

## Original Article

# Height prediction from anthropometric length parameters in Thai people

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Height is an important clinical parameter. However, there were no specific measurements available for particular clinical situations. Although many anthropometric measurements were suggested, no formula was recommended in Thailand. The objective of this study was to develop a formula for height prediction with acceptable validity. Two thousand volunteers were included and were divided consecutively according to both age and gender. Model and validation groups were further separated independently. Linear regression was analyzed to create a predictive formula. Ten parameters were included and analyzed. Of these, demispan, sitting height and knee height were selected with a correlation coefficient of more than 0.5 and significant F test in all age groups and genders. All single parameters and the highest predictive value of double (sitting and knee height) and triple regression models (demispan, sitting and knee height) were proposed and these were modified into a simple formula. After validation of both formulas the correlation, quantitative error and relative error were comparable. The simple formula had more than 90% precision with an error of up to 10 cm in the validation group (89.7 to 99.0% in range). Of these, knee height had the least predictive error in all subgroups. The double and triple models had decreased error only in the younger group. In summary, anthropometric parameters with demispan, sitting height, knee height and combination could be applied to height prediction in the adult Thai with acceptable error. These formulas should be applied only in people who could not be directly measured.

**Key Words:** anthropometry, body measure, body height, linear models, Thai

## INTRODUCTION

Height is an important clinically measured parameter along with BMI and body surface area calculation. These measurements play an inevitable part in drug dose adjustment, nutrition assessment and requirements, as well as for risk stratification.<sup>1-3</sup> Nevertheless, there are some limitations for obtaining this crucial information in special clinical situations such as immobilized patients, elderly people, emergency and critically ill patients. Of these situations, visual estimation is one of the most common methods to guess the patient height. However, this method has an unreliable result. A study of pre-operative supine patients used visual estimation for height by different observers demonstrating marked variation in the ability to assess these characters accurately.<sup>4</sup> 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.<sup>5-15</sup> With our best knowledge,

even though there are some studies of stature prediction in the Asian population, all of them focused on elderly people and there is no suggestive formula to predict height in Thailand.<sup>15-17</sup> Therefore, the objective of this study was to get a more appropriate model to predict height by anthropometric measurement in the adult Thai population.

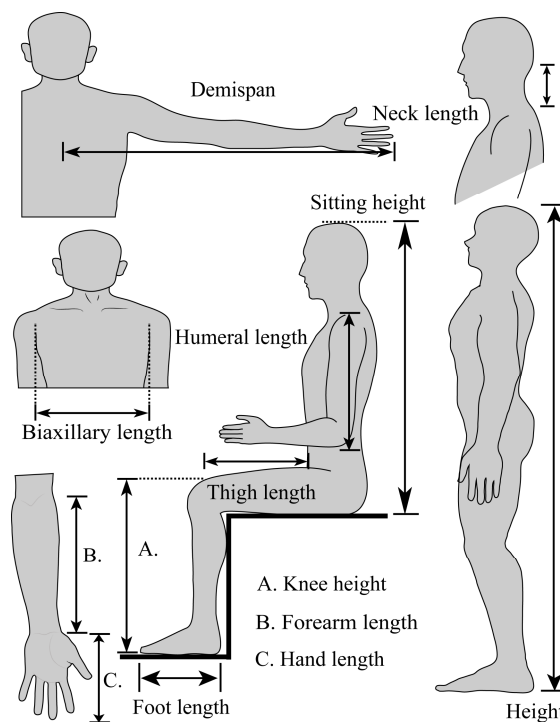
## MATERIALS AND METHODS

The authors enrolled healthy Thai volunteers by an invitation announcement in 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 anthropometric parameter and reliability testing was performed before data

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**Table 1.** Methods of anthropometric length parameter measurements

