|| ISSN(online): 2589-8698 || ISSN(print): 2589-868X ||
International Journal of Medical and Biomedical Studies
Available Online at www.ijmbs.info
NLM(National Library of Medicine ID: 101738825)
Index Copernicus Value 2019: 79.34
Original Research Article Volume 3, Issue 9; September: 2019; Page No. 271-276

Proximal Femoral Morphometry in the Indian Population: Implications for the Design and Selection of Hemiarthroplasty Implants

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Conflict of interest: No conflict of interest.

Abstract

Background: Orthopedic femoral implants are predominantly designed based on Western anthropometric data, which may not accurately reflect the skeletal dimensions of the Indian population. Using ill-fitting implants can lead to periprosthetic fractures, accelerated joint wear, and altered mechanics.

Objective: To perform a detailed osteometric evaluation of the proximal femoral segments in an adult Indian population to provide a reliable database for indigenous implant design.

Material and Methods: An osteometric analysis was conducted on 158 dry, ossified adult human femora. Six parameters were measured using digital calipers and goniometers: Vertical and Transverse Head Diameters (VDH/TDH), Neck-Shaft Angle (NSA), Femoral Neck Length (FNL), Anteroposterior and Vertical Neck Width, and Bi-trochanteric Width.

Results: The mean VDH (45.95 ± 1.59 mm) consistently exceeded the TDH (44.07 ± 1.26 mm), indicating an elliptical head profile. The mean NSA was 128.97° ± 2.60°, showing a significant varus trend compared to Western standards. The Vertical Neck Width averaged 29.40 ± 2.66 mm, though 22.78% of specimens had a width of less than 27 mm, creating a restricted "safety corridor" for internal fixation. Correlation analysis showed no significant relationship between head diameter and neck width (r = -0.027), indicating that these dimensions vary independently.

Conclusion: The Indian proximal femur possesses unique geometric characteristics, including smaller overall dimensions, elliptical head morphology, and a varus-aligned neck. The independence of anatomical variables challenges the logic of "proportional scaling" in manufacturing. These findings advocate for the development of indigenous, modular implants to ensure anatomical congruence and reduce surgical complications in the Indian demographic.

Keywords: Proximal femur, Morphometry, Indian population, Hemiarthroplasty, Orthopedic implants, Vertical neck width.

Introduction

The human femur is the largest and strongest tubular bone in the body, serving as the primary weight-bearing pillar of the appendicular skeleton. Its proximal end is an anatomical masterpiece of biomechanical engineering, characterized by a hemispherical head, a cylindrical neck, and the greater and lesser trochanters.[1] The femoral head, which articulates with the acetabulum to form the hip joint, is designed for multi-axial mobility while sustaining immense compressive forces during locomotion.[2] The spatial orientation of the proximal femur is traditionally defined by two critical angles: the neck-shaft angle (inclination), which averages approximately 135° in adults, and the femoral anteversion angle (torsion). Both are vital for maintaining the lever arm of the abductor muscles and ensuring joint stability.[3]

In clinical practice, the proximal femur is a frequent site of catastrophic morbidity, particularly among the elderly. Femoral neck fractures represent a significant global health burden, often necessitating surgical intervention to restore mobility.[4] Arthroplasty remains the gold standard for these patients. Specifically, hemiarthroplasty—the replacement of the femoral head with a prosthetic component while preserving the natural acetabulum—is the treatment of choice for displaced intracapsular fractures in geriatric patients with lower functional demands.[5] The long-term success of hemiarthroplasty depends on "anatomical congruence," or the precise replication of the patient's native skeletal geometry to ensure optimal load distribution.[6]

Despite the maturity of arthroplasty as a field, surgeons frequently encounter challenges related to prosthetic mismatch. A documented problem is that the majority of commercially available femoral implants were originally designed based on Caucasian anthropometric data. Research has consistently indicated that Western-designed implants may not be ideal for the Asian phenotype. Studies have shown that Indian femora are generally smaller in dimensions and possess different medullary canal shapes compared to Western populations.[7] When an ill-fitting implant is used, it can lead to "overstuffing" of the acetabulum, increased incidence of periprosthetic fractures, and accelerated wear of the acetabular cartilage.[8] Furthermore, a failure to accurately restore the femoral offset leads to altered joint mechanics, causing persistent post-operative pain and abductor limp.[9]

These anatomical variations emphasize the critical need for population-specific morphometric data. While several studies have explored femoral geometry, there remains a gap in comprehensive, standardized data that can guide the indigenous development of implants tailored for the Indian population.[10] Establishing these parameters is not only a forensic necessity for skeletal identification but is fundamentally essential for improving the anatomical fit and clinical survivability of prosthetic components.

