Original Research Article

MORPHOMETRIC ANALYSIS OF THE PROXIMAL FEMUR AND ITS CORRELATION WITH IMPLANT SELECTION IN TOTAL HIP ARTHROPLASTY

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ABSTRACT

Background: Accurate morphometric evaluation of the proximal femur is essential for optimal implant selection and alignment in total hip arthroplasty (THA). Anatomical variations in femoral neck-shaft angle, canal geometry, and metaphyseal–diaphyseal morphology differ across populations, and mismatches between implant design and native anatomy may compromise biomechanics and long-term outcomes. Data specific to Indian patients, directly relating proximal femoral morphometry to implant choice, remain limited. The aim is to assess proximal femoral morphometric parameters in an Indian population and determine their correlation with implant selection for total hip arthroplasty.

Materials and Methods: A prospective observational morphometric study was conducted over 18 months at a tertiary-care teaching hospital in India. One hundred and eighty adult patients (180 hips) undergoing hip imaging for orthopaedic indications were consecutively enrolled after applying predefined inclusion and exclusion criteria. Standardised anteroposterior pelvic radiographs and CT-based measurements (where indicated) were used to evaluate femoral head diameter, neck diameter, neck-shaft angle, femoral offset, canal diameters at predetermined levels, canal flare index, and cortical indices. Based on these parameters, each femur was matched to the most appropriate THA implant category (standard stem, high-offset stem, short metaphyseal stem, diaphyseal-engaging stem, or customised stem). Statistical analysis included correlation coefficients, subgroup comparisons, and regression modelling.

Results: Marked variability in proximal femoral morphology was observed within the study population. Canal flare index, metaphyseal width, and canal diameters 20–40 mm below the lesser trochanter showed strong correlations with recommended implant type. High-offset stems were more frequently indicated in femora with higher neck-shaft angles and relatively narrow canals, whereas metaphyseal-filling stems suited femora with higher canal flare indices and broader metaphyseal regions. Regression analysis identified canal diameter at 20 mm and 40 mm below the lesser trochanter and femoral offset as significant predictors of implant category. These findings emphasise the importance of population-specific morphometric profiles in THA planning.

Conclusion: Proximal femoral morphometry in Indian patients demonstrates considerable variation, with direct implications for implant selection in total hip arthroplasty. Systematic morphometric assessment enhances the accuracy of implant choice, supports anatomical reconstruction, and may reduce complications. Incorporating structured morphometric evaluation into routine preoperative planning is recommended for optimising THA outcomes.

Keywords: Proximal femur; morphometry; total hip arthroplasty; implant selection; femoral canal; neck-shaft angle; canal flare index.

INTRODUCTION

Total hip arthroplasty (THA) is one of the most successful and widely performed orthopaedic procedures, offering substantial pain relief and functional improvement in patients with end-stage hip pathology.[1] The long-term success of THA depends not only on surgical technique and implant material but also critically on precise anatomical reconstruction of the proximal femur. Restoration of femoral offset, leg length, neck-shaft angle, and canal alignment is essential to achieve optimal biomechanics, reduce dislocation risk, minimise polyethylene wear, and enhance implant longevity.[2] The proximal femur demonstrates considerable anatomical diversity across ethnic groups, geographic regions, and even within the same population. These variations influence stem sizing, implant configuration, femoral preparation techniques, and the risk of intraoperative complications such as femoral fractures or suboptimal component positioning.[3] Indian populations, in particular, are known to have narrower femoral canals, lower femoral head diameters, and distinct metaphyseal–diaphyseal morphology compared to Caucasian or East Asian populations. Despite these differences, most commercially available THA implants are based on Western anatomical datasets, which may not accurately match the native femoral anatomy of Indian patients.[4]

Morphometric analysis of the proximal femur provides valuable quantitative data that can guide preoperative templating, improve implant selection, and enhance overall surgical accuracy. Key morphometric parameters such as canal flare index, metaphyseal diameter, femoral head size, cortical thickness, and neck-shaft angle have been closely linked to the need for specific implant categories including standard stems, high-offset stems, short metaphyseal stems, and customised prostheses. Understanding these relationships assists surgeons in selecting the most appropriate implant, thereby reducing operative challenges and improving functional and radiological outcomes.[5,6]

Existing literature from India on femoral morphometry remains limited, often based on small sample sizes or cadaveric analyses, and lacks detailed correlation with implant selection for THA. A comprehensive, imaging-based morphometric evaluation in a larger, clinically relevant population is essential to refine implant planning and tailor prosthesis selection to the anatomical needs of Indian patients.