Parameters (cm)	Position	Point of measurement method
Height	Standing with bare feet	Vertically in midline from heel to vertex (the topmost position of the head)
Demispan	Supine or sitting with shoulder full extension laterally	At ventral surface, started from mid manubrium passed over shoulder, elbow and wrist to tip of third finger.
Biaxillary length	Supine or sitting with arm adduction close to body	At ventral surface, measurement side to side at the junction of deltopectoral groove and anterior axillary fold
Neck length	Sitting with fully neck extension	At posterior, started at external occipital protuberance to tip of spinous process of 7 <sup>th</sup> cervical spine (vertebral prominens at root of neck).
Humeral length	Supine or sitting with 90 degree elbow flexion	At lateral aspect, started point at tip of acromioclavicular eminent to tip of olecranon of elbow of non-dominant arm.
Forearm length	Supine or sitting with elbow extension	At palmar surface, started at olecranon process of elbow to the prominent bone of wrist (styloid process) of non-dominant arm.
Hand length	Supine or sitting	At palmar surface, started at last crease of wrist to tip of mid finger (3 <sup>rd</sup> finger) of non-dominant hand.
Sitting height	Sitting in fully erect posture	Vertically in the midline from upper border of sitting chair to vertex (the topmost point of the head). (Figure 1)
Thigh length	Sitting position or supine with 90 degree flexion of knee and 30-45 degree of hip	From mid inguinal point directed to upper border of patella on ventral surface.
Knee height	Supine or sitting with 90 degree flexion of knee and neutral of ankle	At lateral aspect, started point under the heel of foot and passed over the lateral malleolus to the upper most point of femur condyles. (about 4 cm. proximal to the patella).
Foot length	Supine or sitting	From the tip of heel at posterior to tip of first toe.

**Figure 1.** Measurement of anthropometric length parameters

collection. We excluded 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). This study was approved by the Faculty of Medicine, Chiang Mai University Ethics Committee.

We measured and collected height, demispan, biaxillary length, humeral length, forearm length, hand length, thigh length, knee height and foot length with a

standard measuring tape utilizing the same reference points. Details of the method of measurement were described in Table 1. All parameters were recorded in cm.

The estimated sample included was at least 200 healthy volunteers. However, age and gender were concerned as interactive parameters. Therefore, we further divided the age group into elder and younger group with a cut-off point for age at 60 year-old, based on the official retirement age in our country as well as our previous work which suggested significantly difference body composi-

tion in Thai people above this cut-off point.<sup>18</sup> With these determinations, we intended to collect at least 200 volunteers in each age group and gender. We expected incomplete data of about 20%. Therefore, we expected a data collection of 250 volunteers in each subgroup. Due to external validation after modeling, we also collected the same sample size for this purpose. Therefore, the overall sample was two thousand volunteers.

All of the continuous variable data between age group and gender 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 non-parametric continuous variables. The same groups with the different formula measurements of error and relative error were calculated using paired *t* test for normal distribution and Wilcoxon sign rank test for nonparametric continuous variables. The univariable and multivariable linear regression models were used to identify the relationship between independent variable(s) and height. A statistical difference was defined as *p*-value less than 0.05.

#### Parameters selection, modeling and validation

Two thousand volunteers were separated consecutively and independently into four groups by age group and gender. Each group was further consecutively divided into two groups, the model group and the validation group, which were independent with an equal size of volunteers.

For parameter selection, five-hundred volunteers in each group were used in these processes. These were performed first by testing the interaction of age group and gender based on a previous hypothesis. Parameters were decided via modeling selection by correlation value and significant model fitting R square test (F-test). We determined parameters which were put into the model prediction that should have a correlation coefficient of more than 50% and significant fitting model R square test in all subgroups.

After the parameters selection, modeling creation was performed by linear regression in each modeling subgroup sample of 250 volunteers. Individual and combination model were selected based on R square value, log likelihood, Akaike's information criteria (AIC) and

Bayesian's information criteria (BIC). Parameters which had multicollinearity 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.

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 percentages. 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, <5, 5-10, 10.1-20 and more than 20 % respectively. Agreements of two methods were tested by kappa statistics based on error level.

#### RESULTS

From May 2010 to May 2011, a total of two thousand volunteers were divided into groups of five hundred each in accordance with age group and gender. Eleven parameters of height, length and span were demonstrated in Table 2. Of these, all parameters were significantly different between gender and age group except humeral length, forearm length, hand length and thigh length between age groups in females. Of these differences, we suspected an interaction of these parameters to the height prediction model and beta coefficient which was tested in selected predicted parameters (knee height, demispan and sitting height). The authors found significant interaction within gender and the defined age group. Interaction between age and predictive parameters in each gender and age group of younger (<60 years) and older (≥60 years) individuals were tested again before formula creation. The authors found that there were no significant difference of interaction between age and predictive variables of knee height, demispan and sitting height in all subgroup. Therefore, the authors divided the prediction model in each age group and gender and did not add an age variable into the predictive parameters model. To select parameter to model, the authors' consideration was based on the correlation coefficient (*r*), R square value (*R*<sup>2</sup>) and F test which are demonstrated in Table 3 for each subgroup.