The objective of the present study is to perform a detailed osteometric evaluation of the proximal femoral segments in an adult population. By quantifying parameters such as the femoral head diameter, neck length, and neck-shaft angle, this research aims to provide a reliable, population-specific anatomical database. Ultimately, these findings are intended to assist orthopedic surgeons in more precise prosthetic selection and provide engineers with the necessary dimensions to design anatomically congruent hemiarthroplasty implants for the Indian population.

Material and Methods

Study Design

This was a descriptive, cross-sectional osteometric study conducted on dry human femora. The study was carried out in the Department of Anatomy, Saraswati Medical College, Unnao after obtaining requisite clearance from the Institutional Ethics Committee (IEC). As this study utilized anonymous skeletal remains from the department's bone bank, the requirement for informed consent was waived.

Specimen Selection

A total of 158 dry, completely ossified adult human femora of unknown sex and age were selected for analysis. The bones were categorized into right and left sides.

- **Inclusion Criteria**: Only fully ossified femora with intact proximal segments and well-defined anatomical landmarks were included.
- **Exclusion Criteria**: Specimens showing evidence of previous fractures, gross pathological changes (e.g., severe osteoarthritic lipping, Paget's disease, or bone tumors), or significant post-mortem erosion were excluded to ensure the data reflects a "normal" population baseline for prosthetic design.

Instrumentation

All linear measurements were performed using a digital sliding vernier caliper with a precision of 0.01 mm. Angular measurements (Neck-Shaft Angle) were recorded using a stainless steel goniometer or a standardized digital photographic method to ensure accuracy to within 1°.

Definition of Morphometric Parameters

The following five parameters were measured using standardized osteometric techniques:

- **Vertical Diameter of the Head (VDH):** Measured as the maximum distance between the superior and inferior points of the femoral head in the coronal plane, perpendicular to the axis of the neck.
- **Transverse Diameter of the Head (TDH):** The maximum diameter of the femoral head measured in a plane perpendicular to the vertical diameter.
- **Neck-Shaft Angle (NSA):** Also known as the Angle of Inclination; it is the angle formed by the intersection of the long axis of the femoral shaft and the long axis of the femoral neck.
- **Femoral Neck Length (FNL):** Measured on the anterior surface as the distance between the base of the femoral head and the intertrochanteric line along the mid-axis of the neck.

- **Bi-trochanteric Width:** The distance between the most lateral point of the greater trochanter and the most medial point of the lesser trochanter, a critical dimension for assessing the "proximal flare" for stem fixation.

Measurement Protocol and Technical Error of Measurement (TEM)

To eliminate inter-observer bias, all measurements were conducted by a single investigator. To ensure intra-observer reliability and minimize the Technical Error of Measurement (TEM), each parameter was measured twice on separate occasions. If the difference between the two measurements exceeded 1%, a third measurement was taken, and the median value was recorded as the final data point.

Statistical Analysis

The collected data were entered into a Microsoft Excel spreadsheet and subjected to statistical analysis using SPSS (Version 23.0, IBM Corp.). Descriptive statistics, including the Mean, Standard Deviation (SD), and Range (Minimum and Maximum), were calculated for all parameters. The Student's t-test was employed to identify significant differences between the right and left sides. A p-value of <0.05 was considered statistically significant.

RESULTS

The morphometric analysis was conducted on 158 proximal femur specimens. A comprehensive summary of the linear and angular measurements is presented in Table 1. The data set demonstrated significant variability across all parameters, with the Vertical Neck Width showing the widest relative range.

Table 1: Descriptive Statistics of Proximal Femur Morphometry (n=158)

Parameter	Mean ± SD	95% CI	Median	Range (Min - Max)
Vertical Head Diameter (VDH)	45.95±1.59 mm	45.70−46.20	46.05	43.06−48.45
Transverse Head Diameter (TDH)	44.07±1.26 mm	43.87−44.27	44.15	42.01−46.44
Neck-Shaft Angle (NSA)	128.97∘±2.60∘	128.57−129.38	129	125.00−133.00
Femoral Neck Length (FNL)	31.65±1.98 mm	31.34−31.96	31.91	28.08−34.95
Anteroposterior Neck Width	23.82±1.26 mm	23.62−24.02	23.93	21.54−25.98
Vertical Neck Width	29.40±2.66 mm	28.98−29.82	29.4	25.05−34.06
Bi-trochanteric Width	32.85±2.04 mm	32.52−33.17	32.8	29.26−36.24

Femoral Head and Neck Analysis

The morphometric assessment revealed a mean Vertical Diameter of the Head (VDH) of 45.95 ± 1.59 mm, which consistently exceeded the Transverse Diameter (TDH) of 44.07 ± 1.26 mm. This difference indicates a slightly elliptical head profile, elongated in the vertical plane, with a mean Head Index of 96.05.