Therefore, it is of interest to conduct a detailed morphometric analysis of the proximal femur in an Indian population and evaluate its correlation with implant choice in total hip arthroplasty.

MATERIALS AND METHODS

Study Design: This was a prospective observational morphometric study conducted to analyse proximal femoral anatomy and correlate morphometric parameters with implant selection for total hip arthroplasty (THA).

Study Setting and Duration: The study was conducted in the Department of Orthopaedics of a tertiary-care teaching hospital in India over a period of 18 months (January 2023 to June 2024).

Sample Size Determination: The sample size was calculated to estimate mean morphometric parameters (such as femoral head diameter and canal dimensions) with acceptable statistical precision using the standard formula for continuous variables:

$$n = \frac{Z_{\alpha/2}^2 \cdot \sigma^2}{d^2}$$

Where:

Z_(α/2)=1.96for 95% confidence

σ=5.4mm (standard deviation of femoral head diameter reported in Indian morphometry studies)

d=1.0mm (desired precision)

$$n = (1.96)^2 \times (5.4)^2 \approx 111$$

To allow subgroup comparisons and to compensate for potential exclusions due to technical or anatomical factors, the sample size was inflated by 30%, yielding approximately 144 subjects.

To further strengthen analytical power and achieve a robust dataset, a total of 180 proximal femora (180 patients) were finally included in the study.

Study Population

Consecutive adult patients undergoing hip imaging for routine orthopaedic evaluation were screened. Only images demonstrating normal hip morphology suitable for morphometric analysis were included.

Inclusion Criteria

- Adults aged 18–80 years
- Normal proximal femoral anatomy
- High-quality digital radiographs and/or CT scans
- No previous hip surgeries

Exclusion Criteria

- Proximal femoral fractures
- Hip dysplasia, Perthes disease sequelae, slipped capital femoral epiphysis
- Tumours, infections, or deformities affecting native morphology
- Poor-quality or distorted imaging

Imaging Protocol

All subjects underwent standardised imaging as follows:

1. Pelvis X-ray (AP view)

- Feet internally rotated 15°
- Beam centered at pubic symphysis
- Film-to-focus distance: 100–110 cm
- Digital measurement software (PACS) used for calibration

2. CT Scanning: CT scans were performed in selected cases (n = 62) where detailed canal geometry assessment was necessary.

- Slice thickness: 1–1.25 mm
- Multiplanar reconstruction enabled precise axial and coronal measurements.

Morphometric Parameters Assessed

Femoral Head and Neck Measurements

- Femoral head diameter
- Femoral neck diameter (AP and ML)
- Femoral neck length
- Neck-shaft angle
- Femoral offset

Metaphyseal and Diaphyseal Canal Dimensions

Measured at:

- Level of lesser trochanter
- 20 mm below lesser trochanter
- 40 mm below lesser trochanter
- Femoral isthmus

Derived Functional Indices

- Canal Flare Index (CFI)

$$CFI = \frac{\text{Metaphyseal width}}{\text{Isthmus width}}$$

- Cortical thickness index
- Metaphyseal–diaphyseal mismatch assessment
- Canal morphology classification (stovepipe, normal, champagne-flute)

Implant Selection Correlation

Based on morphometric data, each femur was mapped to the most appropriate THA implant category:

- Standard cementless stem
- High-offset stem
- Short metaphyseal-engaging stem
- Diaphyseal-engaging long stem
- Customised femoral stem

Selection was based on:

- Variation in neck-shaft angle
- Canal diameters at key levels
- Canal flare index
- Offset requirements
- Overall canal shape and metaphyseal geometry

Data Collection and Reliability

Two independent orthopaedic surgeons measured all parameters.

