Zone-wise and Sex-specific Regression Models for Stature Estimation Using Percutaneous Femoral Length in the Contemporary Indian Population: A Cross-Sectional Study

Dr. Sachin Kumar[1], Dr. Ajay Kumar TS[2], Dr. Raj Kumar MG[3], Dr. Srinivasa Reddy P[4]
Third year Junior Resident[1], Professor[2,4], Associate Professor[3]
Department of Forensic Medicine and Toxicology, Sri Devaraj Urs Medical College, Kolar, Karnataka, India.

Corresponding Author:
Dr. Ajay Kumar T S[2],
Professor,
Sri Devaraj Urs Medical College, Kolar, Karnataka, India.
E-mail – ajaytsk@rediffmail.com

Abstract:
Background:
Stature estimation is an essential component of forensic identification, particularly when skeletal remains are available, such as in mass disasters and other medico-legal investigations.
Aim:
To develop sex- and zone-specific regression equations for estimating stature in the contemporary Indian population using percutaneous femoral length measurements.
Methods:
A cross-sectional study was conducted among 480 medical students aged 18-30 years at Sri Devaraj Urs Medical College, Kolar, Karnataka. The study included 60 males and 60 females from each of the four geographical zones of India (North, South, East, and West) selected using a simple random sampling method. The eligible participants were assigned serial numbers, and a computer-generated list was used to select participants. Stature and bilateral percutaneous femoral lengths were measured using standard anthropometric techniques. Pearson's correlation and simple linear regression analyses were performed to derive regression equations for stature estimation.
Results:
The mean age of the participants was 23.32 ± 2.97 years in males and 23.19 ± 2.60 years in females. Males had significantly greater mean stature (173.35 ± 7.36 cm) and femoral length (43.57 ± 3.53 cm) than females (160.19 ± 5.48 cm and 39.73 ± 3.16 cm, respectively; $p < 0.001$), demonstrating clear sexual dimorphism. No significant bilateral differences were observed between the right and left femoral lengths ($p > 0.05$).
A strong positive correlation was observed between stature and percutaneous femoral length ($r = 0.84–0.92$, $R^2 = 0.70–0.86$, SEE = 2.13–3.34 cm), indicating high predictive accuracy and good predictive reliability.
Conclusion:
Percutaneous femoral length is a reliable predictor of stature in the contemporary Indian population. Sex- and zone-specific regression equations provide more accurate estimates of stature than generalized regression equations. This may serve as valuable tools in forensic identification and anthropological investigations.
Keywords:
Stature estimation; Percutaneous femoral length; Forensic anthropology; Regression analysis; Anthropometry.
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Introduction:

Personal identification is a fundamental aspect of forensic medicine and plays a crucial role in medico-legal investigations.[1]

Identification may be complete or partial depending on the available evidence. Partial identification is performed when only fragmented or incomplete biological information is available, requiring the reconstruction of an individual's identity. Age, sex, ancestry, and stature are among the principal biological parameters used in partial identification.

Stature is an important component of the biological profile used in forensic identification.[2] It is influenced by several factors, including genetics, nutrition, environmental conditions, sex, age, and physical activity.[3]

The relationship between stature and long-bone length varies among populations, ethnic origins, and geographical locations.[3]

In India, climatic conditions, dietary habits, and ethnic composition vary considerably across regions. Regression equations developed for one population may not be directly applicable to another.[4] Improvements in socioeconomic conditions over recent decades have contributed to increased average stature in the Indian population, thereby influencing the relationship between stature and long-bone length.[5,6]

Regression equations are the most widely used method for estimating stature when only bones or their fragments are available. Selecting an appropriate regression equation requires consideration of the individual's sex and population of origin.[7]

Femoral length is considered one of the most reliable predictors of stature because it demonstrates a strong correlation with overall body height.[8]

Although several Indian studies have reported regression equations for stature estimation using femoral length, most were limited to a single geographical region or population group. To date, there is limited evidence comparing all four geographical zones of India using a standardized methodology in a contemporary Indian population. In view of this knowledge gap, the present study aimed to develop and compare sex- and geographical zone-specific regression equations for stature estimation using percutaneous femoral length in a contemporary Indian population.

Materials and Methods:

A cross-sectional study was conducted in the Department of Forensic Medicine and Toxicology at Sri Devaraj Urs Medical College (SDUMC), Tamaka, Kolar, Karnataka, among medical students aged 18–30 years.[9]

Sample Size Calculation:

The study included 480 participants selected using simple random sampling. Participants were equally distributed across the four geographical zones of India (North, South, East, and West), with 60 males and 60 females from each zone, resulting in a total of 120 participants per zone.

