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Prediction of Femur Bone Geometry using Anthropometric Data of Indian Population: A Numerical Approach

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The development and validation of a generic model to get preliminary idea about various components of geometry of the femur using mathematical method was presented. The synthesis of the generic model requires the following steps: acquisition of anthropometric data of the patients; x-ray images of hip joint of the patients; measurement of various components of the femur; creation of model using mathematical method; validation of the model. From the results it was apparent that, the geometry of the femur can be obtained through anthropometric data using mathematical approach. The results showed that, the correlation obtained in the age group of 51-60 (M) was better than other age groups of the same category. There was no significant difference between the correlation obtained in male and female categories. The measured values and values obtained through mathematical models showed good correlation. The generic models were validated by comparing observed values with the calculated values and the agreement found was qualitative.

Key words: Modeling, femur, numerical method, bone, geometry

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INTRODUCTION

Presently in developing countries like India, injured/broken femur replacements are carried out using standard sized Austin Moore femur implant selected from a range provided by manufacturers. Femur implant is available in standard sizes of diameter of the femoral head and neck shaft angle. As manufacturer supplied femur implants are used for implantation, there are limitations in design of the implant. Surgeons who perform femur replacement surgeries must rely upon the implant manufacturer to provide appropriately sized implants. These implants are manufactured for masses and not for individuals. However, there is discrepancy as regards the measurement of the parameters. The neck shaft angle varies from approximately 125° up to 132° (Samaha *et al*., 2007). Undersized or overhanging femoral implants could lead to altered soft-tissue tensioning and altered patella femoral stresses (Hitt *et al*., 2003). Non availability of proper shaped and sized femur implant or improper selection of femur implant could create serious problems for the patients in long run (Kay *et al*., 2000; McGrory *et al*., 1995). There is a paucity of literature pertaining to the effects of improperly sized implants on patient outcome.

Importance of hip geometry has been well defined in previous studies (Tastan *et al*., 2006; Crabtree *et al*., 2000; Gnudi *et al*., 1999; Le Bras *et al*., 2006; Kukla *et al*., 2002). Several researchers have derived geometric measurements from DXA (dual energy X ray absorptiometry) images of the hip. These include the Hip Axis Length (HAL), femoral neck length, neck shaft angle and femoral neck width. Of the various geometric measurements that have been studied, HAL represents the best candidate for clinical use (Faulkner, 2009). In this study the parameters mainly, horizontal offset, femoral head diameter and neck shaft angle are considered for modeling (McGrory *et al*., 1995; Isaac *et al*., 1998). Geometry of the femur implant should be perfect in all above three parameters in order to avoid post operative problems and revision surgeries. Many studies showed that, age and/or weight are associated with some of the parameters of hip geometry (Brownbill and Ilich, 2003). The anthropometric data like age, weight and height of the subjects were collected to get relationship between horizontal offset, femoral head diameter and neck shaft angle using mathematical model. Once the geometry of the femur is obtained, it is possible to fabricate custom made implants using integrated system of Computer Aided Design (CAD), Rapid Prototyping (RP) and Computer Aided Manufacturing (CAM), which suits and fits to the individual (Everton *et al*., 2004; Hibi *et al*., 1997; Kashi *et al*., 2006; Chartoff *et al*., 1999; Chelule *et al*., 2007; Khan *et al*., 2001; Tassaduqe *et al*., 2003).

With the advances of computer technology, simulation and 3D visualisation have great potential to benefit medical education, research and practice (Zhu, 2008). But unfortunately the applications of engineering techniques and skills in medical field have not developed beyond certain limits. The objective of the study is to propose a novel approach to predict geometry of femur prosthesis prior to surgery using mathematical modeling. The strength of the modeling is that, it uses simply radiographs of the hip joint. Hence the aim of reduction in the cost, lead time and operation time is achieved. Modeling is based on the outline of the geometrical parameters will help the surgeon in pre-planning of femur joint replacement surgeries.

MATERIALS AND METHODS

Data collection: There is a dearth of data concerning the anthropometric dimensions of the parts of the femur. Determination of outline of the geometry of femur using anthropometric data was a challenging work. This study was carried out in Vidarbha region, central part of India during the year 2009. The study was divided into five steps. In first step of the study, the data of 77 (48 male and 29 female) subjects were collected. The data like age (A), weight (Wt) and height (Ht) of the patients normally recorded at the time of entry of the patient in hospital for treatment. The data measured were expressed in mean and standard deviation. It was clear from the data collected that, the subjects studied were from a wide range of age starting from 35 years to 70 years in case of male subjects and 41 years to 60 years in female. Same interpretation was applicable to weight also. Mean height of male subjects was 167.33 cm whereas in female it was 159.58 cm (Table 1).

