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Original Research Article

A Study of Morphological Variations in Femur: Implications for Use in Orthopedic Procedures

Lakshmi Verma[1*], Varsha Porwal[1**], Tuhin Ghulyani[2*]

[1]PG Resident, [2]Senior Demonstrator,
[*]Dept. of Anatomy, Government Medical College, Kota, Rajasthan.
[**]Dept. of Anatomy, Jhalawar Medical College, Jhalawar, Rajasthan.

Corresponding Author: Tuhin Ghulyani

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ABSTRACT

The principal purpose of this study was to contribute to Indian data on femoral geometry. However emphasis has been given on the amount of variability of a parameter, particularly femoral anteversion angle and neck shaft angle, and its clinical application in orthopaedic procedures. For this study a total of 100 (50 right and 50 left) samples of femora were selected from the medical college at Rajasthan. All femora were dried, adult, and intact. Eights parameters were studied: femoral anteversion angle (FNA), neck-shaft angle (NSA), femoral offset (FO), neck width (NW), Anterior/posterior neck length (ANL & PNL), Oblique/Trochanteric-oblique length (OL & TOL). IMAGEJ software analysis of digital photograph of femora was used to evaluate FNA, NSA & FO. Other materials used were vernier caliper and osteometric board. Statistical analysis was done using SPSS. Coefficient of Variation (CV) in percentage (%) was derived and compared with other studies. In the results FNA showed maximum CV (above 40) and NSA showed minimum CV (below 5). Retroversion was noted in 6% of samples. Our results compared well with other Indian as well as foreign studies. It was noted that FNA consistently showed high variability in the results of other authors. Thus our study shows that FNA is a challenge to surgeons (1) for its high CV (2) prevalence of retroversion and (3) wide range. Therefore anatomical variability in individuals should be kept in mind before planning any hip joint surgical procedure for better long-term outcome.

Key words: Femur, neck shaft angle, anteversion angle, retroversion, anthropology.

INTRODUCTION

Morphology and statistical analysis of femoral anthropometry among different populations reveals a great amount of variation. Femoral anthropometric measurements from different countries are supposed to be affected by racial variations in diet, heredity, climate and life style. Studies have shown that proximal femur geometry can be used reliably to distinguish between races. Gill GW [1] (2001) found racial difference in parameters like anterior-posterior (AP) diameter of the proximal femur, intercondylar notch. Other parameter, such as torsion, is also reported to be different among racial populations. [1-3]

Thus the principal purpose of this study was to contribute to Indian data on femoral geometry for their range, bilateral difference and variations. Among all the parameters studied here the emphasis has been given on femoral version and its clinical correlation. The femoral anteversion angle (FNA) is defined as the angle formed by an imaginary transverse line passing through retrocondylar axis and an imaginary transverse line passing through the neck axis. [4] The neck axis is the line drawn from

the centre of the femoral head to the centre of the femoral neck at the narrowest part of the neck. The transcondylar axis is the tangent to the back of the femoral condyles. If the axis of the neck inclines forward to transcondylar axis this torsion is referred as femoral anteversion, anterior twist, antetorsion, medial femoral torsion or 'plus angle'. If it tilts posterior to the retrocondylar axis it is called retroversion, posterior twist, retrotorsion, or 'minus angle'. But if the axis of the neck is in the same line as that of transcondylar axis then it is known as neutral version. [5-8]

In total hip arthroplasty it is important to restore original hip biomechanics. [4,9,10] Therefore it is important to have in depth knowledge about anteversion, offset or neck-shaft angle, as these parameters affect biomechanics and influence the patient's long-term surgical outcome. [11] The FNA is an important parameter in such hip arthroplasties as well as in corrective osteotomies. [9] But the important thing about FNA is that it varies widely, therefore it is important to know the FNA in a particular population to plan the successful femoral neck reconstructive surgery. Failure to recognize the abnormally anteverted or retroverted hip during reconstruction may compromise ultimate hip stability and range of motion. Considerable research has been undertaken in order to establish the optimal orientation for implants, some suggested FNA of implants of 10° to 15°, whereas charnley [10] recommended 0°. Siwach [12] noted that the implants available in India are designed primarily for use in western population. Undersized or overhanging femoral implants causes altered soft-tissue tensioning and altered patella femoral stresses this could cause malunion and avascular necrosis. Thus the outcome of this study may be useful to clinicians and orthopedicians in evaluating patients as well as in designing of implants for Indian population.

