

Original Article

Use of knee height for the estimation of body height in Thai adult women

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Knee height has been the most frequently used measure for height prediction where full height is difficult to measure. The aim of this study was to develop and validate predictive equations using knee height to estimate the height of Thai women. The female participants were 18-59 years of age and lived in Bangkok or three surrounding provinces. They were assigned to one of two groups; the equation development group (n=488) and the equation validation group (n=188). Standing height and knee height were measured in duplicate using a stadiometer and a knee height calliper. Age and physical characteristics of the equation development group and the validate group were comparable. The measured heights showed a significant strongly positive correlation with the mean knee height ($r=0.84$, $p<0.001$). Mean knee height in a regression model exhibited the most accurate height prediction (adjusted $R^2=0.718$, standard error of estimate=2.80), according to the equation "Height=38.1+2.45 (average knee height) - 0.051(age)". This study proposes a new height estimation equation for Thai adult women using knee height. The equation shows more estimation power than the previous studies conducted in Thailand.

Key Words: actual height, estimated height, knee height, Thai women, validation

INTRODUCTION

Determining an individual's height accurately is important because height is a crucial factor for predicting essential nutritional status indicators, including body mass index (BMI), basal metabolic rate and body composition. Measuring height can be difficult, however, with individuals who are disabled, who cannot stand or who have some physical anomalies such as spasticity, contractures, amputations, or paralysis. It also may be difficult in elderly people with spinal curvature. Therefore, surrogate height measurements—e.g., ulnar length, demi-span, arm span, and knee height—are used to predict height via selected anthropometric measurements. Knee height shows a strong correlation with body height with little error and is the best predictor of body height.^{1,2} To measure knee height, a calliper with an adjustable measuring stick is used. The subject may be in a sitting or supine position with the knee bent at a 90° angle.^{3,4}

Various researchers have proposed predictive knee height equations in different countries for different groups of people.^{1,2,5-15} In Thailand, two studies have formulated knee height equations. However, there were some limitations to these studies. Jitapunkul and Benchajareonwong in 1998 studied a group of inpatients 15-79 years old, which is a wide range and may have affected results.⁵

Chittawatanarat et al in 2012 conducted a study using volunteers in northern Thailand.¹ The Chumlea model, with knee height and age as predictor variables, was the best stature predictor for sex- and racial/ethnic-specific groups.² The equations from the previous studies, however, may not be appropriate for adult Thai women across the whole country. The objective of this study was to develop an equation for estimating body height more accurately than previous studies for this segment of the Thai population.

MATERIALS AND METHODS

A cross-sectional study was conducted between September 2013 and April 2014. A total of 619 participants 18-59 years old living in Bangkok and nearby provinces (in-

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cluding Samut Prakan, Nakorn Pathom, and Pathum Thani) were enrolled in the study. The study group was a good representation for the whole country as people from different regions in Thailand frequently move to Bangkok and its vicinity.

The study excluded women with kyphosis, those unable to stand upright while measuring height, and those with amputated lower limbs or any incidences of bone injury or bone surgery. Participants were divided into a validating group and a predictive equation development group. The participants were assigned random numbers to determine their group. The subjects in the first 20% of the sorted set of random numbers were assigned to be the validating group (n=124). The rest were assigned to the predictive equation development group (n=495).

The participants who had outlier values of age, body height, or knee height in the study were excluded (n=13). The final number of participants in the equation developing and validating group were 488 and 118, respectively. Body height and left and right knee height measurements were obtained twice for each subject. The averages of the two measurements of each left and right knee heights were calculated for each individual. The reliability of the trained research assistants' work was determined using the intra-class correlation coefficient (ICC) (range 0.93-0.97). Standing height was measured using a free-standing stadiometer according to the following guidelines: (1) The participant was barefoot, without any socks, and stood straight with the head facing forward and shoulders relaxed. (2) The arms hung loosely at the sides, with the palms facing forwards. (3) The feet were together, and the knees were straight. (4) The heels, buttocks and shoulder blades of the sample touched the vertical backboard of the stadiometer. (5) During measurement, the subject took a deep breath and stood still.