Inclusion Criteria

- Healthy adult students of SDUMC, Kolar.
- Participants aged 18–30 years.

Exclusion Criteria

- Students with a history of congenital or acquired skeletal deformities**.**
- Individuals with a history of fractures, orthopaedic surgeries, or musculoskeletal disorders affecting the long bones.

Anthropometric Measurements

Participants were asked to stand barefoot on a flat surface in the anatomical position, with their heels together, arms relaxed at their sides, and the head positioned in the Frankfort horizontal plane. Stature was measured using a stadiometer as the vertical distance from the most inferior point of the heel to the vertex of the head. The measurements were recorded to the nearest 0.1 cm.[3,4,5]

Percutaneous Femoral Length:

Percutaneous femoral length was measured with the participant standing erect and weight evenly distributed on both feet. A spreading caliper was used to measure the straight-line distance between two palpable bony landmarks: the most prominent point of the greater trochanter proximally and the most prominent point of the lateral femoral epicondyle distally. The right and left femora were measured with the caliper positioned parallel to the long axis of the femur. The measurements were recorded to the nearest 0.1 cm. [10]

To minimize the measurement errors, all measurements were obtained twice by the same observer, and the mean value was used for analysis.[1,2,4,5]

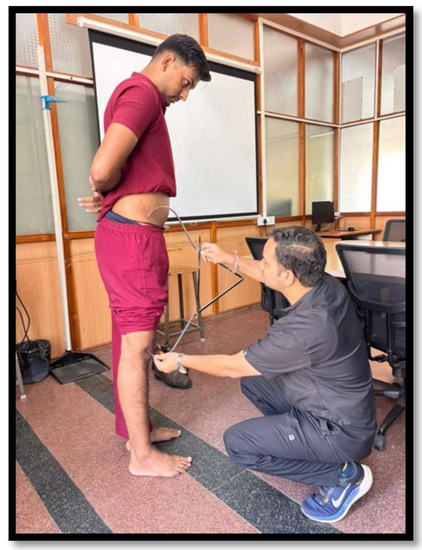

Fig 2. Femur measurement from greater trochanter to lateral epicondyle

Statistical Analysis

The data were analysed using IBM SPSS version 22, and the mean, standard deviation, and range were calculated. Pearson's correlation coefficient was used to assess the relationship between stature and femoral length. Simple linear regression analysis was performed to derive regression equations. A p-value < 0.05 was considered statistically significant. The simple linear regression equation was expressed as Y = A + BX

Where: Y = Height of the individual to be estimated, A = Regression constant, B = Regression coefficient, X = Percutaneous femoral length.

Prior to regression analysis, the assumptions of linearity and normality of residuals were assessed. Linearity was evaluated using scatter plots and residual plots, while normality of residuals was assessed using histograms, Q–Q plots, and the Shapiro–Wilk test. Visual inspection indicated no substantial deviation from these assumptions, supporting the use of simple linear regression models. Residual plots also demonstrated homoscedasticity, supporting the suitability of the regression models.

RESULTS:

A total of 480 participants were included, with equal numbers of males and females from each geographical zone, allowing balanced comparisons across sex and regions.

Table 1. Baseline characteristics of study participants according to sex and geographical zone.

Zone	Sex	n	Age (years) Mean ± SD	Stature (cm) Mean ± SD	Femur length (cm) Mean ± SD	Sex comparison p-value Stature / femur
South	Male	60	22.97 ± 3.24	173.33 ± 5.99	43.46 ± 3.11	<0.001
	Female	60	22.45 ± 1.60	159.20 ± 4.97	38.96 ± 3.34	
North	Male	60	24.45 ± 2.15	173.91 ± 7.61	43.26 ± 3.53	<0.001
	Female	60	24.45 ± 2.15	161.19 ± 5.31	39.90 ± 2.70	
East	Male	60	22.97 ± 3.24	171.83 ± 8.27	43.13 ± 3.42	<0.001
	Female	60	22.97 ± 3.24	161.11 ± 5.47	40.26 ± 3.11	
West	Male	60	22.90 ± 2.92	174.32 ± 7.31	44.43 ± 3.82	<0.001
	Female	60	22.90 ± 2.92	159.27 ± 5.94	39.79 ± 2.88	

Values are presented as mean ± standard deviation (SD). Femur length refers to the right-side measurement. The p-values compare males and females within each geographical zone.

