

# Estimation of Adult Stature Based on Patella Morphology in a Korean Population: Postmortem Computed Tomography-based Study

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**Abstract** : The purpose of this study was to present a regression model to predict stature through the morphological analysis of the Korean patella using postmortem computed tomography (PMCT) data, thereby understanding the anatomical and forensic characteristics of Koreans and securing basic data for this population. This study analyzed PMCT images of 146 subjects (72 males, 74 females) taken at the National Forensic Service between January and December 2022 from the Korean population. The PMCT images were reconstructed into 3D images using the Mimics program, and the morphology of the patella was also measured using this program. We measured six variables of the right patella: PMH (Patella maximum height), PMW (Patella maximum width), PMT (Patella maximum thickness), AFRH (Articular facet ridge height), MAFW (Medial articular facet width), and LAFW (Lateral articular facet width). The average stature was  $1637.91 \pm 87.75$  mm overall,  $1692.92 \pm 75.31$  mm for males, and  $1584.39 \pm 62.36$  mm for females. The overall mean of the measurement variables was  $41.39 \pm 3.80$  mm for PMH,  $44.99 \pm 3.86$  mm for PMW,  $21.56 \pm 1.84$  mm for PMT,  $27.11 \pm 2.76$  mm for AFRH,  $20.64 \pm 2.50$  mm for MAFW, and  $28.03 \pm 2.45$  mm for LAFW. All measured variables were significantly longer in males than in females ( $p < 0.001$ ). Predictive models for stature (y, mm) based on the patella measurement variables (x, mm) were derived with the following results ( $p < 0.001$ ):  $S = 999.506 + 15.425\text{PMH}$ ,  $S = 963.482 + 14.989\text{PMW}$ ,  $S = 1002.098 + 29.488\text{PMT}$ ,  $S = 1293.621 + 12.700\text{AFRH}$ ,  $S = 1287.435 + 16.977\text{MAFW}$ ,  $S = 995.903 + 22.903\text{LAFW}$ . We proposed a Korean-specific regression model for estimating stature based on patella morphology measurements, and this model could be suitable and useful for Koreans in forensic anthropology and clinical practice.

**Keywords** : Patella, Stature estimation, Postmortem computed tomography, 3D reconstruction

## INTRODUCTION

Patella, from the Latin word meaning “small plate,”

is the largest of the sesamoid bones. It is located on the anterior articular surface of the knee joint and has a flat, inverted triangular shape. The patella is formed within the

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tendon of the quadriceps femoris muscle and anatomically acts as a pulley [1]. This structure makes the patella robust and resistant to postmortem changes, making it useful for individual estimation purposes [2]. Additionally, the size and shape of the patella vary depending on the strength and size of the muscle mass, and since males have relatively larger muscles than females, it is possible to predict that sexual dimorphism will occur [3].

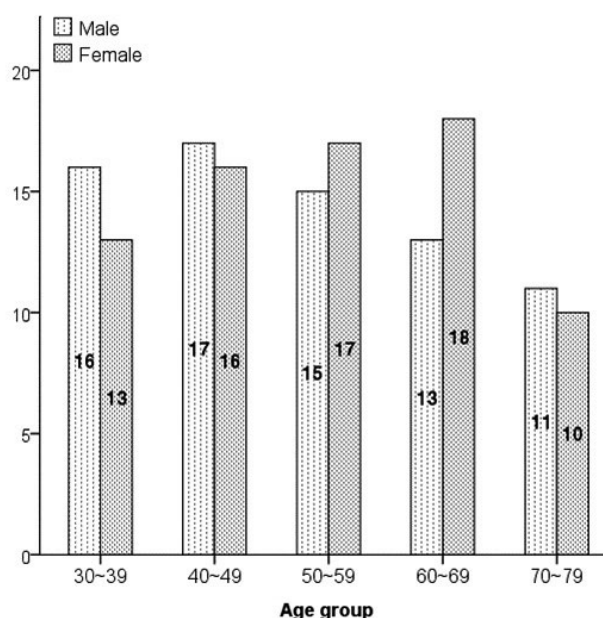
Identifying individuals from skeletal remains is one of the most important anatomical, anthropological, and forensic problems [4]. The components mainly utilized for individual estimation are sex, age, stature, and ethnicity, and for this purpose the human skull or pelvis is mainly used [5,6]. However, when the bones mentioned above are damaged or broken, or in situations involving large-scale disasters, wars, or major accidents, they may need to be replaced with bones other than the skull and pelvis [6]. There are several ways to estimate an individual's identity, and standard methods are based on morphological and quantitative methods, but these can vary depending on the subjectivity of the researcher. Therefore, research methods that objectively verify using statistical analysis of quantitative measurement results are mainly preferred [7]. In modern times, it is based on radiological examinations such as computed tomography (CT) or magnetic resonance imaging (MRI), and measuring with a 3D program using data based on this can be a more objective and accurate method [7].