A knee height calliper was used to measure both right and left knees according to the following guidelines: (1) The subjects sat on a chair with the knee at a 90° angle. (2) The fixed calliper was positioned under the heel of the foot, and the movable calliper was positioned on the anterior surface of the thigh above the femoral condyle and proximal to the patella. (3) Measurements were repeated in cases where the results differ by >0.4 cm. The research protocol has been approved by the Ethics Committee of

Faculty of Tropical Medicine, Mahidol University, Thailand (TMEC 13-039).

The mean and standard deviation (SD) of the continuous data were determined. The intergroup comparisons were performed using an independent sample *t*-test. The associations between outcome variables were determined by Pearson's correlation coefficients. Statistical differences were considered significant at $p < 0.05$. The equation for predicting the height was developed using linear regression model. R^2 and standard error of the estimate (SEE) were analyzed to determine the predictive ability of the equation. The ICC with 95% confidence interval (95% CI) was used for the concordance relation between actual height and estimated height. Two previous predictive equations for age, actual height, and knee height in Thailand are shown in Table 1.

RESULTS

Age, height, and knee height of the entire study group

Although the region studies included Bangkok and the surrounding area, the majority of the enrolled participants (57.3%) were originally from other areas of the country: northern (8.8%), southern (5.8%), northeastern (22.9%), eastern (4.5%) and central (15.3%) Thailand. The ages and physical characteristics of the subjects are shown in Table 2. There were no significant differences in mean age, body height, or knee height between the equation developing group and the validating group.

Correlation of age, height, and knee height of the equation developing group

The actual height showed a significant and strong positive correlation with the average knee height ($r=0.841$, $p < 0.001$). The age of the participants in this study showed a significant negative correlation with actual height and average knee height ($r=-0.383$, and -0.329 , respectively, both $p < 0.001$).

Equations development

Two regression models and the other two previously reported model^{1,5} to estimate height for Thai women are shown in Table 3. The models derived from the present study included a model to estimate the Thai woman's height using average knee height and age as the predictor

Table 1. Previous predictive equations in Thailand for age, actual height, and knee height (KH)

Study	Equation	Age (years)	Actual height (cm)	KH
Jitapunkul & Benchajareonwong ⁵	$H=71.6+1.81$ (KH)	47.6 (15.9) [†]	161 (6.8)	46.8 (2.5)
Chittawatanarat et al ¹	$H=108+1.11$ (KH)	<60	155 (5.4)	42.1 (3.0)

H: height; KH: knee height.

Results are given as the mean (SD)

[†]Range 15-79 years

Table 2. Physical characteristics of the study group

Variables	All (n=606)	Equation developing group (n=488)	Validating group (n=118)	p^{\dagger}
Age (years)	27.7 (12.3)	27.8 (12.4)	27.4 (12.2)	0.753
Height (cm)	158 (5.2)	158 (5.3)	157 (4.9)	0.075
Average KH	49.3 (1.8)	49.3 (1.8)	49.2 (1.6)	0.465

KH: knee height.

[†]Independent *t*-test.

Table 3. R² and SEE of the equations and results for mean, SD, 95% CI result of the estimated height

Equations	Adjusted R ²	SEE	Estimated height (n=118)			
			Mean	SD	95% CI of mean	
					Lower	Upper
Actual height (n=118)			157	4.9	156	158
Present study						
H=30.8+2.57(KH)(Av)	0.706	2.83	157	4.7	156	158
H=38.1+2.45 (KH)(Av)-0.051(age)	0.718	2.80	157	4.6	156	158
Previous study						
H=71.6+1.81(KH) ⁵	-	-	161	3.3	160	161
H=108+1.11(KH) ¹	0.70	-	163	2.0	162	163

SEE: standard error of the estimate; H: height; KH: knee height; Av: average.