The mean age of male participants was 23.32± 2.97 years**,** and that of female participants was 23.19 ±2.60 years; the observed differences were comparatively small, suggesting a relatively homogeneous age distribution among participants. The mean stature was 173.35 ± 7.36 in males and 160.19 ± 5.48 in females. Male participants were significantly taller than female participants (p < 0.001). The mean femoral length was significantly greater in male participants (43.57 ± 3.53 cm) than in female participants (39.73 ± 3.16 cm), confirming significant sexual dimorphism (p < 0.001).

Table 2. Paired comparison of right and left femur lengths in males and females according to geographical zone.

ZONE	BONE	MALE		COMPARISON			FEMALE		COMPARISON		
		RIGHT	LEFT	T	DF	P	RIGHT	LEFT	T	DF	P
So	Fe	43.	43.	-0	11	0.	38.96	39.16	-0	11	0.

South	Femur	46±3.10	60±3.07	.25	8	80	±3.34	±3.37	.32	8	74
North		43.26±3.531	43.50±3.51	-0.38	118	0.70	39.89±2.70	40.17±2.72	-0.55	118	0.98
East		43.13±3.42	42.83±3.40	-0.48	118	0.91	40.25±3.11	39.92±3.10	0.56	118	0.97
West		44.43±3.81	44.12±3.83	0.44	118	0.98	39.78±2.88	39.46±2.92	0.60	118	0.92

T – Student test, DF – Degrees of freedom, P – Probability test.

The paired-samples t-test showed no statistically significant differences between the right and left femoral lengths in either sex, suggesting bilateral symmetry of femoral length ($p > 0.05$).

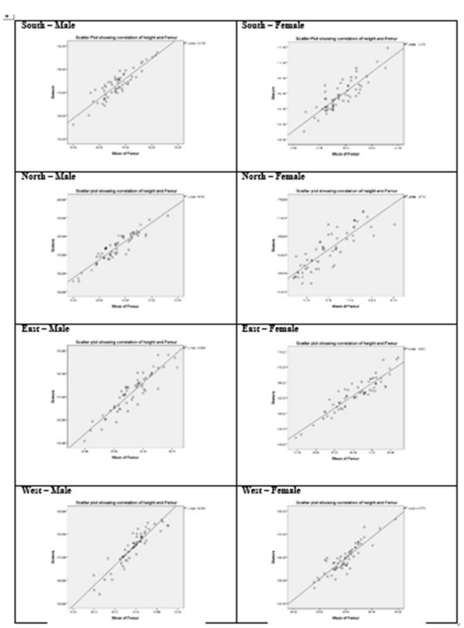

Fig 3. Scatter plots showing the relationship between stature and percutaneous femoral length in male and female participants across the four geographical zones of India.

Scatter plots demonstrated a linear relationship between stature and femoral length across all groups. Residual plots and Q–Q plots confirmed that regression assumptions were adequately satisfied.

Table 3.Correlation coefficients (r) between stature and femur length according to geographical zone.

Zones	Bone	Male		Female		Combined	
		r	p	r	p	r	p
South	Femur	0.89	<0.001	0.85	<0.001	0.88	<0.001
North		0.92	<0.001	0.84	<0.001	0.89	<0.001
East		0.91	<0.001	0.92	<0.001	0.90	<0.001
West		0.91	<0.001	0.87	<0.001	0.91	<0.001

A strong positive correlation between femur length and stature was observed in all groups, with correlation coefficients (r) ranging from 0.84 to 0.92. The highest correlation was observed among male participants from the North zone ($r = 0.92$), while the lowest correlation was observed among female participants from the North zone ($r = 0.84$).

The correlation between stature and femoral length was statistically significant across all geographical zones ($p < 0.001$).

Table 4. Combined simple linear regression equations for right and left femoral lengths across the four geographical zones

Zone	Right-sided regression equation (Y = A+B X)	R^2	SEE	95% CI for b	Left-sided regression equation (Y = A+B X)	R^2	SEE	95% CI for b
South	Stature =82.59+2.03 x Femur length	0.79	4.11	1.84 - 2.22	Stature =82.12+2.03 x Femur length	0.78	4.15	1.84 - 2.22
North	Stature =71.67+2.30 x Femur	0.80	4.04	2.10 - 2.51	Stature =71.06+2.30 x Femu	0.80	4.07	2.09 - 2.51

	length				r length			
East	Stature =73.20+2.23 x Femur length	0.81	3.77	2.04-2.42	Stature =73.78+2.24 x Femur length	0.81	3.77	2.04-2.43
West	Stature =72.05+2.25 x Femur length	0.84	4.01	2.07-2.42	Stature =73.51+2.23 x Femur length	0.83	4.06	2.05-2.41

b = unstandardized regression coefficient (slope); R^2 = coefficient of determination; SEE = standard error of estimate; CI = confidence interval.

