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Evaluation of the reliability of body height estimation from both foot lengths and knee height measurements in population of North India

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Abstract

Introduction: The loss of body height in elders results in challenging threat for Forensic experts, Anatomists as well as Anthropologists by posing difficulties in applying equations based on estimates from adult population. Thus this study is conducted to evaluate the accuracy of body height equations from both foot lengths and Knee height measurements in subjects of all age.

Materials and methods: This evaluative study is conducted on 1000 (500 males and 500 females) asymptomatic, healthy adults, residing in Teerthanker Mahaveer University of cosmopolitan origin with age over 18 years old with no diagnosed history of knee arthropathy and spinal deformity and a written informed consent was taken from the subjects.

Results: The Linear regression equations for body height with knee height in males and females were found to be

B.H. = 75.62+1.79(KH); r^2 =0.55, S.E.E. = 5.1 cms; B.H. =71.92+1.79(KH); r^2 =0.33, S.E.E.= 5.7 cms respectively.

The Linear multiple regression equations for body height with knee height and age in males and females were found to be

B.H.=81.790+1.73(K.H.)-0.15(Age in years); R^2= 0.566, M.S.E.= 25.86

B.H. = 74.137+1.78(K.H.)-0.06(Age in years); R^2= 0.333, M.S.E. = 33.44 respectively.

Conclusion: Knee height is the best predictor of Body height alone as well as inclusion of age as a predictor variable shows improved R^{2*} values in both the sexes along with lowest S.E.E.* values with Simple linear regression and with multiple linear regression showed decreased values of M.S.E.* than both foot lengths in both the sexes.

Keywords: Simple Linear regression equation, Multiple Linear regression equation, *Standard Error of Estimate (S.E.E.), *Mean Squared Error (M.S.E.), *Correlation Coefficient Determination (R^2)

Introduction

Body height is a very significant indicator and measurement of body composition in the assessment of human nutritional status. All human body system are effected by aging like posture, balance and gait thus measuring height imposes great difficulties for individuals who cannot stand or

suffering from various physical anomalies such as contractures, fractures, amputations, paralysis, scoliosis etc with least reliability of measurement. Accurate indirect methods are therefore needed to assess the nutritional status of elderly people (Hurley et al., 1997). Body composition measurement provides information about physiological age in healthy people, risk factors for pathologic process such as atherosclerosis and diabetes and prognosis in the variety of acute and chronic illnesses.

Height decreases with age because of shrinkage of the intervertebral discs; osteoporosis may cause excessive loss of height in some study participants leading to biased results in body composition studies (Barlett, 1991; Cline et al., 1989; Dequeker et al., 1969; Mohanty et al., 2001).Thus body height has to be measured using surrogate or proxy methods like Knee height & foot length which are independent of age. The accuracy of the equation is reduced if used to estimate stature in population in which the equation has not being derived from adults (Chumlea, 1985).Therefore, there is a need to develop equations to estimate stature in adults for use in the research of anthropometric, forensic science as well as nutrition and health as a need for cohort study of knee height measurements from the early adulthood through to the later years of life to verify its age independent characteristics. Reliability of prediction of height from foot length has been reported to be as high as that of long bones(Rutishauser, 1968).

Regression analysis is usually performed to develop simple predictive equations to predict stature according to gender using age as predictor variable.

Therefore present study aimed to predict the best body height indicator and to develop a nationally representative prediction equation for estimation of stature according to gender including age as a predictor variable in order to reduce the inherent problem of sample specificity and enhance accuracy confidence in the estimation.

Materials and methods

For the present study, total 1000(500 males and 500 females) asymptomatic, healthy adults, residing in Teerthanker Mahaveer University of cosmopolitan origin with age over 18 years old with no diagnosed history of knee arthropathy and spinal deformity and a written informed consent were taken from the subjects. The measurements were taken at a fixed time of the day (i.e. 2 to 5 pm) to remove the inconsistencies due to diurnal variations. No Objection Certificate was obtained from the college Ethical research committee.

Sampling Method - : Purposive and Judgment sampling methods as these are best when we are studying a particular set of groups.

Study design-: Evaluative study.

Method

Body Height (B. H.) was measured from the vertex to the tip of the foot heel with an individual standing in anatomical position barefooted using Stadiometer.

Foot length (FL) was measured from the tip of the foot heel (pternion) to the tip of the big toe or any other toe whichever is the longest (acropodion) in centimeters by spreading calipers (Hrdlicka compass) (Hrdlicka, 1920). Independent measurements of both left and right foot of each individual were taken to the nearest 0.01 mm.