Table 4. Power of validation of the equations

Model	Mean difference	SE	95% CI of mean difference		<i>r</i>	ICC	95% CI of ICC	
			Lower	Upper			Lower	Upper
Present model	-0.27	0.24	-0.76	-0.21	0.84	0.842	0.780	0.892
Previous model								
Jitapunkul & Benchajareonwong ⁵	-3.78	0.27	-4.31	-3.26	0.82	0.760	0.672	0.827
Chittawatanarat et al ¹	-6.07	0.32	-6.70	-5.45	0.82	0.580	0.444	0.687

r: pearson's correlation; ICC: intra-class correlation.

variables and another model using only average knee height. When comparing the predictive power of each equation (adjusted R²), we found that the model using average knee height and age was the most accurate for predicting height (adjusted R²=0.718).

Height and estimated height

Estimated heights were calculated according to the two equations from this study and the other two previously reported equations, as shown in Table 3. The power of the estimated height equations from previously reported models differed from the actual height and the estimates from the two new equations formulated during this study. The best equation, which includes average knee height and age, was selected to examine difference in validity (mean bias) and was compared with two existing prediction equations by scatter-plotting (Figure 1). The mean difference was equal to zero when the estimated values were identical to the individual's actual height. The two existing predictive equations showed scattered points distributed more negatively away from zero than did the selected equation from the present study. The estimated height from the previous studies showed relatively more overestimation than the estimated height derived from the present study.

Validating the estimated height derived from knee height

The mean difference of the present predictive equations was -0.27 from the actual height, which was more accurate than the previous equations, which both had higher mean differences. The correlation coefficient (*r*) and ICC results indicated a relation between the actual height and knee height-estimated equations (Table 4). The degree of agreement was computed using the ICC to demonstrate the relation between the actual height and the knee height measurements. The ICC of the developed equations in this study was 0.842, demonstrating a high degree of agreement.¹⁶ Although two previous studies' equation

models showed high correlation coefficient (*r*), they did not demonstrate a high degree of agreement according to ICC analysis.

A Bland and Altman plot was used to illustrate the spread of differences of measured height and predicted height with the upper and lower limits of agreement against the mean of measured height and predicted height (Figure 2). Figure 2a was derived from the present predictive model. Figure 2b and 2c demonstrate two previous models, reported in 1998 and 2012. The effect of age on the individual prediction error was plotted and is shown in Figure 3. The points of present predictive model (Figure 3a) and the two previous models (Figure 3b and 3c) were scattered along a zero difference line.

DISCUSSION

Standing height is the gold standard of height measurement, but it is impossible to measure in individuals who are physically disabled or cannot stand upright. Several published studies have explored knee height as an alternate method for estimating height as it can be performed quickly and by one person. Knee height should therefore be considered a simple, reasonable, accurate method for height estimation. The accurate construction of a predictive equation needs to be developed as the most appropriate means possible and then validated by selecting suitable subjects and considering the influences of all possible factors. In the present study, a new equation was developed after considering those factors and was successfully validated.

This study's results showed that the average subject's height was 147 cm shorter than that of the similar study conducted in 1998 but taller than the results from the study in 2012.^{1,5} In this study, participants' knee height outcomes were greater than those in both previous studies. Almost all previous studies in this area have measured the left knee only.⁶⁻⁹

Chumlea et al were the first to develop equations to estimate height using the right knee, and they recommended