Morphological analysis of patella has been commonly used to determine sexual dimorphism using discriminant function equations [8]. However, previous reports on sexual dimorphism performed on the patella in Koreans are very rare [3,9-12]. In particular, there are very few previous reports suggesting a regression model to estimate stature by analyzing patella morphometric measurements.

The purpose of this study was to present a regression model that can predict stature through morphological analysis of Korean patella using postmortem computed tomography (PMCT) data, thereby understanding the anatomical and forensic characteristics of Koreans and securing basic data for them.

## MATERIALS AND METHODS

This study analyzed PMCT images of 146 subjects (72



**Fig. 1.** Sex and age distribution of Korean PMCT images (n = 146). PMCT, postmortem computed tomography.

male, 74 female) taken at the National Forensic Service between January and December 2022 from Korean population. The study was approved by the Ethics Committee of the National Forensic Service (Institutional Review Board number: 906-211116-HR-003-02). The average age of the subjects at the time of imaging was 53.2 (Range: 30~79) years (Fig. 1). All patella used for measurements were of the right side. PMCT images showing fractures, injuries, deformities, or signs of surgery in the knee region were excluded. The study utilized images from deceased individuals whose primary cause of death was unrelated to the lower limbs.

### 1. PMCT image and data acquisition

In this study, examinations were conducted using the PMCT (Aquilion PRIME TSX-303A, CANON Medical Systems Corp., Tokyo, Japan) equipment at the headquarters of the National Forensic Service. The imaging parameters were set to a tube voltage of 120 kVp, a pitch factor of 0.637, a slice thickness of 1.0 mm, an increment of 0.8 mm, and a rotation time of 0.6 seconds. To optimize bone contrast and sharpness in all images, measurements were performed under bone settings (Window width 1500, window level 500). The PMCT images were provided in DICOM file format. For 3D modeling of the patella, Mimics (Version