The Neck-Shaft Angle (NSA) exhibited a mean of 128.97° ± 2.60°. While the average falls within the standard anatomical range, the distribution indicates a significant inclination toward the lower (varus) end of the spectrum compared to Western benchmarks (typically 130° –135°). Specifically, the median NSA was 129°, and 65.2% of the specimens demonstrated an NSA of 130° or less.

The frequency distribution of the NSA was as follows:

- 120° – 125°: 18 specimens (11.4%)
- 126° – 130°: 85 specimens (53.8%)
- 131° – 135°: 55 specimens (34.8%)

In this cohort, the majority of specimens (53.8%) clustered in the 126° –130° range. Notably, no specimens reached the higher valgus threshold (>135°), reinforcing that even the upper limits of this population remain conservative compared to global orthopedic design standards.

Critical Width Parameters

The Vertical Neck Width, which serves as the primary anatomical constraint for the placement of internal fixation screws, averaged 29.40 ± 2.66 mm. While the mean suggests a sufficient corridor for standard hardware, the lower bound of the observed range (25.05 mm) highlights a significant subgroup of the population (22.8%, n=36) with a vertical width of less than 27 mm. This indicates restricted dimensions for the safe placement of multiple large-diameter cannulated screws or standard femoral nails.

The Anteroposterior (AP) Neck Width was consistently narrower than the vertical width, with a mean of 23.82 ± 1.26 mm. This dimensional difference reinforces the elliptical and flattened (platymeric) morphology of the femoral neck in this cohort.

The Bi-trochanteric Width showed a mean of 32.85 ± 2.04 mm. This parameter exhibited a stable distribution, with a 95% Confidence Interval of 32.52 mm to 33.17 mm. The relatively narrow range of this measurement across all 158 specimens suggests it is a reliable anatomical benchmark for assessing the lateral profile of the proximal femur in this demographic.

Anatomical Indices and Shape Analysis

To move beyond linear dimensions, we evaluated the geometric shape through two primary indices:

- **Femoral Neck Index (FNI):** The mean index was 81.64 ± 8.20. This confirms a platymeric (flattened) neck shape across the cohort. The wide range (65.29 - 100.87) indicates significant individual variation, with some specimens exhibiting extreme vertical elongation relative to their AP width.
- **Head Index:** The mean index of 96.05 ± 4.73 suggests that the femoral head in this population is generally "taller" (vertical diameter) than it is "wide" (transverse diameter), deviating from a perfect sphere (100.00).

Correlation and Independent Variability

Pearson correlation analysis was performed to determine if proximal femoral dimensions could be predicted based on head size or overall width. The correlation between Vertical Head Diameter (VDH) and Vertical Neck Width was found to be negligible (r = -0.027). Similarly, there was no significant correlation between Bi-trochanteric Width and the Neck-Shaft Angle (NSA) (r = -0.072).

These results indicate that proximal femoral dimensions vary independently in this population. Statistically, a larger femoral head does not necessitate a wider femoral neck, nor does a wider bi-trochanteric profile predict a more obtuse neck-shaft angle. This lack of linear scaling underscores the importance of modularity in orthopedic design to accommodate independent geometric variations.

Surgical Sizing Vulnerability Analysis

From a clinical standpoint, the Vertical Neck Width represents the primary anatomical constraint for internal fixation. In this cohort, 22.78% (n=36) of specimens presented with a vertical neck width of less than 27 mm. Such dimensions significantly limit the safety margin for the insertion of standard 6.5 mm or 7.3 mm cannulated screws, particularly when attempting a stable triangular configuration. These findings highlight a substantial portion of the population at higher risk for cortical impingement or iatrogenic fracture if conventional Western-sized hardware is utilized without pre-operative morphometric consideration.

Figure A: The Vertical Head Diameter (VDH).