Second step was to collect x-rays of the same subjects of which anthropometric data was collected. The x rays of all subjects were obtained as a part of patients' treatment. These x rays were used to measure the parameters influencing geometry of femur. Few parameters were identified like, horizontal offset (Ho), Neck Shaft Angle (NSA) and Femoral Head Diameter (FHD) (Fig. 1) as an essential to carry out mathematical modeling. Horizontal offset is also known as femoral offset. For measurement of femoral offset a screened x-ray was taken to show maximum offset. The anatomical axis was drawn and the offset was defined as the distance from the anatomical axis to head centre. Femoral neck shaft angle was formed between neck shaft axis and femoral shaft axis. Similarly femoral head diameter was the maximum

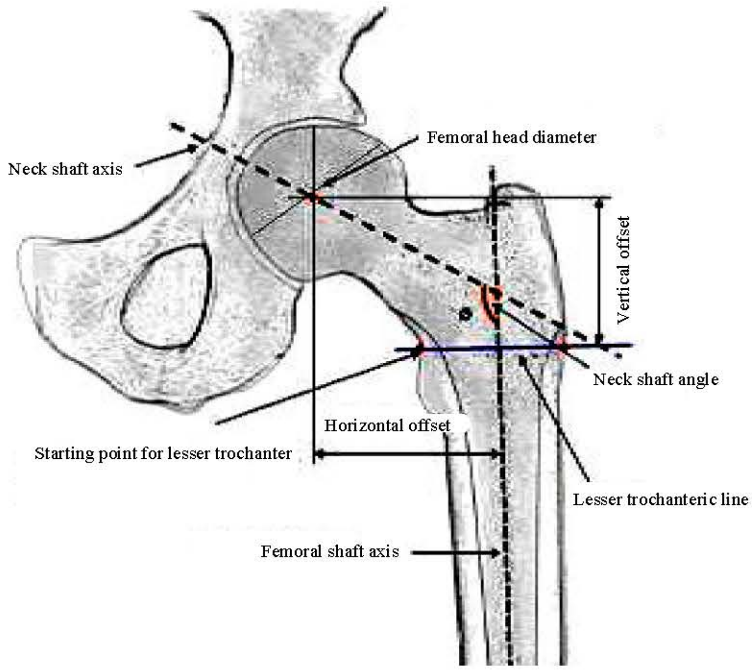

Fig. 1: Femoral head: parameters measured

Table 1: Summary of data collected

	Age (years)				Weight (kg)				Height (cm)			
Gender	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Male	35	71	54.64	10.17	49	86	70.93	7.65	155	181	167.33	7.21
Female	41	60	50.24	5.95	47	70	59.06	6.31	149	172	159.58	7.16

diameter of the head measured perpendicular to the neck shaft axis (Kay *et al*., 2000; McGrory *et al*., 1995; Maheshwari *et al*., 2004; Jain *et al*., 2005; Clark *et al*., 1987; Flecher *et al*., 2007).

In the third step, measurement of identified parameters was carried out by simply marking various dimensions on photocopies of the radiographs of hip joint. The data collected was divided into age groups of male and female subjects to minimize the effect of variations and to get better agreement between observed and calculated values of all parameters. There was a remarkable variation in the femoral bone dimensions. The mean value of horizontal offset in both, male and female, were around 3.8 cm. Neck shaft angle showed variation gender-wise, maximum standard deviation of NSA was 4.64° in the age group of 61-70 years male and minimum standard deviation was 3.41° also in male subjects. Femoral head diameter varied in similar way in male and female with minimum of 3.7 cm and maximum of 5.5 cm (Table 2).

Mean values of Ho, NSA and FHD obtained were closely associated and did not show any abnormal relationship amongst it. Substantial variations in all measured parameters were observed. These variations lead to create mathematical models to obtain outline of femur geometry.

Mathematical modeling: The geometry of femur has been influenced by various parameters, such as horizontal offset, neck shaft angle, femoral head diameter, age, weight, height, race, genes etc. Fourth step was the identification of the factors which may have significant impact on geometry of femur and mathematical modeling to get outline of the femur geometry. Such identified influencing factors were horizontal offset, neck shaft angle, femoral head diameter, age, weight and height. Out of these few like age (A), weight (Wt) and height (Ht) were identified as independent parameters and horizontal offset (Ho), Neck Shaft Angle (NSA), Femoral Head Diameter (FHD) were considered as dependent parameters.