- Mean of the two readings used for analysis
- Inter-/intra-observer reliability calculated using Intraclass Correlation Coefficient (ICC)

Statistical Analysis

- Continuous variables: mean ± SD
- Categorical variables: percentages
- Correlation analysis: Pearson correlation
- Subgroup comparisons: t-test/ANOVA
- Predictive modelling: multivariate linear and logistic regression
- Statistical significance: $P < 0.05$

Ethical Approval

Ethical clearance was obtained from the Institutional Ethics Committee, and written informed consent was obtained from all participants.

RESULTS

A total of 180 proximal femora from 180 adult patients were analysed over the 18-month study period. There was considerable variation in proximal femoral morphology across the study population. Femoral head diameter, neck dimensions, and canal diameters showed wide anatomical dispersion, reflecting population-specific variability. The mean neck-shaft angle demonstrated a physiologic range consistent with Indian morphometric characteristics. Metaphyseal and diaphyseal canal measurements exhibited distinct differences, enabling clear classification of canal shapes into normal, stovepipe, and champagne-flute configurations. The canal flare index displayed strong variability and served as an important indicator of metaphyseal–diaphyseal morphology. Correlation analysis demonstrated that canal diameters at 20 mm and 40 mm below the lesser trochanter were highly predictive of implant category. Femoral offset and neck-shaft angle were also significantly associated with the need for high-offset stems. Regression modelling further confirmed metaphyseal width and canal flare index as strong predictors of metaphyseal-engaging stem suitability. Overall, morphometric characteristics of the Indian population indicated the need for more customised or high-offset implants in a significant proportion of femora.

Table 1: Demographic characteristics of the study population (n = 180)

Variable	Category	Number (%)
Age (years)	18–40	62 (34.4%)
	41–60	81 (45.0%)
	>60	37 (20.6%)
Sex	Male	104 (57.8%)
	Female	76 (42.2%)

This table presents the demographic distribution of the study participants.

Table 2: Femoral head and neck morphometry (n = 180)

Parameter	Mean ± SD
Femoral head diameter (mm)	44.8 ± 3.9
Femoral neck diameter (AP) (mm)	31.2 ± 3.4
Femoral neck diameter (ML) (mm)	25.6 ± 2.8
Femoral neck length (mm)	35.7 ± 4.1

This table summarises proximal femoral head and neck dimensions.

Table 3: Femoral neck–shaft angle and offset measurements

Parameter	Mean ± SD
Neck-shaft angle (°)	131.4 ± 4.6
Femoral offset (mm)	38.9 ± 5.2

This table outlines angular and offset parameters.

Table 4. Canal diameters at key reference levels (n = 180)

Level	Mean Diameter (mm)
At lesser trochanter	28.4 ± 3.1
20 mm below LT	20.6 ± 2.7
40 mm below LT	17.9 ± 2.4
Femoral isthmus	13.1 ± 1.9

This table illustrates diaphyseal and metaphyseal canal widths.

Table 5: Metaphyseal and diaphyseal morphology (n = 180)

Parameter	Mean ± SD
Metaphyseal width (mm)	39.2 ± 4.3
Cortical thickness index	0.62 ± 0.08
Medullary canal width (isthmus) (mm)	13.1 ± 1.9

This table compares metaphyseal and diaphyseal structural parameters.

Table 6: Canal flare index distribution

CFI Category	CFI Range	Number (%)
Stovepipe	<3.0	34 (18.9%)
Normal	3.0–4.7	102 (56.7%)
Champagne-flute	>4.7	44 (24.4%)

This table depicts the distribution of canal flare patterns.

Table 7: Classification of femoral canal shape (n = 180)

Canal Shape	Number (%)
Normal	108 (60.0%)
Stovepipe	41 (22.8%)
Champagne-flute	31 (17.2%)

This table demonstrates femoral canal shape distribution.

Table 8: Morphometric predictors of implant category (univariate correlation analysis)

Parameter	Correlation (r)	P-value
Offset → high-offset stem	0.61	<0.001
NSA → high-offset stem	0.47	<0.001
Canal diameter @20 mm → stem size	0.72	<0.001
Canal flare index → metaphyseal stem	0.69	<0.001

This table presents correlation values for key morphometric predictors.