**Table 2.** Anthropometric length parameters by gender and age group

Measurement parameters (cm)	Male*			Female*		
	<60 yrs (n=500)	≥ 60 yrs (n=500)	<i>p</i>	<60 yrs (n=500)	≥ 60 yrs (n=500)	<i>p</i>
Height	166.1±6.0	162.1±7.2	<0.01	155.1±5.4	151.9±6.4	<0.01
Demispan	86.9±4.9	84.2±5.3	<0.01	79.9±4.1	79.4±4.5	0.05
Biaxillary length	38.8±3.5	36.3±3.6	<0.01	36.2±4.2	35.7±3.8	0.04
Neck length	10.3±1.2	9.8±1.2	<0.01	9.8±1.4	9.6±1.1	<0.01
Humeral length	36.3±3.4	34.2±4.6	<0.01	33.5±3.0	33.2±3.3	0.15
Forearm length	25.0±2.3	24.5±2.4	<0.01	23.2±2.0	23.1±2.1	0.45
Hand length	18.4±1.2	18.1±1.4	<0.01	17.1±1.1	17.2±1.2	0.28
Sitting height	85.9±3.9	82.2±5.3	<0.01	81.0±3.3	78.3±4.5	<0.01
Thigh length	39.3±4.0	38.7±3.7	<0.01	35.2±3.1	35.2±3.4	0.89
Knee height	48.6±3.3	47.3±3.7	<0.01	42.1±3.0	43.1±3.6	<0.01
Foot length	24.9±1.5	24.4±2.1	<0.01	22.5±1.3	23.0±1.7	<0.01

\* *p* <0.01 for all comparisons between males and females

**Table 3.** Correlation coefficient(r), adjusted R<sup>2</sup> and p-value for anthropometric length parameters and actual height

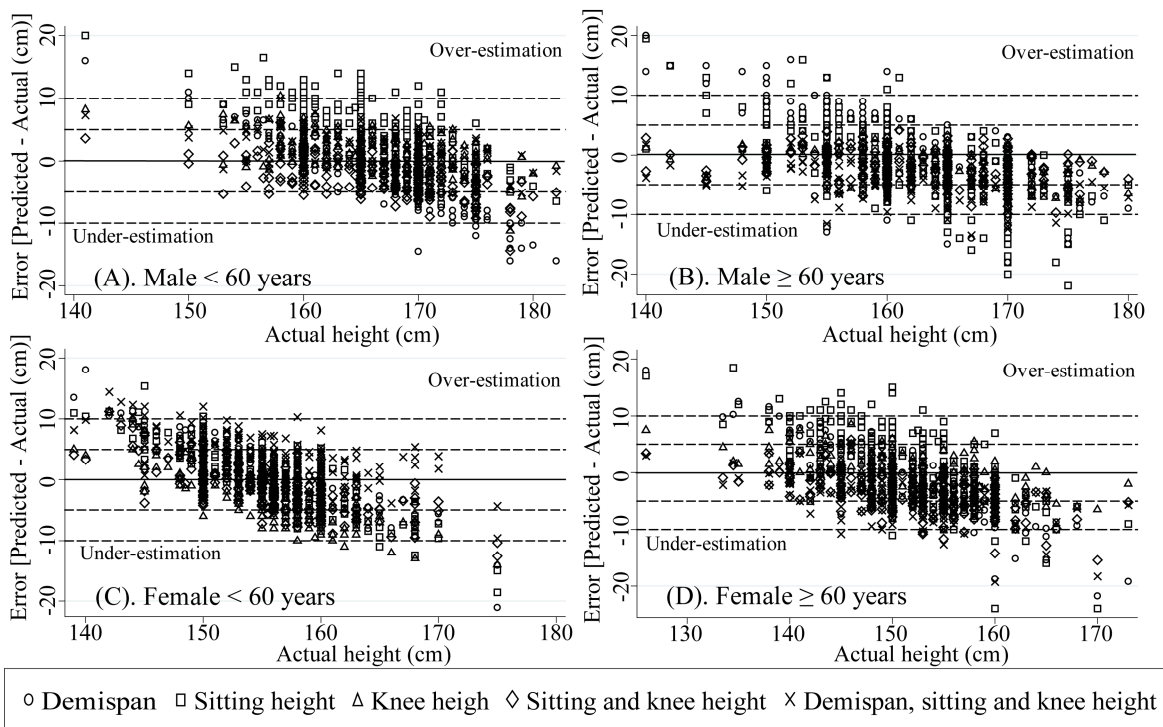
Measurement parameters	Male						Female					
	<60 yrs (n=500)			≥ 60 yrs (n=500)			<60 yrs (n=500)			≥ 60 yrs (n=500)		
	r	R <sup>2</sup>	p	r	R <sup>2</sup>	p	r	R <sup>2</sup>	p	r	R <sup>2</sup>	p
Demispan	0.55	0.27	<0.01	0.58	0.28	<0.01	0.52	0.30	<0.01	0.53	0.34	<0.01
Biaxillary length	0.20	0.04	0.96	0.35	0.08	0.48	0.20	0.04	0.58	0.28	0.12	0.15
Neck length	0.17	0.01	0.37	0.24	0.08	0.12	0.08	0.03	0.52	0.28	0.06	0.02
Humeral length	0.41	0.08	<0.01	0.30	0.10	0.05	0.28	0.16	0.03	0.31	0.09	0.72
Forearm length	0.35	0.08	<0.01	0.35	0.04	0.20	0.28	0.12	<0.01	0.21	0.12	0.76
Hand length	0.39	0.15	0.37	0.47	0.13	0.93	0.39	0.15	0.12	0.37	0.22	0.72
Sitting height	0.59	0.35	<0.01	0.54	0.27	<0.01	0.59	0.35	<0.01	0.52	0.29	<0.01
Thigh length	0.61	0.20	0.21	0.71	0.40	<0.01	0.44	0.37	<0.01	0.64	0.51	<0.01
Knee height	0.87	0.42	<0.01	0.91	0.72	<0.01	0.65	0.76	<0.01	0.85	0.84	<0.01
Foot length	0.43	0.22	0.10	0.51	0.17	0.01	0.48	0.19	<0.01	0.41	0.26	0.89