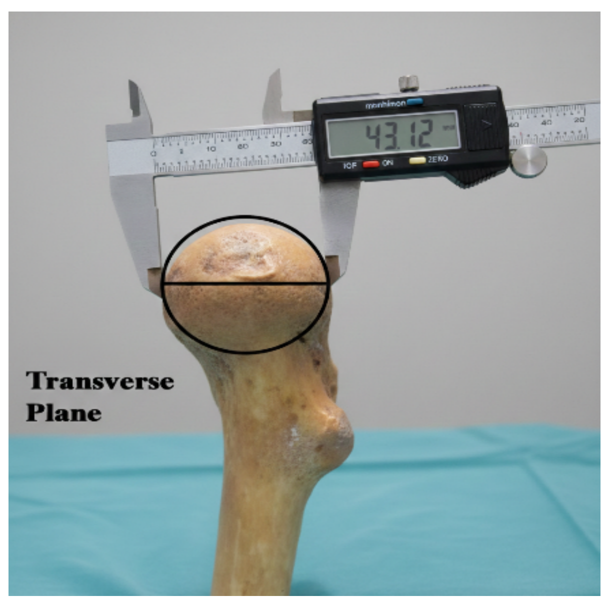

Figure B: The Transverse Head Diameter (TDH)

Figure C: The Vertical Neck Width.

Figure D: The Neck Shaft Angle

DISCUSSION

The proximal femoral morphometry observed in this study (n=158) demonstrates distinct anatomical characteristics that differ significantly from global averages often used in the design of orthopedic implants. Our findings reinforce the premise that the Indian population possesses a smaller skeletal frame with unique geometric proportions, particularly regarding the femoral head sphericity and neck-shaft alignment (Siwach & Dahiya, 2003).[10]

The Clinical Significance of Head Sphericity and Dimensions

The mean Vertical Head Diameter (VDH) of 45.95 ± 1.59 mm and Transverse Head Diameter (TDH) of 44.07 ± 1.26 mm in our cohort are substantially smaller than those typically reported in Western literature, which often exceed 50 mm (Noble et al., 1988)[6]. Furthermore, our calculated Head Index of 96.05 indicates a slightly elliptical profile. As highlighted by Mahaisavariya et al. (2002)[11], using a standard spherical implant in a population with elliptical head morphometry can lead to localized stress concentration and accelerated acetabular wear. For surgeons, this underscores the necessity of population-specific acetabular and femoral head sizing to optimize the "fit and fill" in total hip arthroplasty.

Neck-Shaft Angle (NSA) and Biomechanical Leverage

The mean NSA in our study was 128.97° ± 2.60°, with a significant clustering (53.8%) between 126° and 130°. While this falls within the traditionally accepted "normal" range, it trends toward a more varus alignment compared to the standard 135° often found in generic implants. Thipse JD et al. (2016) noted that a varus trend in the Indian population significantly alters the biomechanical moment arm. A lower NSA increases the bending moment across the femoral neck, which can increase the risk of fatigue failure in implants not specifically rated for such load profiles (Husmann et al., 1997)[8]. In our cohort, the absence of any specimens above 133° strongly suggests that high-valgus implants are anatomically mismatched for this demographic.

The "Safety Corridor": Surgical Implications of Vertical Neck Width

The Vertical Neck Width remains the most critical anatomical constraint for internal fixation. Our mean value of 29.40 ± 2.66 mm is consistent with other Indian studies.[12] Crucially, 22.78% (n=36) of our specimens possessed a neck width of less than 27 mm. In such cases, the insertion of three parallel 6.5 mm or 7.3 mm cannulated screws for neck fractures becomes technically hazardous. As noted by Mavrogenis AF et al. (2017)[13], insufficient bone bridging between screws in a narrow neck increases the risk of iatrogenic fracture or "cortical blowout" during hardware insertion. This finding advocates for the use of smaller-profile fixation devices or personalized surgical planning for nearly a quarter of the patients in this population.

Independence of Variables and Modular Design

A pivotal finding of this study is the negligible correlation between Vertical Head Diameter and Vertical Neck Width (r = -0.027). This statistical independence suggests that larger individuals do not necessarily possess proportionally wider femoral necks. This challenges the engineering logic of "proportional scaling" in medical device manufacturing. Yang Y et al. (2019)[14] argued that because proximal dimensions vary independently, a modular implant system is superior to a monolithic one for Asian patients, as it allows for the independent selection of head diameter and neck thickness.

CONCLUSION

It was concluded in the study that the proximal femoral morphometry in the Indian population differs significantly from the Western anthropometric data traditionally used in orthopedic implant design. The findings reveal that Indian femora are generally smaller, featuring an elliptical head profile and a more varus neck-shaft angle with a mean of 128.97°. Furthermore, the lack of correlation between dimensions such as head diameter and neck width indicates that these parameters vary independently, challenging the efficacy of "proportional scaling" in manufacturing. Consequently, the study emphasizes the critical need for indigenous, modular, and population-specific implants to ensure anatomical congruence and minimize surgical risks like iatrogenic fractures or accelerated acetabular wear.

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