Table 9: Implant category distribution based on morphometry (n = 180)

Implant Category	Number (%)
Standard stem	68 (37.8%)
High-offset stem	49 (27.2%)
Short metaphyseal-engaging stem	36 (20.0%)
Diaphyseal long stem	17 (9.4%)
Customised stem	10 (5.6%)

This table summarises implant type recommendations derived from measurements.

Table 10: Regression analysis for predictors of implant selection

Predictor	Adjusted β / OR	95% CI	P-value
Canal diameter @ 20 mm	β = 0.41	—	<0.001
CFI	β = 0.36	—	<0.001
Femoral offset	β = 0.28	—	0.002
Neck-shaft angle	β = 0.21	—	0.009

This table details independent predictors of implant type obtained from multivariate regression.

Table 11: Interobserver reliability (ICC values)

Parameter	ICC
Femoral head diameter	0.94
Neck-shaft angle	0.92
Canal diameter @ 20 mm	0.96
Canal flare index	0.91

This table reports measurement reliability across observers.

Table 12: Side-wise comparison (Right vs Left femora)

Parameter	Right (n=92) Mean ± SD	Left (n=88) Mean ± SD	P-value
Head diameter (mm)	44.9 ± 4.0	44.7 ± 3.8	0.72
NSA (°)	131.6 ± 4.5	131.2 ± 4.6	0.48
Canal diameter @20 mm (mm)	20.7 ± 2.6	20.5 ± 2.8	0.61

This table compares morphometric symmetry.

[Table 1] describes the demographic characteristics of the study population, showing a predominance of middle-aged adults and a slightly higher male representation, indicating the clinical profile of patients undergoing hip imaging in this centre. [Table 2] summarises the femoral head and neck morphometry, revealing substantial variation in femoral head diameter and neck dimensions, which highlights the anatomical diversity relevant for selecting implant head size and neck compatibility. [Table 3] outlines the neck-shaft angle and femoral offset distribution, demonstrating a wide range of angular anatomy and offset values that directly influence the requirement for standard versus high-offset stems during THA. [Table 4] presents canal diameters at key anatomical levels, showing progressive tapering from the metaphysis to the diaphysis and identifying canal width as a primary determinant of stem size and design. [Table 5] highlights key metaphyseal and diaphyseal structural indices, including cortical thickness and medullary canal width, which assist in predicting implant fixation strategies and stem fit. [Table 6] depicts the classification of canal flare index patterns, showing that normal CFI morphology predominates, but a substantial number of stovepipe and champagne-flute canals exist, necessitating tailored implant selection. [Table 7] compares the distribution of canal shape categories and reinforces the variability between normal, stovepipe, and champagne-flute configurations, emphasizing the importance of recognising canal configuration before stem selection. [Table 8] demonstrates significant correlation patterns between morphometric parameters and implant choices, identifying canal diameter at 20 mm, neck-shaft angle, and femoral offset as key predictors guiding selection of stem type. [Table 9] details the implant category distribution derived from morphometric findings, showing that standard stems are most common but high-offset stems and short metaphyseal stems are required in a large proportion of patients. [Table 10] identifies independent predictors of implant choice through multivariate regression, confirming canal diameter, CFI, offset, and NSA as the strongest determinants of whether a standard, high-offset, or metaphyseal stem is most appropriate. [Table 11] reports excellent inter-observer reliability across all major morphometric measurements, confirming the reproducibility and accuracy of the measurement methodology applied in this study. [Table 12] evaluates side-wise morphological symmetry and shows no significant differences between right and left proximal femora, supporting the use of contralateral templating when required.

DISCUSSION

The present study provides a detailed morphometric evaluation of the proximal femur in an Indian population and demonstrates how anatomical parameters correlate with implant selection for total hip arthroplasty (THA). The findings highlight substantial variability in proximal femoral dimensions and canal morphology, underscoring the need for population-specific morphometric databases to support accurate preoperative planning.[7,8]

The demographic distribution showed that the majority of patients belonged to the 41–60 year age group, reflecting the typical population undergoing hip imaging in tertiary orthopaedic centres. The balanced representation of sexes strengthens the applicability of the morphometric findings across genders.[9]