r= correlation coefficient, R<sup>2</sup>= Adjusted R-square

Only three parameters (demispan, sitting height and knee height) were chosen for model prediction which was previously mentioned in the selection criteria. Even though we did not include some parameters in the model prediction because there was less correlation coefficient and the F test was not significant in every subgroup, the humeral length, forearm length and thigh length had potential trends in some volunteer groups.

After parameter selection, model creations were performed by linear regression in the modeling group of 250 volunteers each. All single parameters were selected to create a regression model formula in each subgroup and demonstrated in Table 4. For double and triple parameters, the authors selected only the most beneficial in the additional parameter for outcome predictions by comparing R square, log likelihood, AIC and BIC in each model. The authors found that together the predictive model of double parameter between sitting height and knee height had

the highest predictive capacity with the above criteria in which R<sup>2</sup> in males and females were 0.79 to 0.82 and 0.68 to 0.71, respectively. In addition, these parameters also had the lowest AIC and BIC values when compared to the other double selected parameters model. For triple parameters, multicollinearity of parameter in model occurred when knee height and thigh length were combined in the model in the younger male group. The most predictable model of triple parameters included demispan, sitting height and knee height, which demonstrated the regression model in Table 4 in each subgroup. For these criteria, the authors proposed five models for height prediction in each subgroup. As the formula difficulty was a concern, the original regression formulas were adapted into modified simple formulas. The coefficient and intercepts were adjusted to the nearest integer number and produced better psychological understanding.