Knee Height (K.H.) defined as the distance from the heel of the foot to the top of the right thigh's femoral condyles anterior surfaces, 4 cms proximal to the patella) with the ankle and knee each flexed to a 90^0 angle measured by Ross Knee Height calipers with modified horizontal fixed blade, recorded in centimetres.

All the above readings were tabulated & subjected to statistical analysis using mean ± standard deviation of data evaluated with Z – test by computing the correlation coefficient (-1 to +1) with excel on window professional 2007. To determine the statistical association between body height, both foot lengths and knee height measurements the Pearson s correlation analysis was used. The data procured was statistically analyzed at the $p<0.05$ and 0.01 level. Derivation of Linear regression equations was done to calculate the height from both foot lengths and knee height of an individual.

Results and observations

Table1 - Mean± Standard values of Body Height, Foot Length, Knee Height & Age in both Males and Females

	MALE	**FEMALE**	**Z VALUE**
HEIGHT	168.14±7.708	157.68±7.068	22.389**
RIGHT FOOT LENGTH	24.949±1.376	22.937±1.157	25.895**
LEFT FOOT LENGTH	24.935±1.389	22.913±1.199	25.628**
KNEE HEIGHT	51.6±3.21	47.7±2.26	22.213**
AGE (in years)	21.67±4.50	21.78±4.43	0.423^{ns}

**Strongly Significant as p-value < 0.01; ns=non- significant

Table 2: Single Linear Regression Formulae for Body Height (cms) from Foot Length and Knee Height.

SEX	**VARIABLES**	**EQUATIONS**	**S.E.E. (cms)**	**COEFFICIENT OF DETER-MINATION (r^2)**	**Adjusted (r^2)**	**P Value**
MALE	RT.FOOT LENGTH	B.H.=69.99+3.93(FL)	5.491	0.493	0.492	<0.01
	LT. FOOT LENGTH	B.H.=70.93+3.89(FL)	5.489	0.493	0.492	<0.01
	KNEE HEIGHT	**B.H.=75.62+1.79(KH)**	**5.123**	**0.559**	**0.558**	**<0.01**
	AGE	B.H.=178.43+(-0.474)(Age)	7.414	0.076	0.074	<0.01
FEMALES	RT.FOOT LENGTH	B.H.=89.82+2.95(FL)	6.188	0.234	0.233	<0.01
	LT. FOOT LENGTH	B.H.=93.17+2.81(FL)	6.216	0.228	0.226	<0.01
	KNEE HEIGHT	**B.H.=71.92+1.79(KH)**	**5.785**	**0.331**	**0.330**	**<0.01**
	AGE	B.H.=161.32+(-0.16)(Age)	7.036	0.011	0.009	<0.01

B.H.: Body Height, S.E.E.: Standard Error Estimate

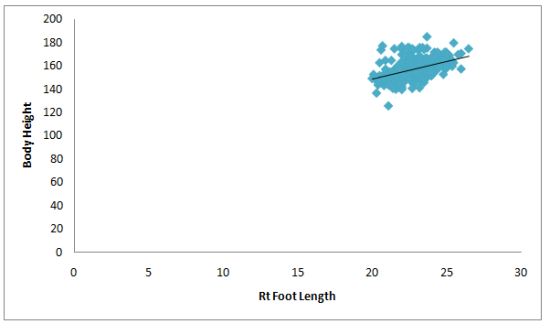

Fig. No. 1 Scatter diagram showing Correlation between body height & Right Foot Length in Females.

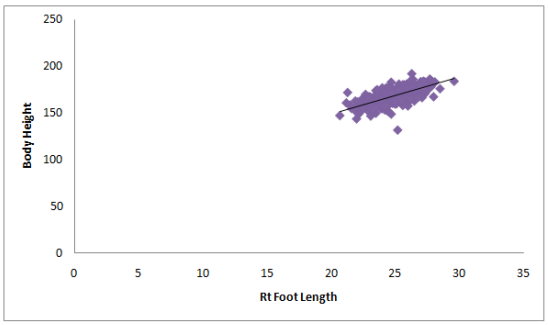

Fig.No.4 Scatter diagram showing Correlation between body height & Right Foot Length in Males.

