13	3.51(3.51)	5.38(4.57)	0.04
Percent error	9.60(8.23)	6.95(5.18)	0.01	6.89(7.10)	9.49(8.45)	0.12
Female	*n=18*	*n=250*		*n=24*	*n=250*	
Absolute error	4.06(4.02)	4.38(3.63)	0.84	4.98(3.29)	4.92(4.03)	0.94
Percent error	8.14(8.82)	7.58(5.85)	0.71	9.50(6.91)	9.73(8.66)	0.90
Chest + hip circumference						
Male	*n=31*	*n=250*		*n=28*	*n=250*	
Absolute error	5.70(5.97)	3.91(3.18)	<0.01	3.39(2.57)	4.17(3.74)	0.28
Percent error	9.12(7.01)	5.92(4.89)	<0.01	6.43(4.77)	7.22(6.45)	0.53
Female	*n=18*	*n=250*		*n=24*	*n=250*	
Absolute error	3.95(5.30)	3.72(3.10)	0.77	5.03(3.61)	4.19(3.50)	0.26
Percent error	8.29(12.05)	6.78(5.97)	0.34	9.48(6.85)	7.98(6.84)	0.31

Table 3.11 compared the predicted height and body weight accuracy value in term of mean (S.D.) of absolute error and percent error between previous healthy study (Appendix B and C) and external validation in admitted patient. For height prediction, knee height predicted formula in admitted patient had significant higher error as well as percent error (p<0.01) than healthy volunteer except in younger female. Demispan predicted formula had lower error of mean and percent error especially there was significant difference in elderly male people. Sitting height predicted formula was comparable results between groups except there was significant higher error in younger male patient.

For body weight prediction, there were statistical significant differences between patient and healthy volunteer in both chest containing variable formulas (C and C+Hp) in younger male and only chest containing formula (C) in elderly female. The others had comparable results with mean absolute error around 3-6 kg (S.D. range 2.19 – 7.06 kg) and mean percent error less than 10% (S.D. range 1.54 – 12.05%) (Table 3.11)

Study conclusion

The external validation of simple formula could be concluded as following.

(1) For height prediction, overall predictive formula could estimate actual body height with mean absolute error range around 3 – 4 cm (S.D. range 1.51 – 4.13 cm) and mean percent error up to 3 percent (S.D. range 1.01 – 2.61%) except using knee height and sitting height in younger male patient.

(2) For body weight prediction, most accurate estimation range located up to 90 kg with mean error less than 8 kg (S.D. range 2.19 – 7.06 kg) or 10% of error (S.D. range 1.54 – 12.05%)from actual weight except chest (C) containing formula in younger male and older female patient. Using all of these formulas in obese patient had tendency of an underestimation.

(3) When comparing the accuracy of height prediction with healthy volunteer, most error range between groups of height predictive results were comparable except higher error of knee height and sitting prediction in younger male. However, using demispan formula had tendency of more accurate (less error) than healthy volunteer.

(4) When comparing the accuracy of body weight prediction with healthy volunteer, most error range between groups of height predictive results were comparable except chest containing formula in some group patient (both C and C+Hp in younger male; C in elderly female).

5. Conclusion

Anthropometric measurements can be applied in clinical practice. Height, body weight and body fat predicted equations have been proposed. Race, age, gender and anthropometric measurement sites are independent factors to determine validity. This chapter reviewed the global availability of predicted formulas as well as model prediction created in Thai people. In addition, external validation using of simple formulas of height and weight prediction were performed in clinical situation and it were summarized.

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