A strong correlation was observed between femoral length and stature across all geographical zones, with R^2 values ranging from 0.78 to 0.84 and SEE values ranging from 3.77 to 4.15 cm. Only minimal differences were observed between the right and left femoral measurements.

Table 5. Simple linear regression equations for stature estimation according to geographical zone.

Zone	Male (Y = A+BX)		Female (Y = A+BX)	
	Right	Left	Right	Left
South	Stature = 98.59+1.72 R^2 = 0.79, SEE = 2.73, 95% CI for slope(b) → 1.49-1.94	Stature = 97.27+1.74 R^2 = 0.80, SEE = 2.69, 95% CI for slope(b) → 1.51-1.97	Stature = 109.49+1.27 R^2 = 0.73, SEE = 2.58, 95% CI for slope(b) → 1.07-1.47	Stature = 109.82+1.26 R^2 = 0.73, SEE = 2.60 95% CI for slope(b) → 1.06-1.46
North	Stature =87.38+2.00 R^2 = 0.86, SEE = 2.86 95% CI for slope(b) → 1.78-2.21	Stature =86.21+2.01 R^2 = 0.86, SEE = 2.78 95% CI for slope(b) → 1.80-2.22	Stature =94.73+1.66 R^2 = 0.71, SEE =2.84, 95% CI for slope(b) → 1.39-1.94	Stature =95.32+1.64 R^2 = 0.70, SEE = 2.90, 95% CI for slope(b) → 1.36-1.91
East	Stature =76.35+2.21 R^2 = 0.84, SEE =3.34, 95% CI for slope(b) → 1.95-2.46	Stature =76.64+2.22 R^2 =0.83, SEE =3.34, 95% CI for slope(b) → 1.96-2.47	Stature =95.91+1.62 R^2 = 0.85, SEE =2.13, 95% CI for slope(b) → 1.44-1.79	Stature =96.53+1.61 R^2 = 0.84, SEE = 2.18, 95% CI for slope(b) → 1.43-1.80
West	Stature =96.21+1.75 R^2 =0.84, SEE = 2.91, 95% CI for slope(b) → 1.55-1.95	Stature =97.18+1.74 R^2 =0.84, SEE =2.92, 95% CI for slope(b) → 1.55-1.94	Stature =87.33+1.80 R^2 = 0.77, SEE =2.86, 95% CI for slope(b) → 1.55-2.06	Stature =89.20+1.77 R^2 =0.76, SEE =2.91, 95% CI for slope(b) → 1.51-2.03

The coefficient of determination (R^2) ranged from 0.70 to 0.86, indicating that 70%–86% of the variation in stature was explained by femoral length. The highest R^2 value was observed in females of the East zone (R^2 = 0.85), followed by males of the East and West zones (R^2 = 0.84). The standard error of estimate (SEE), which reflects the precision of stature estimation, ranged from 2.13 cm to 3.34 cm. The lowest SEE (2.13 cm) was observed in females of the East zone, whereas the highest SEE (3.34 cm) was observed in males of the East zone.

Discussion:

The present study was conducted to develop population- and sex-specific regression equations for stature estimation using percutaneous femoral length across four geographical zones (South, North, East, and West) of India.

Male participants had significantly greater mean stature and femoral length than female participants. The overall mean stature was 173.35 ± 7.36 cm in males and 160.19 ± 5.48 cm in females. Comparable findings were observed by Charak et al.[11], who reported a mean stature of 174.27 ± 6.89 cm in males and 161.00 ± 7.55 cm in females, and Arif et al.[12], who reported a mean male stature of 173.89 ± 6.77 cm. The observed sexual dimorphism reflects normal biological variation in skeletal growth between males and females and supports the use of sex-specific regression equations for stature estimation.

In the present study, no statistically significant differences were observed between the right and left femoral lengths in either sex across all geographical zones ($p > 0.05$). Similar observations were reported by Raghavendra,[13] Raju et al.[14] and Patnaik et al.[15], who reported that either side of the femur can be reliably used for stature estimation.