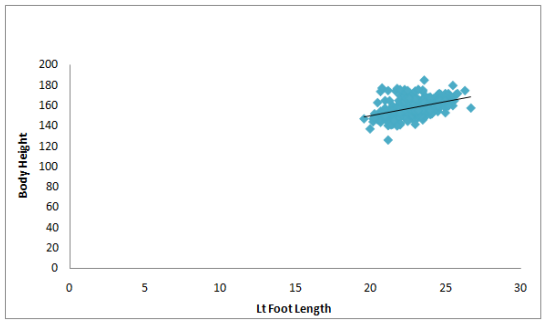

Fig.No.2 Scatter diagram showing Correlation between body height & Left Foot Length in Females.

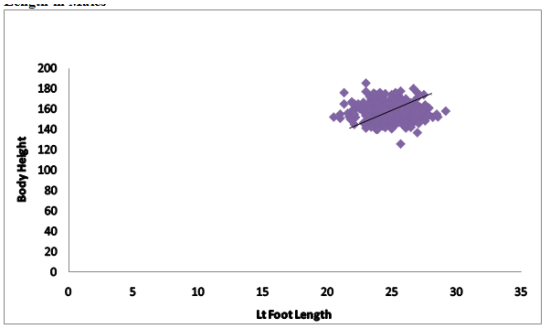

Fig.No.5 Scatter diagram showing Correlation between body height & Left Foot Length in Males.

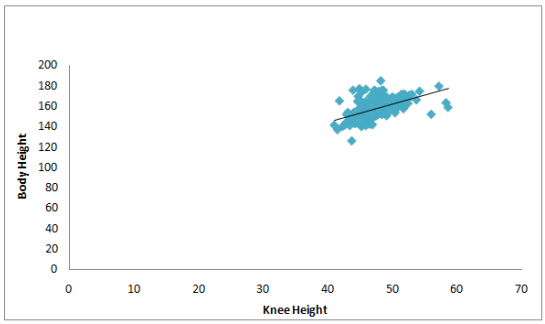

Fig.No.3 Scatter diagram showing Correlation between body height & Knee height in Females.

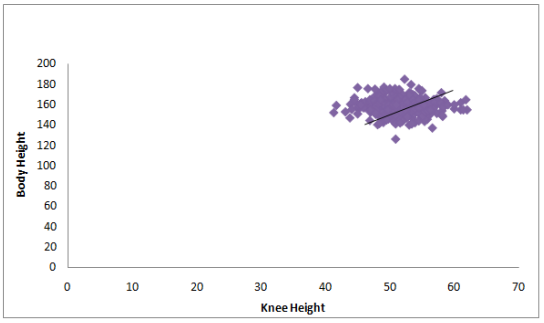

Fig.No.6 Scatter diagram showing Correlation between body height & Knee height in Males.

Table 3: Linear Multiple Regression Formulae for Body Height (cms) from Foot Lengths and Knee Height with Age as predictor variable.

SEX	VARIABLES	EQUATIONS	MEAN SQUARED ERROR	(R^2)	ADJU-STED (R^2)	P VALUE
MALE	RT.FOOT LENGTH & AGE	B.H.=79.232+3.774(RFL)-0.242(Age in years)	29.069	0.512	0.510	<0.01
	LT.FOOT LENGTH & AGE	B.H.=80.057+3.740(LFL)-0.239(Age in years)	29.083	0.512	0.510	<0.01
	KNEE HEIGHT & AGE	**B.H.=81.790+1.736(K.H.)-0.152(Age in years)**	**25.865**	**0.566**	**0.564**	**<0.01**
FEMALE	RT.FOOT LENGTH& AGE	B.H.=92.759+3.082(RFL)-0.265(Age in years)	37.008	0.262	0.259	<0.01
	LT.FOOT LENGTH & AGE	B.H.=96.192+2.934(LFL)-0.264(Age in years)	37.360	0.255	0.252	<0.01
	KNEE HEIGHT & AGE	**B.H.=74.137+1.782(K.H.)-0.069(Age in years)**	**33.441**	**0.333**	**0.330**	**<0.01**

**Strongly Significant as p-value < 0.01; (R^2) =Coefficient of determination

In both males and females Knee height (0.74, p<0.01) & (0.57, p<0.01) showed highest significant correlation with body height respectively as compared to both foot lengths. Moreover with inclusion of age with knee height to estimate body height the value of $\mathbf{R^2}$(0.566,p<0.01) & (0.333,p<0.01) increases in both males and females respectively as compared to the value of $\mathbf{R^2}$(0.512, p<0.01) & (0.26, p<0.001) of both foot lengths with age in both males and females and Mean squared error values (25.86 &33.44) decreases in both males and females respectively as compared to M.S.E. values (29.0 &37.3)of both foot lengths with age in both males and females predicting better fitted line with all data points. Thus it showed that Knee height is the reliable, accurate and best predictor of body height in both the sexes.