Femoral head and neck measurements revealed marked variability in head diameter, neck diameter, and neck length. These parameters are critical determinants of prosthetic head size selection, neck compatibility, and restoration of hip biomechanics.[10] The mean femoral head diameter observed aligns with earlier Indian studies, which consistently report smaller head sizes compared with Western populations. These differences emphasise the importance of avoiding direct application of Western implant templates when templating Indian hips.[11]

The neck-shaft angle (NSA) in this study demonstrated a mean value of approximately 131°, consistent with known Indian anatomical characteristics and slightly higher than Caucasian averages. Variations in NSA significantly influenced implant offset selection hips with higher NSA frequently required high-offset stems to maintain appropriate abductor tension and reduce the risk of limping. Femoral offset showed substantial individual variation, which also influenced whether a standard or high-offset stem was needed to restore native biomechanics.[12,13]

Metaphyseal and diaphyseal canal measurements were among the most important findings of the study. Canal diameters at 20 mm and 40 mm below the lesser trochanter demonstrated strong predictive value for stem size and type.[14] These levels represent the upper diaphyseal region where cementless stems achieve primary stability, making these measurements essential for accurate stem selection. The progressive tapering from metaphysis to isthmus was clearly defined and supports the utility of digital templating for predicting stem fit.[15]

The canal flare index (CFI) distribution indicated that a normal pattern was most common, but a significant number of hips demonstrated stovepipe or champagne-flute configurations. Stovepipe morphology predisposes to poor metaphyseal fit and therefore favours diaphyseal-engaging or customised stems. Conversely, champagne-flute femora accommodate metaphyseal-engaging stems more effectively. Recognition of these patterns preoperatively reduces intraoperative stem selection mismatch.[16]

Correlation analyses demonstrated strong associations between canal dimensions, offset, NSA, and implant category. Regression modelling identified canal diameter at 20 mm below the lesser trochanter as the strongest independent predictor of implant category, reinforcing the importance of diaphyseal measurements in cementless THA planning. CFI, offset, and NSA also showed significant predictive influence. These quantitative correlations provide objective criteria that can augment or refine the surgeon's preoperative templating process.[17,18]

The implant category distribution showed that although standard stems were suitable in a majority of hips, a considerable proportion required high-offset stems, short metaphyseal stems, or even customised stems. This highlights a crucial point: Indian femoral anatomy does not always conform to Western implant design assumptions, and reliance on standard templates may risk malalignment, inadequate canal fill, or suboptimal restoration of biomechanics.[19]

The measurement reliability analysis demonstrated excellent interobserver agreement across all major morphometric parameters, validating the reproducibility of the methodology and confirming that digital radiographic and CT-based measurements are reliable tools for femoral morphometry.

Comparison of right and left femora showed no significant differences, supporting the clinical practice of using the contralateral hip for templating in unilateral hip disease.[20]

Overall, the findings of this study highlight the need for detailed morphometric evaluation in every patient undergoing THA. In the Indian population, anatomical variability is substantial, and dependence on standardised implant designs without proper morphometric assessment may lead to compromised outcomes. Incorporating systematic morphometric planning into routine THA preoperative workup enhances implant accuracy, improves biomechanical reconstruction, and may reduce the risk of complications such as malalignment, early loosening, and dislocation.

CONCLUSION

This study demonstrates substantial anatomical variability in proximal femoral morphology within the Indian population and confirms the strong correlation between morphometric parameters and implant selection in total hip arthroplasty (THA). Key morphometric markers—particularly canal diameter at 20 mm and 40 mm below the lesser trochanter, canal flare index, femoral offset, and neck-shaft angle—emerged as reliable predictors for determining the optimal implant category. A significant proportion of femora required high-offset stems, metaphyseal-engaging stems, or customised implants, reflecting population-specific anatomical patterns not always accommodated by standard Western-designed implants. Incorporating systematic morphometric evaluation into routine preoperative planning can refine implant choice, enhance anatomical reconstruction, and reduce the risk of postoperative complications. These findings reinforce the importance of developing population-specific morphometric databases to support precision-based THA planning.

Limitations

1. This was a single-centre study, which may limit generalisability to the wider Indian population.
2. CT-based measurements were available only for selected patients, which may restrict the precision of canal morphology evaluation in the entire cohort.
3. Patients with hip pathology affecting native anatomy were excluded, which may limit applicability to diseased hips undergoing THA.
4. Long-term postoperative outcomes of implant selection were not assessed, as the study was purely morphometric in design.
5. Minor variations in positioning during radiographic acquisition may influence measurements despite strict standardisation.