The zone-wise comparisons revealed differences in mean stature and femoral length across the North, South, East, and West regions. These differences may be attributed to genetic diversity, environmental influences, nutritional status, and socio-economic factors prevalent in different parts of India. These findings support the need for population- and region-specific regression equations.[16]

In the South Indian population, a strong positive correlation between femoral length and stature was observed (r = 0.89 in males and 0.85 in females), indicating that femoral length is a reliable predictor of stature in both sexes. Our findings corroborate studies from South India by Raghavendra,[13] Raju et al.,[14] and Rajesh et al.,[17] which reported correlation coefficients ranging from 0.80 to 0.94. The remaining variation may be attributable to biological variability and other anthropometric factors not included in the model. The regression models developed in the present study (R^2 = 0.73–0.80; SEE = 2.5–2.7 cm) demonstrated good predictive accuracy, explaining approximately 73–80% of the variation in stature with relatively low prediction error. The similarity of these findings to those reported in earlier South Indian studies suggests that femoral length remains a robust and dependable anthropometric parameter for stature estimation.

The North Indian population demonstrated the strongest correlation between femoral length and stature in the present study (r = 0.92 in males and 0.84 in females), with coefficients of determination (R^2) ranging from 0.71 to 0.86. These findings indicate that femoral length is a highly reliable predictor of stature in this population, explaining approximately 71–86% of the variation in stature. The results are consistent with those reported by Kaur et al.,[18] who observed correlation coefficients ranging from 0.85 to 0.93 in a North Indian population. The strong correlations and good prediction observed may reflect regional genetic and environmental influences, supporting the reliability of femoral measurements for stature estimation.

In the East Indian population, strong positive correlations between femoral length and stature were observed in both males (r = 0.916) and females (r = 0.922), with high coefficients of determination (R^2 = 0.84–0.85) and low standard errors of estimate, indicating excellent predictive accuracy of the regression models. These findings are comparable with those reported by Patnaik et al.,[15] supporting the reliability of femoral length as a predictor of stature. Although the correlation coefficient was marginally higher in females than in males, both regression models demonstrated similarly high predictive performance, reinforcing the applicability of sex-specific equations for stature estimation in this population.

In the West Indian population, strong positive correlations between femoral length and stature were observed in both males (r = 0.91) and females (r = 0.87), with coefficients of determination (R^2 = 0.77–0.84), indicating good predictive performance of the regression models. These findings are consistent with studies conducted in Gujarat by Patel et al.[19] and Varu et al, supporting the reliability of femoral length as a predictor of stature in the West Indian population.

The present findings are also consistent with several international studies that have identified femoral length as one of the strongest predictors of stature. Trotter and Gleser,[5] demonstrated that the femur is one of the most reliable long bones for stature estimation. Studies from Nigerian[20] and Javanese[21] populations have reported strong correlations between femoral length and stature, with regression coefficients ranging from 0.752-0.794 and 0.514-0.525, respectively). Estimation of the stature of an individual in India by using formulae designed by western workers involves an error of 5% to 8%.[22] These variations are attributable to differences in ethnicity, body proportions, nutrition, environmental influences, and secular trends in growth.

Overall, the findings demonstrate significant regional and sex-specific variations in stature and femoral length among the Indian population. These variations are likely influenced by genetic diversity, nutritional status, socioeconomic conditions, and climatic factors, underscoring the importance of developing population- and sex-specific regression equations for accurate stature estimation in forensic practice.

These equations may assist forensic experts in identifying unknown individuals from incomplete remains during mass disasters, criminal investigations and anthropological examinations.

Limitations and Future directions:

- Participants may not represent the entire Indian adult population because medical students generally have similar educational and socioeconomic backgrounds.
- Environmental, nutritional, and socioeconomic factors were not analysed separately and therefore could not be evaluated for their potential influence on stature and femoral length.
- Intra-observer reliability was not assessed using the intraclass correlation coefficient (ICC).

Future studies should include multicentre populations, broader age groups, and diverse ethnic populations.

Conclusion:

The present study demonstrates that percutaneous femoral length is a reliable predictor of stature in the Indian population, with strong positive correlations across all geographical zones (r = 0.848–0.928), high coefficients of determination (R^2 = 0.70–0.86), and low standard errors of estimate (SEE). Significant sexual dimorphism was observed, with male participants exhibiting greater stature and femoral length than female participants. Regional variations across the North, South, East, and West zones of India further highlight the need for population- and region-specific regression equations.

The present study concludes that sex- and zone-specific regression equations provide greater accuracy for stature estimation and should be preferred whenever the individual's sex and geographical origin are known.

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Declaration:

This study was approved by the Institutional Ethics Committee of Sri Devaraj Academy of Higher Education and Research, Kolar. (Ref: SDUAHER/R&D/CEC/SDUMC-PG/361/NF/2025-26)

The participants signed the consent form after understanding the purpose of the research.

Consent for publication:

Written informed consent was obtained from all participants after explaining the purpose of the study.

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Competing Interests:

The authors declare no competing interests.

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