**Figure 2.** 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.

**Table 4.** Height prediction and error by regression and modified simple formula

Parameters	Regression formula <sup>†</sup>	r <sup>‡</sup>	E <sup>§§</sup>	RE <sup>§§</sup>	Simple formula <sup>†</sup>	r <sup>‡</sup>	E <sup>§§</sup>	RE <sup>§§</sup>
<b>Male&lt;60</b>								
D	118.75+0.55(D)	0.67	4.1±3.0* (-13.1/18.5)	2.5±1.9* (-7.3/13.1)	120+0.5(D)	0.67	4.4±3.3* (-16.0/16.0)	2.5±1.9* (-9.0/11.3)
S	88.60+0.90(S)	0.59	4.1±2.9* (-12.6/16.0)	2.5±1.7* (-7.2/11.3)	85+1.0(S)	0.59	5.9±3.9* (-8. /20.0)	2.5±1.7* (-4.6/14.2)
K	89.44+1.58(K)	0.87	2.5±1.8 (-12.7/8.7)	1.5±1.1 (-7.1/5.6)	90+1.6(K)	0.87	2.8±2.0 (-11.2/10.4)	1.68±1.3 (-6.5/5.6)
S+K	72.75+0.30(S) +1.40(K)	0.89	2.3±1.7* (-11.6/8.9)	1.40±1.1* (-6.5/5.6)	70+0.3(S) +1.4(K)	0.89	3.0±2.2 (-14.4/6.1)	1.8±1.3 (-8.1/3.9)
D+S+K	69.27+0.09(D)+ 0.27(S)+1.35(K)	0.90	2.2±1.7* (-12.6/8.3)	1.34±1.0* (-7.1/5.2)	70+0.1(D)+ 0.3(S)+ 1.3(K)	0.90	2.6±2.0* (-10.8/10.0)	1.5±1.2* (-6.1/6.3)
<b>Male≥60</b>								
D	83.80+0.92(D)	0.51	5.3±4.1* (-20.0/17.4)	3.2±2.5* (-11.7/12.4)	80+1.0(D)	0.51	5.1±4.1* (-18.0/20.0)	3.2±2.7* (-10.6/14.3)
S	79.93+0.99(S)	0.51	5.3±4.4* (-22.8/18.6)	3.3±2.6* (-13.0/13.3)	80+1.0(S)	0.51	5.2±4.2* (-22.0/19.5)	3.2±2.6* (-12.6/13.9)
K	80.31+1.73(K)	0.92	2.2±1.3 (-5.7/5.3)	1.4±0.8 (-3.3/3.4)	80+1.7(K)	0.94	2.4±1.9 (-7.6/3.6)	1.5±1.2 (-4.3/2.3)
S+K	64.90+0.29(S)+ 1.55(K)	0.92	2.3±1.5 (-8.3/5.6)	1.4±0.9 (-4.9/3.5)	65+0.3(S) +1.5(K)	0.93	2.6±2.0 (-9.9/4.2)	1.6±1.2 (-5.8/2.6)
D+S+K	53.56+0.29(D)+ 0.25(S)+1.33(K)	0.92	2.7±1.8* (-10.7/5.3)	1.5±1.2 (-6.4/3.5)	55+0.3(D)+ 0.2(S)+1.3(K)	0.93	4.6±2.6* (-13.5/2.1)	2.8±1.6* (-8.1/8.9)
<b>Female&lt;60</b>								
D	101.92+0.67(D)	0.65	3.6±3.0 (-21.5/17.5)	2.3±2.0 (-12.3/12.5)	100+0.7(D)	0.65	3.6±3.1* (-21.1/18.1)	2.4±2.1* (-12.1/12.9)
S	88.4+0.82(S)	0.56	3.7±3.1* (-18.5/15.6)	2.4±2.0* (-5.8/9.8)	90+0.8(S)	0.56	3.7±3.1* (-18.6/15.4)	2.4±2.0* (-10.6/10.6)
K	108.27+1.11(K)	0.70	3.2±2.6 (-10.1/14.0)	2.1±1.7 (-6.0/7.2)	110+1.0(K)	0.70	4.2±2.9 (-14.0/11.0)	2.7±1.8 (-8.0/7.7)
S+K	74.41+0.52(S) +0.92(K)	0.77	2.9±2.3* (-10.5/13.0)	1.9±1.5* (-6.0/9.2)	75+0.5(S) +0.9(K)	0.76	3.3±2.4* (-12.6/11.2)	2.1±1.5* (-7.2/7.8)
D+S+K	60.36+0.30(D)+ 0.45(S)+0.80(K)	0.79	3.1±2.4 (-10.5/10.3)	2.0±1.5 (-6.0/7.2)	60+0.3(D)+ 0.5(S)+ 0.8(K)	0.81	3.9±2.9 (-9.6/14.3)	2.5±1.9 (-5.4/10.1)
<b>Female≥60</b>								
D	96.82+0.70(D)	0.57	4.4±3.5* (-20.0/19.8)	3.0±2.4* (-11.4/9.9)	95+0.7(D)	0.57	4.5±3.5* (-21.8/18.0)	2.9±2.3* (-12.8/14.3)
S	73.5+1.00(S)	0.46	5.0±3.9* (-25.5/17.0)	3.3±2.5* (-15.9/12.6)	75+1.0(S)	0.46	5.1±4.0* (-24.0/18.5)	3.4±2.7* (-15.0/13.8)
K	87.49+1.50(K)	0.87	2.71±1.94 (-6.0/9.0)	1.8±1.3 (-3.9/6.3)	87+1.5(K)	0.87	2.7±1.9 (-6.5/8.5)	1.78±1.31 (-4.2/6.0)
S+K	64.36+0.43(S) +1.25(K)	0.87	2.6±2.0 (-11.4/10.0)	1.7±1.3 (-6.7/6.8)	65+0.4(S) +1.2(K)	0.87	4.1±2.8* (-15.4/ 5.8)	2.7±1.8* (-9.1/4.0)
D+S+K	52.19+0.24(D)+ 0.41(S)+1.14(K)	0.87	2.6±2.2 (-13.4/5.8)	1.7±1.5 (-8.4/6.6)	50+0.2(D)+ 0.5(S)+1.0(K)	0.85	4.1±3.0* (-19.3/5.4)	2.7±1.9* (-12.1/3.7)