Discussion

Estimation of the body height from the various body parts using the easiest and most reliable method as regression analysis now days has become necessary for Anatomists, Anthropologists and Forensic experts with the increasing evidences of dismembered human remains found due to road side accidents, mass disasters and vengeful attitude of humans to identify them.

The Correlation coefficient of body height was observed with both foot lengths r=0.70 in males and with right foot length r= 0.48 and with left foot length r=0.47 in females. The value of r of body height with knee height in males is 0.74 and in females is 0.57. All the r values are significantly higher in males as compared to females similar to other workers. Knee height showed the better degree of correlation in both males

and females as compared to both foot lengths.

The relationship between body height and knee height by both simple and multiple linear regressions was found to be more significant as compared to one with both foot lengths (table nos. 2& 3).In simple linear regression, r^2 values (table no. 2) with low value of Standard error of estimate (S.E.E.) indicates greater reliability in the body height estimation. The values of S.E.E. for body height from both foot lengths and knee height in males are 5.4cms and 5.1cms respectively while in females values are 6.2cms and 5.7cms respectively while in multiple linear regression, with inclusion of age with knee height to estimate body height the value of R^2 (table no.3) and Mean squared error values of knee height with age (25.86 &33.44) decreases in both males and females respectively as compared to M.S.E. values (29.0 &37.3) of both foot lengths with age in both males and females respectively. Both the statistics predicted better fitted line with all data points. Thus Knee height is an accurate and best predictor of body height in both males and females with better reliability. With the inclusion of age to knee height the regression (multiple linear regressions) improved the value of R^2 as compared to knee height alone as well as with both foot lengths with age. Thus indicating and confirming knee height is independent of age.

In both models of regression the slopes for Knee height ranged 1.73 to 1.79cms and the slopes for age ranged from -0.06 to -0.47cms in both males and females. Regarding the decline of height according to Cline et al (1989) with age was seen amongst individuals 45years and above. The mean annual rate of decline of height was approximately -0.5cms/year regardless of age due to thinning of intervertebral disc or changes in postural habits of individuals.

Table 4: Comparison of present study on body height with foot length and knee height with various authors for better and ease of understanding in a tabulated form.

AUTHOR	PARAMETERS	MALES	FEMALES
Patel et al (2012) Gujarat, INDIA	1.Correlation coefficient(r)	0.925	0.741
	2.Regression equations	Ht = 77.89+(3.55)FL	Ht = 38.0+(5.192)FL
Ozaslan et al (2012) TURKEY	1.Height	1724.37±68.65mms	1620.10±64.19mms
	2.Foot Length	250.86±13.56mms	228.86±10.74mms
	3.Correlation coefficient(r)	0.696	0.496
	4.Coefficient of Determination (r^2)	0.484	0.246
	5.Regression equations	840.88+3.52(FL),S.E.E.=49.40mms	941.95+2.96(FL),S.E.E.=55.95mms
Mansur DI et al (2012) NEPAL	1.Height	165.66±8.34cms	156.70±6.16cms
	2.Foot Length	23.89±2.09cms	22.64±1.36cms
	3.Correlation coefficient(r)	0.688	0.587
	4.Regression equations	Y=100.1+2.74(RFL) Y 100.2+2.738(LFL)	Y=96.31+2.66(RFL) Y=96.40+2.66(LFL)
Uhrova P.et al	1.Height	180.6±7.1cms	168.3±6.6cms