Various methods have been used to measure the FNA on dry bones as well as in living subjects, namely measuring the FNA mechanically on dry bones. [8,13-15] as well as in living subjects by using roentgenography, [5,16] ultrasound, [17] computerized tomography]9,18-21] or MRI. [22] Ruwe PA (1992) [23] and Adamczyk E (2010) [24] used physical examination to determine FNA. Estimation of anteversion on dry bone is still considered the most accurate method. In this study, the FNA was evaluated using digital photograph of femur in standardized specimen positioning as well as reference points in IMAGEJ software. [25]

MATERIALS AND METHODS

A total of 100 (50 right and 50 left) samples of femora were selected from the medical college at Rajasthan. Inclusion criteria: dried, adult, completely ossified and intact femora. Exclusion criteria: any femora with damage, degenerative changes, pathology, deformities or previous fractures. Parameters studied are femoral anteversion angle (FNA), neck shaft angle (NSA), femoral offset (FO), neck width (NW), anterior/posterior neck length (ANL/PNL), oblique length (OL) and trochanteric-oblique length (TOL).

For measurement of femoral anteversion angle: cephalocaudal view of each femur was taken. Femur was placed on a flat surface of osteometric board, covered with graph sheet, with posterior surface of its condyles and greater trochanter touching the smooth horizontal surface of the board. The camera was placed parallel to the lines on graph paper. Femur was focused in the center of field of camera in a way that femoral neck axis was perpendicular to camera's view. Digital photograph was taken and transferred to computer thereafter it was analyzed in IMAGEJ software.

Following points were drawn in IMAGEJ software.

1. **Center of the femoral head:** It was defined as the center of the circle best fit for the femoral head.
2. **Center of neck:** It was defined as the midpoint of the narrowest part of antero-posterior thickness of the neck.

3. **The head neck axis**: A line was drawn from the center of femoral head and passing through the midpoint of femoral neck.
4. **Retrocondylar axis:** represented by surface of board and hence a horizontal line in digital photograph.
5. **Femoral ante version angle (FNA):** The angle was measured between the above two lines in the IMAGEJ software. (Fig 1)

For the measurement of NSA and FO: anteroposterior view of each femur was taken. Femur was placed flat on osteometric board, with anterior surfaces facing upwards. The femoral neck was placed parallel to the surface of board by manually rotating the femoral shaft internally and supporting the lateral femoral condyle (if the neck axis was anteverted) or by rotating the femoral shaft externally and supporting the medial condyle (if the neck axis was retroverted). Photographs were taken by placing camera higher in a stand. To measure FO, a measuring scale was kept over the proximal end and included in the digital image to standardize the distance.

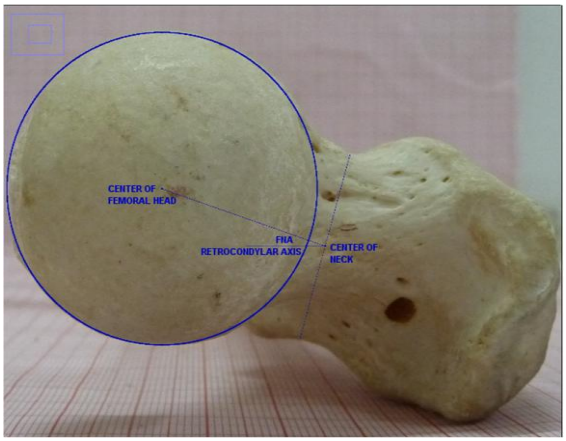

Fig 1: Analysis of the Photograph by 'IMAGEJ software' showing relevant axis and the measurement of femoral anteversion angle (FNA)