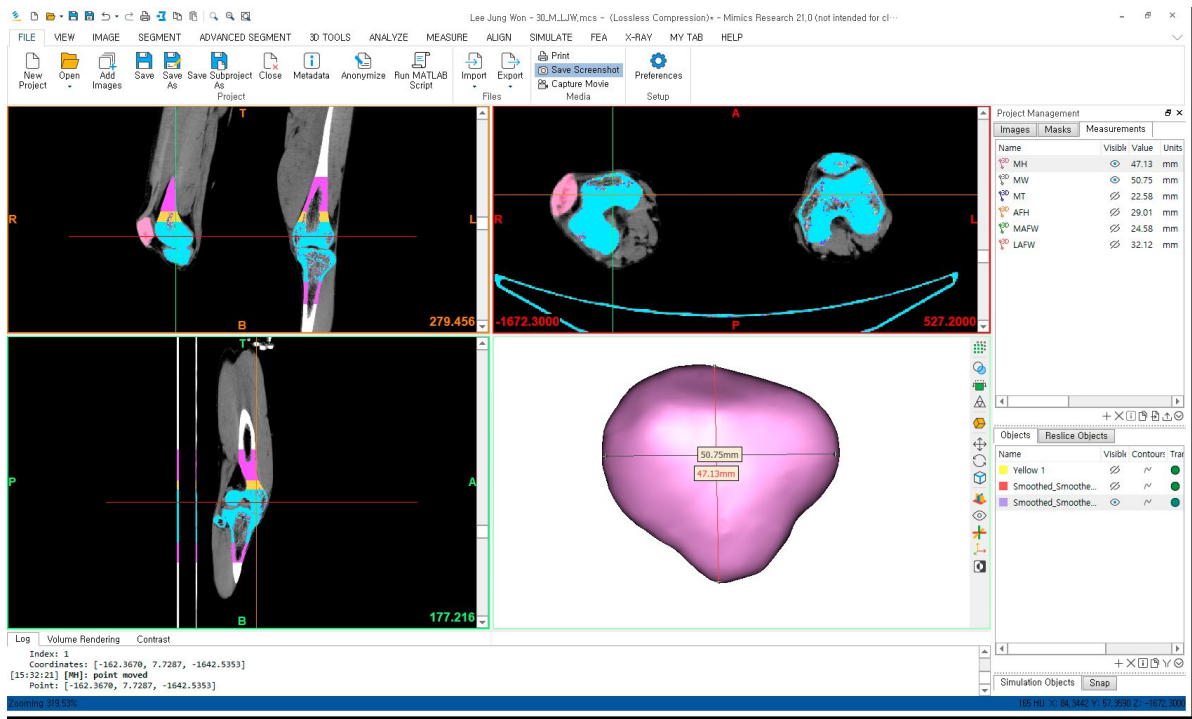


Fig. 2. 3D Reconstruction of PMCT images using Mimics version 22.0.

22.0, Materialise, Leuven, Belgium) was used to generate 3D models from the DICOM data based on coronal, sagittal, and axial planes. To create the 3D image of the patella, Hounsfield Unit (HU) values, which are related to gray-scale, were adjusted in the 3D model. After creating a new mask, the threshold value was adjusted from a minimum of 226 HU to a maximum of 3071 HU to isolate the patella. To measure the patella, the generated mask was used to create a patella object using the calculate part function (Fig. 2).

## 2. Measurement of patella morphology

Patellar morphology measurements were performed using Mimics software. For all measurements, two researchers independently measured the length. The following are the definitions of the patellar measurement variables according to previous research (Fig. 3) [3]:

PMH (Patella maximum height): The maximum distance between the highest and lowest points of the patella.

PMW (Patella maximum width): The maximum distance between the lateral margins on both sides of the patella.

PMT (Patella maximum thickness): The maximum distance at the thickest part of the patella.

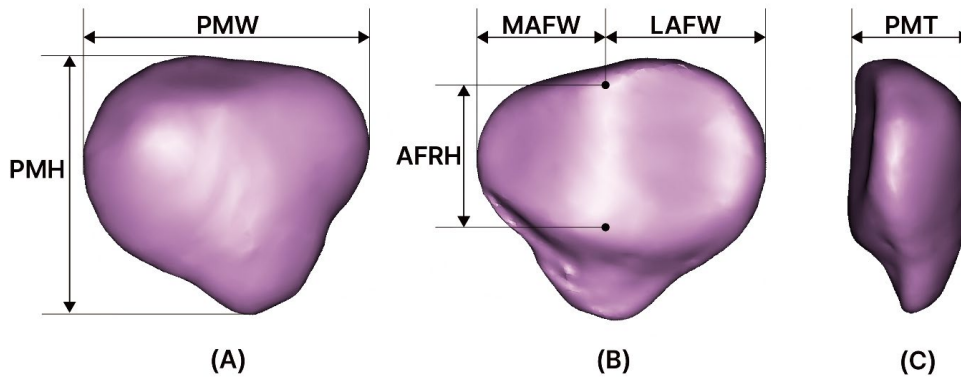
AFRH (Articular facet ridge height): The length of the line connecting the highest points where both articular facets meet.

MAFW (Medial articular facet width): The maximum width of the articular facet on the medial side, based on the articular facet ridge.