Input to the model was age, weight and height of the patient and output gained was horizontal offset, neck shaft angle and femoral head diameter of the femur. These components give specific idea to the surgeon about

Table 2: Summary of measured dependent parameters from X rays

Parameters	Gender	Age group (years)	No. of observations	Min	Max	Mean	SD
Horizontal offset (Ho) (cm)	Male	35-50	17	3.0	4.5	3.817	0.457
	Male	51-60	15	2.7	4.5	3.846	0.520
	Male	61-70	16	3.1	4.6	3.818	0.421
	Female	41-50	16	3.0	4.5	3.8	0.470
	Female	51-60	13	3.1	4.5	3.815	0.457
Neck shaft angle (NSA) (°)	Male	35-50	17	125	139	131.76	3.70
	Male	51-60	15	125	137	131.66	3.41
	Male	61-70	16	126	141	131.87	4.64
	Female	41-50	16	123	137	131.25	3.89
	Female	51-60	13	124	138	131.07	4.00
Femoral head diameter (FHD) (cm)	Male	35-50	17	3.7	5.5	4.33	0.419
	Male	51-60	15	3.8	5.2	4.40	0.409
	Male	61-70	16	3.6	5.1	4.33	0.417
	Female	41-50	16	3.8	5.2	4.34	0.427
	Female	51-60	13	3.7	5.4	4.30	0.460

required shape and size of the implant to be fitted at the time of femur replacement surgery with the help of radiographs only.

$$Ho = f(A, Wt, Ht)$$

$$NSA = f(A, Wt, Ht)$$

$$FHD = f(A, Wt, Ht)$$

Where:

A = Age of the patient (years)
Wt = Weight of the patient (kg)
Ht = Height of the patient (cm)

A linear approach was suitable for determination of two dimensional measurements (Isaacson and Keller, 1966). A multiple regression analysis was used to find out the relationship between dependent parameters and independent parameters. The equations derived for each of the groups to get dependent parameters are given below.

Group I: Male/35-50:

$$Ho = 1.836\left[(A)^{0.464}(Wt)^{-0.029}(Ht)^{-0.174}\right]$$

$$NSA = 332.115\left[(A)^{-0.094}(Wt)^{-0.003}(Ht)^{-0.108}\right]$$

$$FHD = 555.101\left[(A)^{-0.079}(Wt)^{-0.102}(Ht)^{-0.803}\right]$$

Group II: Male/51-60:

$$Ho = 789.68\left[(A)^{-0.634}(Wt)^{-0.222}(Ht)^{-1.355}\right]$$

$$NSA = 19.523\left[(A)^{0.096}(Wt)^{-0.037}(Ht)^{0.327}\right]$$

$$FHD = 0.055\left[(A)^{0.0089}(Wt)^{-0.031}(Ht)^{0.872}\right]$$

Group III: Male/61-70:

$$Ho = 4.957\left[(A)^{0.162}(Wt)^{-0.415}(Ht)^{0.16}\right]$$

$$NSA = 51.93\left[(A)^{0.201}(Wt)^{0.105}(Ht)^{-0.069}\right]$$

$$FHD = 0.241\left[(A)^{1.136}(Wt)^{0.2507}(Ht)^{-0.575}\right]$$

Group IV: Female/41-50:

$$Ho = 13.928\left[(A)^{-0.642}(Wt)^{-0.017}(Ht)^{0.239}\right]$$

$$NSA = 69.625\left[(A)^{0.066}(Wt)^{-0.058}(Ht)^{0.122}\right]$$

$$FHD = 0.0442\left[(A)^{0.449}(Wt)^{-0.107}(Ht)^{0.652}\right]$$

Group V: Female/51-60:

$$Ho = 2614.49\left[(A)^{-1.47}(Wt)^{-0.355}(Ht)^{0.162}\right]$$

$$NSA = 47.218\left[(A)^{0.331}(Wt)^{0.106}(Ht)^{-0.147}\right]$$

$$FHD = 3.238\left[(A)^{0.273}(Wt)^{-0.277}(Ht)^{0.0599}\right]$$

In the fifth and last step mathematical models for all five groups were validated with the measured values from the radiographs of the hip joint.