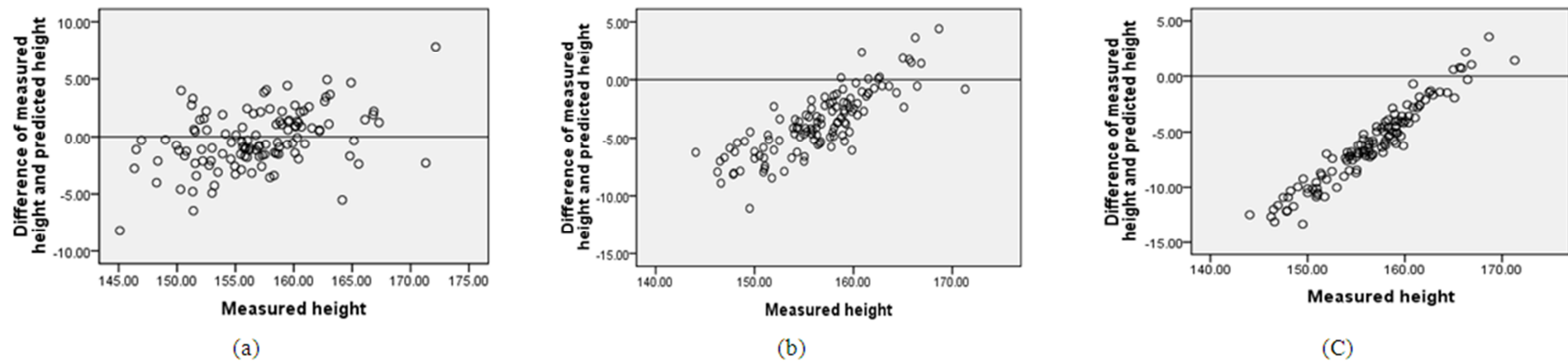


Figure 1. Plot of the difference in the measured heights and predicted heights against actual heights. a=present model. b=1998 model. c=2012 model.

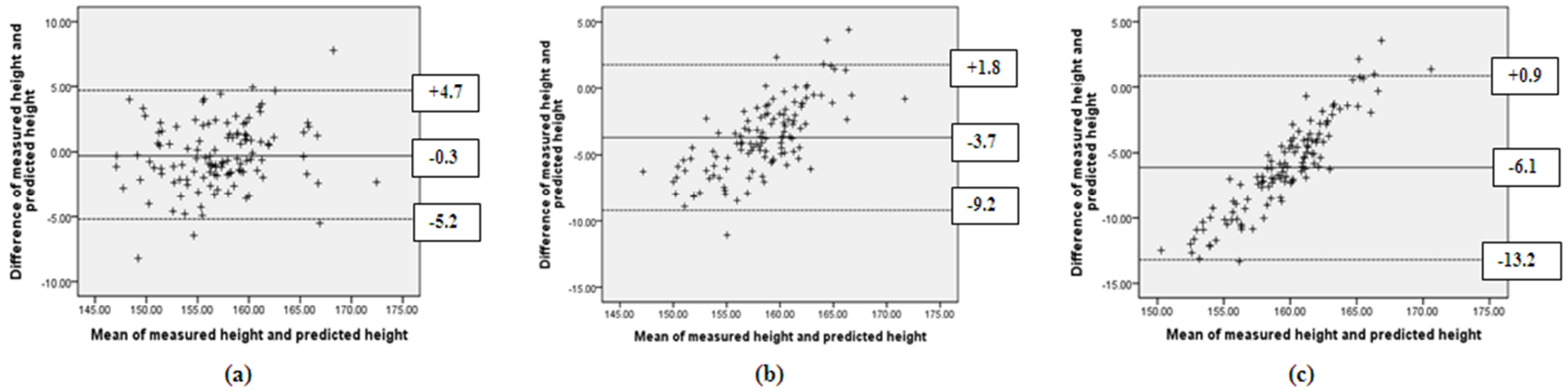


Figure 2. Bland and Altman plots of the difference in the measured heights and predicted heights against the mean of the measured heights and predicted heights. a=present model. b=1998 model. c=2012 model.

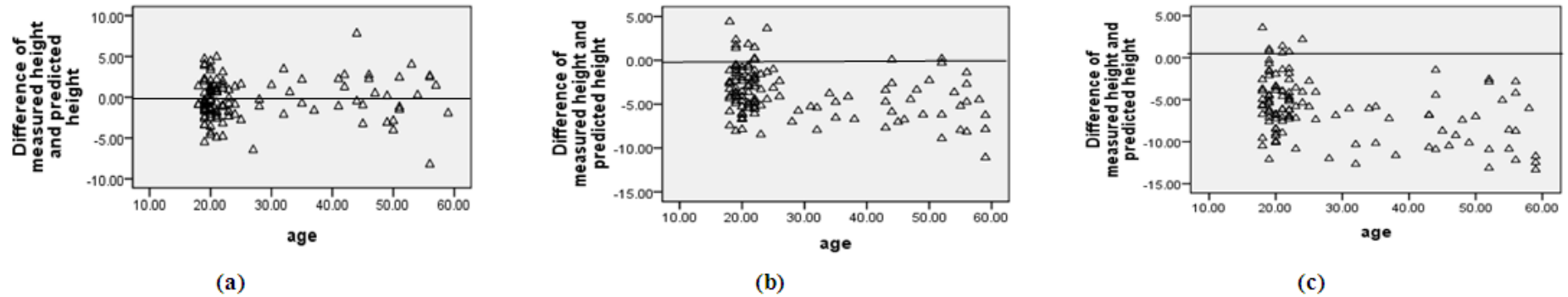


Figure 3. Plots of the difference of the measured heights and predicted heights against age. a=present model. b=1998 model. c=2012 model.