OL & TOL were measured using osteometric board. Where, OL is the vertical distance from the highest point of the head to the intercondylar plane; TOL is from the highest point of the greater trochanter to the infra condylar plane. ANL, PNL & NW were recorded using sliding caliper. Where, ANL is the distance from the head-neck border to the midpoint of the intertrochanteric line; PNL is from the base of the head-neck border to the mid-point of the intertrochanteric crest; NW was defined as minimum distance between superior and inferior margins of the neck.

Statistical analysis

Statistical analysis was done by using SPSS software. Results are presented as Mean±SD, 95% confidence interval and range values. Unpaired t-test was used to compare two groups (Right vs Left). Coefficient of Variation (CV) in percentage (%) was derived using following formulae: CV (in %) = Standard Deviationx100 / Mean

RESULTS

Table 1 shows mean Mean ± SD values of the parameters. FNA ranged from -6.67° to 37.41°. Upper limit (UL) and lower limit (LL) of 95% confidence interval (CI) of the parameters are in Table No.1. No significant difference was observed, in left and right side, in any of the parameters measured (p> 0.05). Among hundred samples studied the retroversion was found in six femora (6%). Of these four femora belonged to right side and two were of left side. None of the femora showed neutral version. (Table no 2)

Table 1: Measurements of different parameters

S.no	Parameter n=100	Mean ± SD	CV in %	Minimum	Maximum	UL and LL (95% CI)
1.	FNA	13.45±8.58	63.79	-6.67	37.41	11.77 to 15.13
2.	NSA	124.95±6.09	4.87	112.47	138.75	123.76 to 126.14
3.	FO	35.41±4.91	13.87	25.6	52.4	34.45 to 36.37
4.	OL	406.5±28.29	6.96	350	488	400.96 to 412.04
5.	TOL	389.72±28	7.18	337	465	384.23 to 395.21
6.	ANL	28.79±4.08	14.17	20	39	27.99 to 29.59
7.	PNL	35.59±3.74	10.51	28	45	34.86 to 36.32
8.	NW	24.86±4.07	16.37	17	36	24.06 to 25.66

Table 2: Number of cases of retroversion noted in FNA

FNA side	Number of cases with percentage (%)
Left (n=50)	2 (4%)
Right (n=50)	4 (8%)
Total (n=100)	**6 (6%)**

DISCUSSION

The coefficient of variation is a measure of spread that describes the amount of variability relative to the mean. Because the coefficient of variation is unitless, it can be used to compare distributions obtained with different units. [26] In present study the coefficient of variation (in %) was noted as: in FNA (63.79%), NSA (4.87%), FO (13.87%), ANL (14.17%), PNL (10.51%), NW (16.37%), OL (6.96%) and TOL (7.18%) respectively. The greater the CV the higher is the dispersion of values in data for that parameter. Thus the highest dispersion was noted in the data of FNA. In addition FNA has shown to have a wide range from in adults. [9] Hence the mean alone is not sufficient to determine the true distribution a parameter.

Table 3: Comparison of Coefficient of variation percentage (%CV) T-total, R-right, L-left, M-male, F-female