Table 3: Calculated vs. measured parameters (average)

		Ho-average		NSA-average		FHD-average	
Gender	Age group	Calculated	Measured	Calculated	Measured	Calculated	Measured
Male	35-50	3.817	3.818	132.39	131.76	4.36	4.32
	51-60	3.84	3.84	131.60	131.66	4.406	4.40
	61-70	3.8125	3.81	131.875	131.87	4.3375	4.3375
Female	41-50	3.7666	3.882	131.246	131.272	4.322	4.345
	51-60	3.7914	3.815	130.669	131.076	4.276	4.307

Table 4: Regression line equation and correlation coefficient

		Parameters obtained through models					
		Horizontal offset (Ho)		Neck shaft angle (NSA)		Femoral head diameter (FHD)	
Gender	Age group	Regression line	R^2	Regression line	R^2	Regression line	R^2
Male	35-50	y = 1.307x -1.174	0.928	y = 2.019x -135.6	0.904	y = 1.159x -0.727	0.917
	51-60	y = 0.886x +0.444	0.929	y = 1.032x -3.377	0.969	y = 1.224x -0.911	0.956
	61-70	y = 1.390x -1.472	0.927	y = 1.075x -10.46	0.930	y = 1.129x -0.536	0.946
Female	41-50	y = 2.207x -4.431	0.966	y = 2.163x -152.7	0.923	y = 1.377x -1.607	0.937
	51-60	y = 1.087x -0.308	0.95	y = 0.975x + 3.671	0.938	y = 1.532x -2.247	0.952

RESULTS

Table 3 showed all results of mean value of horizontal offset, neck shaft angle and femoral head diameter of all subjects arranged gender-wise and age group wise. All above equations were used to obtain mean values of Ho, NSA and FHD. Variations in measured and calculated value of all three parameters were noted. The mathematical models of all age group and both gender were successful in extracting good results. Each calculated value and measured value of all three parameters was used to obtain regression line equation and ultimately correlation was derived. Table 4 showed all results of regression line and coefficient of correlation, each calculated value of Ho, NSA and FHD was compared with measured value and good agreement was found between all parameters.

Total 15 graphs were obtained for male and female subjects of all age groups for Ho, NSA and FHD parameters. All graphs showed correlation coefficient more than 0.9 for all categories indicating the good relationship between measured and calculated parameters.

DISCUSSION

It was revealed that, the geometric parameters of the femur bone can be predicted prior to surgery, which will help surgeons to preplan and simulate surgery. Preoperative understanding of femur geometry is essential for the preparation of surgical procedures and the success of such surgeries depend on good prediction of unknown variable parameters. In this method conventional X-ray technique has been used for understanding the femur bone geometry. This study showed unique results which are yet untouched. Similar kinds of studies were carried out, but this was the first attempt to obtain geometry of femur using anthropometric data.

Nelson and Megyesi (2004) studied sex and ethnic differences in bone architecture. One of the limitations of these models was that, ethnic variations in femur geometry were not counted though these differences are less. Clark *et al.* (1987) revealed that, there were substantial variations in neck shaft angle, horizontal offset from person to person. There were substantial geographical differences in femoral geometry (Crabtree *et al.*, 2000; Greendale *et al.*, 2003). Sena and Piyasin (2008) studied contour of skull using 2-dimesional image data where as Buranarugsa and Houghton (1991) studied contour of skull using cartesian coordinate data. Schenkar *et al.* (1999) explained the application of advanced technologies to achieve physical models of bone. But these models do not require any type of technology or computational work. Only requirement is to measure various anthropometric parameters carefully. Hildebolt *et al.* (1990) illustrated the use of three dimensional CT measurements to find out skull contours. Clark *et al.* (1987) studied the neck orientation with respect to femur geometry. Many studies (Gnudi *et al.*, 1999; Isaac *et al.*, 1998; Kukla *et al.*, 2002; Jain *et al.*, 2005) have worked on finding one of the parameters of the femur geometry. The suggested approach for obtaining overall geometry of femur bone was simplest and quite accurate. However, predicted results are based on the measured/observed anthropometric data; it is sometimes subjected to variations by the system utilized. The suggested model will enable surgeons to imagine and preplanning of operation prior to the actual operation.

CONCLUSION

This approach was a novel approach, which showed good results and potential in making use in practice. Surgeons do not require any computational skills and use of any high end imaging tools like computed tomography or magnetic resonance imaging. It helps in selection of proper femur implant and hence may decrease the lead time and operation time. However, the correctness of geometry of femur obtained by the mathematical models must be clinically confirmed before implanting the femur prosthesis.

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