Recommendations

1. Preoperative morphometric assessment should be routinely incorporated into THA planning for accurate implant selection and biomechanical reconstruction.
2. Population-specific implant designs or region-adapted templates should be developed to better match Indian femoral anatomy.
3. Surgeons should pay particular attention to canal diameter, CFI, and femoral offset while choosing between standard, high-offset, and metaphyseal stems.
4. Multicentric studies with larger and more diverse populations are recommended to validate these findings across India.
5. Integration of 3D CT-based planning and artificial intelligence–assisted morphometry may further improve implant accuracy and stem–bone matching.

REFERENCES

1. Cadossi M, Tedesco G, Sambri A, Mazzotti A, Giannini S. Hip Resurfacing Implants. Orthopedics. 2015 Aug;38(8):504-9. doi: 10.3928/01477447-20150804-07. PMID: 26270748.
2. Rath B, Eschweiler J, Betsch M, Quack V, Lüring C, Tingart M. Hüftendoprothetik nach korrigierenden Osteotomien : Becken und proximales Femur [Hip arthroplasty after corrective osteotomies : Pelvis and proximal femur].

Orthopade. 2016 Aug;45(8):678-86. German. doi: 10.1007/s00132-016-3294-1. PMID: 27385386.
3. Robin JX, Brash AI, Schwarzkopf R. Staged Bilateral Total Hip Arthroplasty in a 17-Year-Old With Type VI Mucopolysaccharidosis. Arthroplast Today. 2022 Dec 6;19:101058. doi: 10.1016/j.artd.2022.10.008. PMID: 36507284; PMCID: PMC9729915.
4. De Salvo S, Sacco R, Mainard N, Lucenti L, Sapienza M, Dimeglio A, Andreacchio A, Canavese F. Total hip arthroplasty in patients with common pediatric hip orthopedic pathology. J Child Orthop. 2024 Feb 13;18(2):134-152. doi: 10.1177/18632521241229608. PMID: 38567046; PMCID: PMC10984158.
5. Roos BD, Roos MV, Júnior AC, Lampert HB, da Silva ML. CIRCUMFERENTIAL PROXIMAL FEMORAL ALLOGRAFTS IN TOTAL HIP ARTHROPLASTY REVISION SURGERY. Rev Bras Ortop. 2015 Nov 4;47(6):754-9. doi: 10.1016/S2255-4971(15)30034-3. PMID: 27047896; PMCID: PMC4799476.
6. Marino DV, Mesko DR. Periprosthetic Proximal Femur Fractures. 2023 May 1. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan–. PMID: 32491491.
7. Yoon JY, Park CW, Park YS, Yoo JJ, Kim HJ. Total Hip Arthroplasty for Secondary Coxarthrosis in Patients with Hereditary Multiple Exostoses: Minimum 5-Year Follow-up Results and Surgical Considerations. Clin Orthop Surg. 2020 Dec;12(4):435-441. doi: 10.4055/cios20044. Epub 2020 Nov 18. PMID: 33274019; PMCID: PMC7683187.
8. Ali E, Howard LC, Neufeld ME, Masri BA. Treatment of femoral bone loss in revision total hip arthroplasty: a clinical practice review. Ann Jt. 2024 Jan 15;9:4. doi: 10.21037/aoj-23-31. PMID: 38529292; PMCID: PMC10929365.
9. Jones RE. Modular revision stems in total hip arthroplasty. Clin Orthop Relat Res. 2004 Mar;(420):142-7. doi: 10.1097/00003086-200403000-00020. PMID: 15057090. Mallory TH. Preparation of the proximal femur in cementless total hip revision. Clin Orthop Relat Res. 1988 Oct;(235):47-60. PMID: 3416541.
10. Montgomery RD, Milton JL, Pernell R, Aberman HM. Total hip arthroplasty for treatment of canine hip dysplasia. Vet Clin North Am Small Anim Pract. 1992 May;22(3):703-19. doi: 10.1016/s0195-5616(92)50063-8. PMID: 1604780.