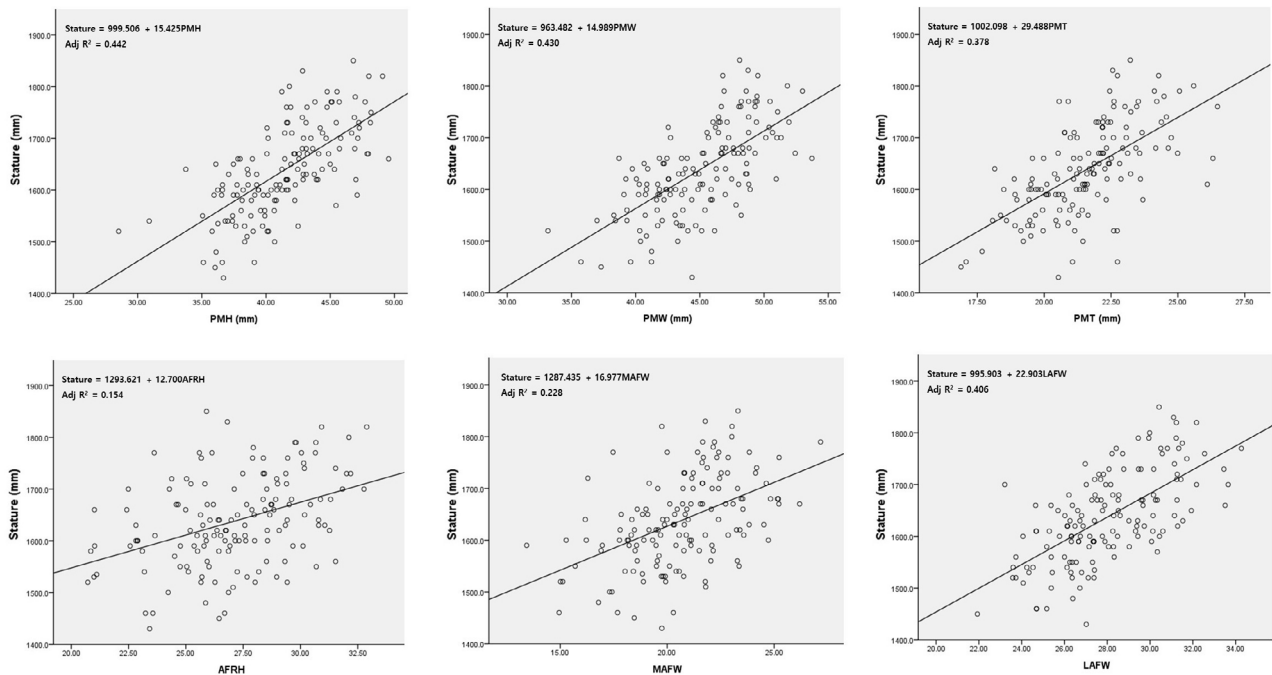
LAFW (Lateral articular facet width): The maximum width of the articular facet on the lateral side, based on the articular facet ridge.

## 3. Statistical analysis

All data processing and statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Co., Armonk, NY, USA). The intraclass correlation coefficient (ICC) was used to calculate the interclass reliability of the measurements. According to the definition of Koo and Li [13], the ICC was interpreted as “excellent” if it was 0.81 or higher, “good” between 0.61 and 0.80, “moderate” between 0.41 and 0.60, and “bad” if it was less than 0.40. The independent sample t-test was performed to compare the



**Fig. 3.** Measurement of patella morphology. (A), Anterior view; (B), Posterior view; (C), Lateral view; PMH, Patella maximum height; PMW, Patella maximum width; PMT, Patella maximum thickness; AFRH, Articular facet ridge height; MAFW, Medial articular facet width, LAFW, Lateral articular facet width



**Fig. 4.** Scatter plot of patella measurement variables versus stature. PMH, Patella maximum height; PMW, Patella maximum width; PMT, Patella maximum height; AFRH, Articular facet ridge height; MAFW, Medial articular facet width; LAFW, Lateral articular facet width.

average of the measurement parameters by sex. The relationship between all measured variables and stature was analyzed by correlation analysis, and a higher correlation coefficient (Pearson R) indicates a stronger correlation between the variables. Linear regression analysis was used to derive a regression equation that can predict stature for all measured variables. A *p*-value < 0.05 was considered statistically significant.

## RESULTS

The results of the inter-class correlation coefficients for the measurement parameters showed that Cronbach's alpha ranged from 0.815 to 0.958, and all were classified under the 'excellent' reliability category (Table 1). The average stature was 1637.91 ± 87.75 mm overall, 1692.92 ± 75.31 mm for male, and 1584.39 ± 62.36 mm for female. The overall mean of the measurement variables was

41.39 ± 3.80 mm for PMH, 44.99 ± 3.86 mm for PMW, 21.56 ± 1.84 mm for PMT, 27.11 ± 2.76 mm for AFRH, 20.64 ± 2.50 mm for MAFW, and 28.03 ± 2.45 mm for LAFW. All measured variables were significantly longer in male than in female ( $p < 0.001$ ) (Table 2).

All correlations between stature and morphometric variables of the patella were significant ( $p < 0.001$ ). There was a weak negative correlation ( $r = -0.395$ ) between stature and age. Stature and PMH ( $r = 0.668$ ), PMW ( $r = 0.659$ ), PMT ( $r = 0.618$ ), and LAFW ( $r = 0.641$ ) showed strong positive correlations, while AFRH ( $r = 0.400$ ) and MAFW ( $r = 0.483$ ) showed weak positive correlations (Table 3).