S.no	Author	Year	Population	FNA CV	NSA CV	FO CV
1.	Reikeras et al [27]	1982	Norwegian	T:64.42% M:67.65%, 60.75%	-	-
2.	Schneider B [22]	1997	German	60.58%	-	-
3.	Sugano et al [18]	1998	Japanese	46.97%	-	-
4.	Massin et al [28]	2000	French	-	-	15.12%
5.	Mahaisavariya et al [29]	2002	Thai	67.28%	4.8%	-
6.	Maruyama et al [30]	2001	Japanese	T:86.73% M:91.83% F:81.63%	3.84%	-
7.	Khang et al [31]	2003	Korean	CT: 59.78% Cadaver:41.34% Total:56.98%	CT:4.78% Cadaver:4.29%	-
8.	Siwach RC [12]	2003	Indian	57.66%	-	-
9.	Umebese et al [5]	2005	Nigerian	-	4.96%	
10.	Saikia KC [19]	2008	Indian	42.16%	-	-
11.	Rokade S [14]	2008	Indian	73.39%	-	-
12.	Shrikant AR [15]	2009	Indian	75.86%		-
13.	Atkinson HD et al [32]	2010	British	-	-	M: 10.51% F:10.77%
14.	Kulig K [17]	2010	American	53.14 (USG) 59.47 (MRI)	-	-
15.	Zalawadia A [8]	2010	Indian	148.39%	-	-
16.	Maheshwari [33]	2010	Indian	58.75%	-	-
17.	Rawal et al [34]	2012	Indian	T: 38.72% M: 55.12%,F: 23.18%	T: 4.41% M: 4.22%,F: 4.40%	-
18.	Gujar et al [35]	2013	Indian	-	T-4.4 % L-3.99 % R-4.91%	-
19.	Koerner [20]	2013	American	T:109.28% M:108.5 F:112.72	-	
20.	Wright et al [21]	2014	Netherlander	Total : 65.08% Males: 75.51% Females: 52.26%	T: 4.03% M: 3.98% F:3.82%	-
21.	Jiang N et al [36]	2015	Chinese	T: 88.33% M: 92.78%,F: 63.06% L: 90.75%,R:86.26 %	T: 3.20% M: 3.28%,F: 2.80% L: 3.14%, R:3.24%	-
22.	Ming Han et al [37]	2015	Chinese	T: 145.95% L: 131.36%,R: 180.23%	T : 3.09% L: 3.57%, R: 3.31%	T: 10.25% L: 11.593% R: 10.27%
23.	Tércio Henrique S. et al [38]	2015	Brazilian	-	L: 7.15% R: 4.18%	L: 18.46% R: 17.82%
24.	Present study	2015-16	Indian	T: 63.79% L: 63.72% R:64.14%	T: 4.87% L: 4.17% R: 5.53%	T : 13.87% L: 12.03% R:15.50%

All these parameters are important in designing the implants for hip joint. When we compared our results with other studies from authors of different countries we noted that our results are comparable with their reported values. In NSA and femoral length the CV was noted to be below 10; In FO, NW and femoral neck length the CV was

below 20. The CV obtained for FO was slightly higher than reported by other authors. Whereas in the case of FNA it was noted that it's high values of CV was reported by all the authors from other countries and working on different populations (Table 3). Therefore CV of FNA was multiple times of CV of other parameters studied, it was mostly above 40. Highest CV was noted in the result of another Indian author Zalawadia A [8] (148.39%). Ming Han et al [37] and Koerner et al [20] also reported values as high as 145.95% and 109.28%. Thus the CV in FNA was substantial in all the studies and the ranges included values which were well beyond what modern prostheses are currently being produced. Greater CV highlights the degree of variability for that parameter. Tayton [3] opined that femoral neck ante version is a result of forces acting through the hip during daily activities. This could be the reason for high variability in this parameter in individuals. Though CV for NSA was as low as 4.87% but high values for FNA is of concern and challenge to clinicians and orthopedicians to produce a range of prosthesis for femur implants which can include values for most of the patient. Such high variability of a parameter should be taken care of while performing surgical procedure.