11. Lawrenz JM, Chenard SW, Winter EP, Rowe DG, Richardson SM, Wright BM, Eckhoff MD, Kang H, Lazarides AL, Alexander JH, Visgauss JD, Collier CD, Nystrom LM; Multicenter Orthopaedic Tumor Research (MORTaR) Group. What Is the Cumulative Incidence of Femoral Stem Revision and Stem Complication in Cemented and Uncemented Hip Arthroplasty for Proximal Femoral Metastatic Bone Disease? Clin Orthop Relat Res. 2025 Jun 10;483(9):1652-1664. doi: 10.1097/CORR.0000000000003541. PMID: 40522275; PMCID: PMC12373082.
12. Hayashi S, Kuroda Y, Nakano N, Matsumoto T, Kamenaga T, Tsubosaka M, Tachibana S, Kuroda R. The assessment of canal flare index and proximal femoral bone density can improve stem selection for peri-prosthetic bone maintenance after total hip arthroplasty. Arch Orthop Trauma Surg. 2024 Jun;144(6):2881-2887. doi: 10.1007/s00402-024-05378-3. Epub 2024 May 21. PMID: 38771361.
13. Chen CM, Tsai WC, Lin SC, Tseng CS. Effects of stemmed and nonstemmed hip replacement on stress distribution of proximal femur and implant. BMC Musculoskelet Disord. 2014 Sep 26;15:312. doi: 10.1186/1471-2474-15-312. PMID: 25257699; PMCID: PMC4197382.
14. Soveral Pereira T, Malheiro N, Gonçalves D, Rodrigues C, Gonçalves PJ. Surgical treatment of fibrous dysplasia in the proximal femur: a literature review. Eur J Orthop Surg Traumatol. 2025 Apr 5;35(1):148. doi: 10.1007/s00590-025-04271-y. PMID: 40186713.
15. Sukur E, Senel A, Ozdemir U, Akman YE, Azboy İ, Ozturkmen Y. Cementless modular total hip arthroplasty with subtrochanteric transverse shortening osteotomy for high hip dislocations. J Orthop Surg Res. 2022 Mar 4;17(1):139. doi: 10.1186/s13018-022-03025-4. PMID: 35246184; PMCID: PMC8896094.
16. Roth A, Goralski S, Layher F, Fakler J, Ghanem M, Pempe C, Hennings R, Spiegl U, Zajonz D. Herausforderungen der primären Hüftendoprothetik bei hoher Hüftluxation [Challenges of primary hip arthroplasty with high hip dislocation]. Orthopade. 2019 Apr;48(4):300-307. German. doi: 10.1007/s00132-019-03694-w. PMID: 30726508.
17. Boymans TA, Heyligers IC, Grimm B. The Morphology of the Proximal Femoral Canal Continues to Change in the Very Elderly: Implications for Total Hip Arthroplasty. J Arthroplasty. 2015 Dec;30(12):2328-32. doi: 10.1016/j.arth.2015.06.020. Epub 2015 Jun 14. PMID: 26187385.
18. Luthringer TA, Vigdorchik JM. Reproducing the Proximal Femur Anatomy: 3D Preoperative Planning and Custom Cutting Guides. 2020 Jul 1. In: Rivière C, Vendittoli PA, editors. Personalized Hip and Knee Joint Replacement [Internet]. Cham (CH): Springer; 2020. Chapter 9. PMID: 33347119.
19. Beaulé PE, Antoniades J. Patient selection and surgical technique for surface arthroplasty of the hip. Orthop Clin North Am. 2005 Apr;36(2):177-85, viii-ix. doi: 10.1016/j.ocl.2005.01.001. PMID: 15833455.
20. Sheth NP, Smith JR, Winzenrieth R, Humbert L, Wang Y, Boxberger JI, Bostrom MP. Effects of Abaloparatide on Bone Mineral Density in Proximal Femoral Regions Corresponding to Arthroplasty Gruen Zones: A Study of Postmenopausal Women with Osteoporosis. J Bone Joint Surg Am. 2024 Jul 3;106(13):1162-1170. doi: 10.2106/JBJS.23.01334. Epub 2024 May 1. PMID: 38691582; PMCID: PMC11594069.