(2011) SLOVAKIA	2.Foot Length 3.Correlation coefficient(r) 4.Regression equations	RFL=37.9±1.7cms; LFL=37.8±1.5cms	RFL=38.4±2.3cms; LFL=38.6±1.8cms
		RFL=0.759; LFL=0.755	RFL=0.722; LFL=0.704
		68.563+4.200RFL,S.E.E.= 4.69 67.720+4.227LFL,S.E.E.=4 .73	59.825+4.473RFL,S.E. E.=4.66 64.454+4.262LFL,S.E. E.=4.78
Cheng HS et al (2001) TAIWAN	1.Correlation coefficient(r) 2.Regression equations	0.73	0.68
		stature = 85.10 + 1.73KH - 0.11 age; R^2 = 0.61	stature = 91.45 + 1.53 KH -0.16 age; R^2 = 0.58
Zhang et al (1998) Melbourne, AUSTRALIA	1.Height 2.Knee Height 3.Regression equations	166.6±6.4cms	155.8±5.4cms
		49.0±2.5cms	45.1 ±2.2
		S=67.78+2.01KH; R^2=0.59,root M.S.E.=4.07 S=71.70+1.98KH-0.044Age; R^2=0.59,root M.S.E.=4.03	S=74.08+1.81KH; R^2=0.55,root M.S.E.=4.17 S=78.46+1.79KH-0.066Age; R^2=0.56,root M.S.E.=4.01
Chittawatanarat et al (2012) THAILAND	1.Height 2.Knee Height 3.Correlation coefficient(r) 4.Regression equations	166.1±6.0	155.1±5.4
		48.6±3.3	42.1±3.0
		0.87	0.65
		89.44+1.58Knee Height, S.E.E.=1.5±1.1	108.27+1.11 Knee Height, S.E.E.=2.1±1.7
Han T S (1996) ENGLAND	1.Regression equations	Y=54.9+2.30×KH-0.06×age R^2=0.79, S.E.E.= 3.2cms	Y=71.3+1.91×KH-0.10×age R^2=0.72, S.E.E.=3.4cms
Present study	1.Height	168.14±7.7	157.68±7.0
	2.Foot Lengths	RT=24.949±1.37 LT=24.935±1.38	RT=22.937±1.15 LT=22.913±1.19
	3.Knee Height	51.6±3.21	47.7±2.26
	4.Age	21.67±4.50	21.78±4.43
	5.Correlation coefficient(r)	RT. FL=0.702, LT.FL=0.702, **KH=0.747**	RT. FL=0.484, LT. FL=0.477, **KH=0.575**
	6.Coefficient of Determination (R^2)	RT.FL=0.493& RT.FL with age=0.512 LT.FL=0.493& LT.FL with age=0.512 KH=**0.559**& KH with age=**0.566**	RT.FL=0.234 & RT.FL with age=0.262 LT.FL=0.228 & LT.FL with age=0.255 KH=**0.331** & KH with age=**0.333**

	7.Adjusted R^2	RT.FL=0.492& RT.FL with age=0.510 LT.FL=0.492& LT.FL with age=0.510 KH=0.558& KH with age=0.564	RT.FL=0.233& RT.FL with age=0.259 LT.FL=0.226& LT.FL with age=0.252 KH=0.330& KH with age=0.330
	8.Linear Regression equations with Standard Error of Estimate(S.E.E.)& Mean Squared **E**rror(M.S.E.)	B.H.=69.99+3.93(RFL)S.E.E=5.491 B.H.=79.23+3.77(RFL)-0.24(Age in years)M.S.E.=29.069 B.H.=70.93+3.89(LFL)S.E.E= 5.489 B.H.=80.05+3.74(LFL)-0.23(Age in years)M.S.E.=29.083 B.H.=75.62+1.79(KH)**S.E.E=** **5.123** B.H.=81.79+1.73(K.H.)-0.15(Age in years)**M.S.E.=25.865**	B.H.=89.82+2.95(RFL) S.E.E=6.188 B.H.=92.75+3.08(RFL) -0.26(Age in years)M.S.E.=37.008 B.H.=93.17+2.81(LFL) S.E.E= 6.216 B.H.=96.19+2.93(LFL) -0.26(Age in years)M.S.E.=37.360 B.H.=71.92+1.79(KH)**S.E.E=** **5.785** B.H.=74.13+1.78(K.H.) -0.06(Age in years)**M.S.E.=33.441**

Comparison (table 4) shows that present study results and observations are discussed and motivated by previous workers with some additional features.

Conclusion

Knee height is the best predictor of Body height alone as well as inclusion of age as a predictor variable shows improved R^2 values in both the sexes along with lowest S.E.E. values with Simple linear regression and with multiple linear regression showed decreased values of M.S.E. than both foot lengths in both the sexes.

Out of the two parameters, it seems that knee height has a high precision and reliability as compared to both foot lengths. Still it is suggested that a combination of two or more parameters be certainly be more useful, applicable and reliable as***"Two are better than one"*** **-By Solomon**

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Conflict of interest: None.

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