In the simple linear regression analysis for predicting stature, the  $R^2$  values were as follows: PMH  $R^2 = 0.446$ , PMW  $R^2 = 0.434$ , PMT  $R^2 = 0.382$ , AFRH  $R^2 = 0.160$ , MAFW  $R^2 = 0.233$ , and LAFW  $R^2 = 0.410$ , with all relationships being significant ( $p < 0.001$ ). Predictive models for stature (y, mm) based on the patella measurement vari-

ables (x, mm) were derived, and the results are as follows (Table 4) (Fig. 2):

- (1) Stature = 999.506 + 15.425PMH,
- (2) Stature = 963.482 + 14.989PMW,
- (3) Stature = 1002.098 + 29.488PMT,
- (4) Stature = 1293.621 + 12.700AFRH,
- (5) Stature = 1287.435 + 16.977MAFW,
- (6) Stature = 995.903 + 22.903LAFW.

To make it easier to understand the sex identification regression models, scatter plots and regression lines for all patella measurement variables have been presented.

## DISCUSSION

In this study, a linear model for estimating stature using morphometric measurements of the patella is presented. Estimating sex, stature, and age are important factors in individual estimation [14]. However, a review of the literature reveals that most studies on the patella have focused on analyzing sexual dimorphism, and research on stature estimation using the patella has not been sufficiently explored [3,9-12]. In forensic anthropology, stature estimation is crucial for victim matching when handling unidentified skeletal remains [14]. Therefore, presenting a regression model for estimating stature using small bones like the patella, in addition to studies that use long bones, may enhance the accuracy of individual estimation in various forensic contexts.

The mean values of patellar measurements were compared by sex, and the results showed that males had significantly longer measurements than females for all pa-

**Table 1.** Inter - class correlation coefficients for all measurements. PMH, Patella maximum height; PMW, Patella maximum width; PMT, Patella maximum height; AFRH, Articular facet ridge height; MAFW, Medial articular facet width; LAFW, Lateral articular facet width.

Parameter	Inter - class	
	ICC	95% CI
PMH	.958	.942~.970
PMW	.992	.989~.994
PMT	.908	.872~.933
AFRH	.929	.902~.949
MAFW	.815	.744~.867
LAFW	.859	.804~.898

**Table 2.** Comparison of patella morphology measurement parameters by sex. PMH, Patella maximum height; PMW, Patella maximum width; PMT, Patella maximum height; AFRH, Articular facet ridge height; MAFW, Medial articular facet width; LAFW, Lateral articular facet width.

Parameter (mm)	Male (n = 72)	Female (n = 74)	Total	p
Stature	1692.92 ± 75.31	158.439 ± 62.36	1637.91 ± 87.75	
PMH	44.08 ± 2.67	38.77 ± 2.77	41.39 ± 3.80	
PMW	47.72 ± 2.76	42.34 ± 2.77	44.99 ± 3.86	
PMT	22.42 ± 1.51	20.73 ± 1.76	21.56 ± 1.84	<0.001
AFRH	28.27 ± 2.47	25.98 ± 2.56	27.11 ± 2.76	
MAFW	21.89 ± 2.02	19.43 ± 2.32	20.64 ± 2.50	
LAFW	29.44 ± 2.29	26.66 ± 1.23	28.03 ± 2.45	

The data are expressed by mean ± SD

rameters (Table 2). Previous literature reviews also report that, regardless of race, males are generally significantly larger or longer than females [3,9-12]. Our study on the Korean population showed similar results, suggesting no disagreement regarding the sexual dimorphism of the patella.

In this study, measurements were taken only on the right patella. Previous studies have reported that measurements taken on both sides of the patella did not differ significantly between the left and right sides [4,15,16]. As most previous studies have shown no significant dif-

ference in results between the body sides of the patella, it can be said that processing by measuring and analyzing only the right side in this study is more efficient.

The PMH of the patella in Korean subjects in this study was measured as  $44.08 \pm 2.67$  for males and  $38.77 \pm 2.77$  for females. In a Chinese study [15], the measurements were  $42.81 \pm 2.43$  for males and  $37.07 \pm 2.15$  for females. In a Japanese study [17], the measurements were  $41.1 \pm 2.7$  for males and  $36.6 \pm 2.1$  for females. PMH values were slightly higher in Koreans compared to both males and females in the three countries.

The PMW of the patella in Korean subjects in this study was measured as  $47.72 \pm 2.76$  for males and  $42.34 \pm 2.77$  for females. In a Chinese study [15], the measurements were  $47.01 \pm 2.94$  for males and  $41.25 \pm 2.48$  for females. In a South African study [18], the measurements were  $45.3 \pm 3.26$  for males and  $40.33 \pm 3.28$  for females. The PMW values for the Chinese, who are also Asians, were similar to our results. However, the measurements for Westerners showed a somewhat narrower shape.