that right side of the body be used for anthropometric measurements.^{2,3} Berger et al reported that right and left knee heights were practically identical.¹⁰ This study assessed both the left and right knee heights as well and found no significant difference.

The mean actual body height showed a significant, strongly positive correlation with the left, right, and average knee heights. Aging has been shown to be associated with height reduction, supported by significant negative correlations of age and actual height, and the left, right, and average knee height. The results in this study were in line with those of other studies.^{5,11-13} This shows that the relation between age and actual body height should be used as a variable in models for estimate height and should exhibit higher prediction power. The SEE from the final model in this study, which includes age and average knee height (Table 3), was 2.8. Therefore, the average distance of the data points from the fitted line was about 2.8 cm.

Some previous models from other countries had included age as a variable.^{11,14,15} Zhang et al found a negative correlation between height and age, and they included age in a height predictive model.¹¹ Li et al conducted a Chinese-based study that developed a knee height-to-stature regression model and included age as a variable.¹⁴ Hwang et al also developed a height predicting formula using knee height and age as variables in female Korean subjects.¹⁵ The model in this study that incorporated age showed a higher predictability than knee height alone. Unfortunately, previous models for Thai populations did not take age into account.

We developed a new predictive equation for height by collecting more samples than previous studies and sampling only adult women. The present model showed a higher degree of agreement than existing models, especially when using age as a variable. The equations derived from average knee height in this study provided only slight differences in predictive power between the left and right knees, which mean that either knee may be used for height-prediction measurements.

The present estimated height equation may be more representative for the whole Thai adult female population than previous studies because participants in this study lived in or near the capital but had migrated there from other areas of Thailand.

One limitation of the study was having a study group with a relatively large age range, which presented the risk that the results might be biased because of secular effects. In the younger women, the proportion of knee height to body height could be different – not because of age but as such but as a result of secular growths changes. For example, the current younger generation might have suffered less from stunting, which is related to relative leg length and thus knee height. In this study, we excluded participants who were outlier in regard to age, height, and knee height because the height calculation might be inaccurate due to stunting that occurred during their childhood.

Conclusion

The purpose of this study was to provide a new predictive equation to calculate body height from the knee height in

Thai adult women. This equation can be applied to obtain an accurate height estimate in clinical and field settings. The present equations show closer agreement with actual height than previous equations. This study found that knee height and age was the most significant predictor variables needed to estimate total height. It was also shown that either knee could be used to provide an accurate evaluation.

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AUTHOR DISCLOSURES

The author has no conflict of interest to disclose.

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在泰国成年女性中用膝盖高度估计身高

当身高难以测量时，膝关节高度常被用于身高预测。本研究的目的是使用泰国妇女膝盖高度估计身高并验证预测方程。选择年龄在18-59岁之间，居住在曼谷或周边三省的成年妇女作为研究对象。将研究对象分配到两组中的一组，方程拟合组（488例）和方程验证组（188例）。使用测距仪和膝盖高度卡尺测量站高和膝盖高度。拟合组和验证组的年龄和身体特征具有可比性。测得的身高与平均膝盖高度呈显著正相关（ $r=0.84$ ， 0.001 ）。在回归模型中膝盖高度对身高具有最准确的预测价值（调整 $R^2=0.718$ ，标准误差=2.80），根据公式“高度=38.1+2.45（平均膝盖高度）-0.051（年龄）”。这项研究提出了利用泰国成年妇女膝盖高度估计身高的新的估计方程。该方程比以前在泰国进行的研究具有更高的估计能力。

关键词：实际身高、估计身高、膝关节高度、泰国女性、证实性