<sup>†</sup> Formula derived from modeling groups (250 in each subgroup), <sup>‡</sup> Correlation coefficient and error calculated from validation groups (250 in each subgroup). <sup>§</sup> Mean±S.D. (minimum / maximum), \* *p*<0.05 when comparing to knee height model error or relative error.

r= correlation coefficient, E= Absolute error (cm), RE = Relative error [Relative error=(Predicted height – Actual height) x 100/(Actual height)], D=Demispan, S=Sitting height, K=Knee height, S+K= Sitting and Knee height, D+S+K= Demispan, sitting and knee height.

In the regression model, the correlation co-efficient ranged from 0.46 to 0.92. 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 for the demispan model in the younger

female group. Although the reason for this phenomenon is unknown, there was also a tendency for difference in both error and relative error with  $p$ -value as 0.10. 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.

For simple formula validation, in which intercepts and coefficients were adjusted, correlative coefficient, error quantity and relative error between original and modified formulas were calculated and compared. The correlation coefficients in each formula were comparable. In addition, 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 2 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 10% were 5.7, 9.5, 1.0, 1.1 and 2.6% respectively. The authors further stratified actual height into three groups (shorter, normal and taller groups which was defined as less than 140, 140-160 and more than 160 cm, respectively). Of these criteria, there were trends of over estimation in the sample that had an actual height of less than 140 cm, while under-estimations were observed in an actual height of more than 160 cm. Most of prediction error of more than 10 cm occurred in the demispan and sitting model (under-estimation 3.4 and 3.8%, over-estimation 2.8 and 6.5%, respectively) while the other modified simple models had up to 1.7% over and under-estimation.

## DISCUSSION

Even though height is an important parameter in clinical practice there are limitations in some clinical situations. Anthropometric measurements for height prediction were suggested to solve this problem and many formulas have been reported. These measurements included sitting height, demispan, arm span, ulnar length, hand dimensions and knee height.<sup>5,8-9,11-17</sup> However, ethnic differences, gender and age are a major concern in this regard for application and external validation for other populations. In Asian groups, one Malaysian elderly prediction model had reported and confirmed significant differences between it and other ethnic groups. In addition, these deviations also occurred within other Asian models.<sup>16</sup> For this reason, as well as a lack of Thai data reported for these relationships, the authors designed these anthropometric measurements to propose an appropriate and simple relation model with acceptable validity for height prediction in the adult Thai population.

The authors endeavored greatly to simplify the formula. Therefore, a stratified prediction model based on an interaction term might achieve these purposes. Of these, both gender and age groups were tested, and revealed significant interactions among the anthropometric parameters and height prediction. These findings are comparable to

previous studies.<sup>15-17,19</sup> Although previous formulas proposed by Chumlea *et al.* using knee height and age as predictive variables for height prediction have been proposed in elderly western people.<sup>13</sup> The age variable was not included into prediction formulas in our models because there was no significant interaction between age and predictive variables of knee height, demispan and sitting height after subgroups were divided by gender and age group. In addition, error and relative error on increasing age had no correlation error in each of our validation subgroups.