The results of measuring the PMT of the patella in Koreans in this study were  $22.42 \pm 1.51$  for males and  $20.73 \pm 1.76$  for females. In a Chinese study [15], the measurements were  $23.91 \pm 1.54$  for males and  $21.52 \pm 1.17$  for females. In a Japanese study [19], the measurements were  $22.3 \pm 1.47$

**Table 3.** Correlation between morphometric variables of the patella and stature. PMH, Patella maximum height; PMW, Patella maximum width; PMT, Patella maximum height; AFRH, Articular facet ridge height; MAFW, Medial articular facet width; LAFW, Lateral articular facet width.

	Pearson correlation (r)	<i>P</i>
Age	-.395	
PMH	.668	
PMW	.659	
PMT	.618	< .001
AFRH	.400	
MAFW	.483	
LAFW	.641	

**Table 4.** Linear regression analysis for predicting stature based on patella shape measurement variables. PMH, Patella maximum height; PMW, Patella maximum width; PMT, Patella maximum height; AFRH, Articular facet ridge height; MAFW, Medial articular facet width; LAFW, Lateral articular facet width.

	Unstandardized coefficient		Standardized coefficient	<i>t</i>	<i>p</i>	<i>R</i> <sup>2</sup>
	B	SE	$\beta$			
(Constant)	999.506	59.552		16.784		
PMH	15.425	1.433	.668	10.765	< .001	.446
(Constant)	963.482	64.384		14.965		
PMW	14.989	1.426	.659	10.513	< .001	.434
(Constant)	1002.098	67.589		14.826		
PMT	29.488	3.123	.618	9.441	< .001	.382
(Constant)	1293.621	66.175		19.549		
AFRH	12.700	2.429	.400	5.229	< .001	.160
(Constant)	1287.435	53.342		24.135		
MAFW	16.977	2.565	.483	6.618	< .001	.233
(Constant)	995.903	64.384		15.468		
LAFW	22.903	2.288	.614	10.009	< .001	.410

for males and  $20.7 \pm 1.51$  for females. When comparing the three countries, PMT showed similar results among the Asian populations.

Previous studies have reported that the patella of Asians is thinner and smaller than that of Westerners. When comparing the results of this study with the measurements of studies on Westerners (Spanish, African American, South African whites and blacks, Southern Italians), the average measurement value of this study was found to be higher [3,6,18,20,21]. Previous studies have reported that Westerners have larger patella than Asians, but there may be errors in such claims. Therefore, additional studies are needed to analyze morphological differences by race.

In this study, a regression equation was derived to predict height based on patella morphometric parameters, and the respective coefficients of determination were  $R^2=0.446$  for PMH,  $R^2=0.434$  for PMW,  $R^2=0.382$  for PMT,  $R^2=0.160$  for AFRH,  $R^2=0.233$  for MAFW, and  $R^2=0.410$  for LAFW. Yoo et al. [22] reported that there was a correlation in all overall measurement variables of the patella, with the highest correlation observed for patella thickness ( $R^2=0.299$ ). Similarly, Kim et al. [23] found that patella thickness was significantly correlated with height, reporting an  $R^2$  of 0.349. Our results showed a stronger significant relationship in most measurement parameters compared to previous studies, with coefficients of determination ( $R^2$ ) being higher for PMH, PMW, and LAFW than for PMT. Although the relationship for patella thickness was similar to previous studies, additional research is needed to precisely compare the relationships between other variables. Furthermore, this study is the first to present a regression model for stature prediction based on patella measurement parameters in a Korean population, suggesting its potential usefulness in clinical and forensic applications.

Our study has the following limitations: First, although we did not account for the morphological errors between the actual patella and the 3D reconstructed bone, it has been reported in previous studies that 3D reconstructed images using the Mimics program provide high accuracy and reliability when compared to actual anatomical measurements [24]. Second, we did not consider biological characteristics such as age and weight, which may affect the estimation of human stature. Third, we cannot completely rule out the possibility of a decrease in human stature due to aging and changes in stature after death.

Lastly, since this study was conducted on subjects aged 30-79, it may be difficult to apply it to subjects under 30 years of age.

## CONCLUSIONS

In conclusion, this study analyzed various measurement variables for patella morphology, finding that males were significantly longer than females in all variables. We proposed a Korean-specific regression model for estimating stature based on patella morphology measurements, and this model can be used as anatomical and forensic basic data that fits the characteristics of the Korean population.

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