Table 4: Comparison of Coefficient of variation percentage (%CV)

S. No	Author	Year	FNL Mean (mm)	Femoral length	Neck width
1.	Da Silva [39]	2003	-	R-6.89% L-6.47%cm	-
2.	Calis HT et al [40]	2004	-	-	R-8.21% L-7.78%
3.	Subhash Gujar et al [35]	2013	11.05%	5.85%	-
4.	Baharuddin MY et al [41]	2011	M- 6.2%, F-5.29%	-	M- 11.7%, F-16.61
5.	Tércio Henrique S. et al [38]	2015	TL-14.65%, TR- 14.57%	TL-8.32%, TR-8.26%	TL-12.76% ,TR-11.95%
6.	Present Study • Anterior • Posterior	2015	A:14.17% P:10.51%	OL-6.96% TOL-7.18%	16.37%

In-depth knowledge of morphological variations in femur is important for orthopedicians in procedures like reconstructive surgery of the hip like total hip arthroplasty, femoral stem replacement in hemiarthroplasty surgery, derotation osteotomy of femurs. [30]

FNA should be properly restored in these surgical operations to achieve stability of the prosthetic joints. Femoral neck anteversion is important in reconstructive surgery such as total hip arthroplasty, and many researchers have been undertaken in order to develop the optimal orientation of the hip prosthesis.

Retroversion

The prevalence of retroversion in the present study was 6%. Kingsley (1948) [42] observed that retroversion is a rather frequent finding. Koerner (2013) [20] found high proportion of prevalence of retroversion in ranging from 23.5% in African American females, white males (21.4%), African American males (15.1%), Hispanic males (7.2%) and all groups of females (>14.3%). Furthermore, they observed that nearly 6% of both African American males and females exhibited >10° retroversion. Kate and Robert (1963), [43] Jain AK [44] and Shrikant AR [13] reported it to be 7.7, 9.3 and 9.4% respectively in Indian population. Whereas, one Indian author Dwivedi (2016) [7] observed retroversion in only 2.2% of samples. Hartel MJ (2016) [9] in his study on 1070 CT of femur reported retroversion in 7.8% of the cases. We attribute the reason for difference in results to difference in methodology i.e. difference in reference points and techniques.

Table 5: Comparison of Femoral length

S.No	Author	Year	Region	Right	Left	Mean
1.	Da silva et al [39]	2003	Brazil	40.9 ± 2.82 cm	40.98 ± 2.65cm	-
2.	Subhash gurjar et al [35]	2013	Indian	439.9±25.98mm(N=119)	436.5±25.31mm (N=131)	438±25.64mm(N=250)
3.	Tércio Henrique S. et al [38]	2015	Brazil	F-102.68± 6.19 M- 114.39± 7.23 in mm	F- 102.48± 5.91 M- 114.06± 7.79 in mm	TL-108.27± 9.01 TR-108.57± 8.93 in mm
4.	Present study	2015	Indian	409.84±28.37 mm	403.16±28.1mm	406.5±28.29 mm

While comparing the length of the femur we found similar values on both sides, much like Da silva et al [39] and Ferrario et al. [45] numerically, our values were smaller than those observed by most of the authors. Hoaglund & Low (1980) [46] found among Caucasians a mean of 45.1 cm for men and 43.7 cm for women whereas among Chinese from Hong Kong they found a mean of 43 cm for men and 39 cm for women. Studying Indians Isaac et al [47] and S. Gujar et al [35] observed a mean of 43.47 cm and 43.8 cm respectively. Again we attribute the numerical differences to different morphometric techniques and measuring points. (Table no 5)

CONCLUSION

The purpose of this study is to contribute to Indian data on femoral geometry. Here we also made an attempt to measure FNA by standardized positioning and reference points. Our study further focused on CV in our results and other literature. In our findings, in similarity with other Indian and foreign authors, we observed that NSA exhibited least CV (below 5%) and FNA showed substantial CV (above 40%) among all the parameters studied. Other parameters like FO and NW of proximal femoral geometry showed CV in the range of 10-20. This could be due to variable forces acting on femur in daily activities of the person. Though we observed difference in techniques in measuring FNA and femoral length but comparison of CV has given similar results. Thus our results further emphasize the fact that variability of a parameter should be kept in mind before planning a surgical procedure. FNA is a challenge to surgeons not only for its high CV but also prevalence of retroversion and its wide range. Therefore surgeons have to be careful as it can affect the long term outcome for procedures if its variability is not taken into consideration.

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