For the selection of anthropometric predictors, at least six parameters were suggested that could be a single independent variable to stature prediction but the present study showed only three parameters (demispan, sitting height and knee height) in all subgroups.<sup>5,8-9,11-17</sup> However, humeral length and forearm length might be predictors in younger volunteers according to the present data. Although there is no exact theoretical clarification, these phenomenon might be explained by vertebral degenerative changes in the elderly while the arm length remains stable.<sup>15</sup> Thigh length was the other interesting predictor in the elderly. However, the authors did not select this variable in their prediction model for two reasons. Firstly, there was no significant alteration (F test;  $p$  value) during the model selection process in the younger male group. In addition, there was a multicollinearity effect with other parameters in the double and triple predictor model, especially with knee height. Secondly, there were variations of measurement between measurers due to difficulty in landmark location in fat volunteers and is precision depended on the hip and knee position.

The authors created regression models with 1000 volunteers (250 in each group). Of these, simple regression models were modified from the original regression formula. Both formulas were validated with the other 1000 volunteers (250 each). Correlation, quantitative error and relative error were comparable and produced acceptable results between the original and simple formulas. In the single parameters group, knee height had the highest correlation and less error compared to the others within the groups. Therefore, the knee height models were used as references for comparing errors between formulas in each subgroup. Double and triple parameters might decrease error in only some subgroups. However, contrast results occurred in the elderly male and female groups. (Table 4)

The simple model had more than 90% precision with error up to ten cm in the validation group (89.7 to 99.0% in range). Of these, the precision error occurred differently and depended on the actual stature. The shorter group had more over-estimation while vice versa was observed in higher group, and negative correlation was significant in all subgroups (Figure 2). These correlations had the same direction with a recent Italian study on middle aged volunteers by knee height prediction.<sup>19</sup> However, these were different from a previously reported elderly Chinese arm span model which demonstrated negative correlation error only in the male gender.<sup>15</sup>

Although the authors endeavored to control and monitor every step of the investigation process as well as during data analyses, there were some inevitable limitations. Firstly, 95% 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. Secondly, 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. Thirdly, model creations were performed based on healthy subjects. Although we endeavor to propose several length variables for height prediction and we expected these might be applied to subjects with unknown height. However, external validation into diseased patients should be performed in future studies. Finally, there was an unequal distribution in terms of age, nearly 60% of subjects were between 60-70 years of age; although there was no significant interaction between age and the measured parameters. In addition, distribution of error in each gender and age group were equally scattered. However, future study for external validation and precision might be over or under estimating in elderly people age more than 70 years. Therefore, the authors suggested the utilization of these formulas should be applied only for unavailable stature data in specific clinical situations.

In conclusion, anthropometric parameters with demi-span, sitting height, knee height and combination could be applied for height prediction in the adult Thai population. Although knee height had the highest precision as a single predictive parameter others parameters were also proposed with acceptable error. A combination of double and triple model might decrease 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 when direct measurement of height is not possible.

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#### AUTHOR DISCLOSURES

All authors have no conflict of interest. This study was a part of thesis in the epidemiology PhD project of Assistant Professor Kaweesak Chittawatanarat.

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## Original Article

## Height prediction from anthropometric length parameters in Thai people

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### 藉由體長參數預測泰國人的身高

身高為一個重要的臨床參數。然而對於特定的臨床狀態，卻沒有一個專一的測量方法。雖然有許多體位測量方法被建議用來估量泰國人民的身高，但尚未有一個公式用於計算身高。這篇研究之目的在於發展出一個有效且能用以預測身高的公式。將 2000 位自願者根據年齡及性別加以區分。模式組及效度組再進一步獨立區分。用線性迴歸分析產生預測模式。共測量 10 個參數並放入分析。在這 10 個參數當中，中指尖到胸骨中心的距離、坐高及膝高與身高的相關係數，無論在男性或女性，及在各年齡層均大於 0.5，且皆具有顯著相關。接著提出這 3 個參數單獨、具有高預測值的雙變項(坐高與膝高)及三變項的迴歸模式，並加以修飾成簡化的公式。在進行原始及簡化公式的效度檢測後，發現兩者在相關係數、量性誤差及相對誤差都不相上下。按照誤差上限 10 公分的條件下，簡化的公式在效度組有大於 90% 的精確度(範圍是 89.7% 至 99.0%)。而這些單獨變項中，膝高在各組別有最小的預測誤差。雙變項及三變項模式只有在年輕族群有降低誤差。總結而論，體位參數中以中指尖到體中央的距離、坐高、膝高以及兩者或三者合併模式可用來預測泰國成人的身高，而其誤差是可以被接受的範圍。但這些公式應只被用於無法直接測量身高的人。

**關鍵字：**體位、體位測量、身高、線性模式、泰國人