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The usefulness of spatial assessment of proximal femoral morphology in preoperative planning of cementless hip arthroplasty

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ABSTRACT

Introduction: Accurate preoperative planning for cementless total hip arthroplasty (THA) requires precise assessment of proximal femoral morphology to ensure implant stability and long-term survival.

This study aimed to evaluate the variability of proximal femoral morphology using computed tomography (CT)-based morphometry and to determine its clinical relevance in selecting the appropriate type of femoral prosthesis.

Materials and methods: A retrospective analysis was performed on 99 patients (58 men, 41 women; mean age 61 ±6.6 years) who underwent lower-limb CT angiography between 2017–2019. Patients with a history of trauma, congenital or degenerative deformities were excluded. Radiological parameters assessed included: femoral length (relative and absolute), neck-shaft angle, canal flare index (CFI), Dorr classification, and femoral torsion angles (angle of varus deformity of the femur, angle of posterior convexity of the proximal femur and angle of anterior convexity of the middle part of the femur). Statistical analysis was conducted using Statistica 13.0 with significance set at $p \leq 0.05$.

Results: No statistically significant differences were found between right and left femur across all parameters. The mean relative femoral length was 44.6 ±3.0 cm, neck-shaft angle 127.3 ±5.0°, and mean CFI 4.53 ±0.59. Dorr type B morphology predominated (68%), followed by types A (19%) and C (13%). Males had significantly longer femur ($p < 0.001$), while CFI correlated positively with age ($r = 0.38$; $p < 0.05$).

Conclusions: Proximal femoral morphology demonstrates high interindividual variability but no relevant side-to-side asymmetry. Computed tomography-based 3D assessment enhances the accuracy of preoperative planning and may help in selecting the optimal prosthesis for cementless hip arthroplasty.

Keywords: total hip arthroplasty; femoral morphology; canal flare index; Dorr classification; computed tomography; preoperative planning.

INTRODUCTION

Hip osteoarthritis (OA) remains one of the leading causes of pain and disability in adults, particularly in the elderly population. The pathogenesis of OA is multifactorial (systemic, local, and individual factors). Systemic factors may predispose to an increased risk of generalized osteoarthritis, while abnormal joint mechanics, resulting e.g. from injury, may initiate progressive degeneration in a single joint. In the complex process of OA development, it is important to consider both non-modifiable (from an individual point of view) risk factors, such as gender and age, and modifiable factors, where there is potential for intervention to reduce the risk of occurrence and the rate of progression of the disease [1]. Even subclinical anatomical abnormalities have been shown to increase the risk of OA. Lane et al. found that a reduction in the Wiberg center-edge angle or acetabular dysplasia, defined as acetabular depth <9 mm in older Caucasian women, is associated with an increased risk of OA [2]. It is also accepted that acetabular dysplasia is an important risk factor for degenerative hip joint diseases in both sexes [3]. Other studies have pointed out that individual changes in the shape of the femoral head are associated with an increased risk of OA, even in young patients [4, 5].

Total hip arthroplasty (THA) provides substantial pain relief and functional recovery, yet long-term outcomes depend on accurate implant selection and optimal fixation. Cementless stems have become increasingly popular, especially in younger, active patients, because they allow bone ingrowth and long-lasting stability [6, 7]. However, their success largely depends on anatomical compatibility between the femoral canal and the stem.

When planning total hip replacement treatment, many factors must be taken into account: the type of implant, implant fixation, surgical technique, patient age, gender, detailed preoperative diagnosis, mental state, activity level, previous course of the disease, current health status, and finally, the patient's expectations regarding the surgery and life expectancy. Preoperative clinical examinations must also assess the patient's gait, hip joint range of motion, condition of the knee joint on the same side, and the lumbosacral spine, including any coexisting deformities. Possible differences in limb length should also be taken into account, as the procedure may result in postoperative asymmetry or unexpected limb lengthening [8, 9].

Cementless prostheses currently in use have a porous surface that is partially or completely covered with a rough layer or a biological material, such as hydroxyapatite. The implants are inserted into the prepared bone bed and fixed by press-fit to ensure adequate cup stability, with additional stabilising screws also available. Each cup is lined on the inside with a polyethylene insert featuring an overhang to increase coverage of the prosthesis head. Alternatively, a ceramic insert can be used [10].

Another criterion for classifying cementless prostheses is the shape of the stem, which may or may not correspond to the curvature of the femur ("anatomical" stems vs. "straight" stems). Stems are also offered in 2 typical lengths: long stems, where the peripheral end is embedded in the femoral canal, and intertrochanteric stems, where the peripheral end of the stem does not exceed the apex of the posterior convexity of the femur, located a few centimetres below the lesser trochanter.

Individual variations in femoral geometry – such as cortical thickness, neck-shaft angle, canal shape, and curvature – can affect implant fit and stress distribution. Morphometric parameters, including the canal flare index (CFI) and Dorr classification, help predict the suitability of cementless fixation. Recent advances in 3D computed tomography (CT) reconstruction have enabled detailed evaluation of bone morphology, supporting personalized implant selection.

The present study analyzed the proximal femoral morphology in an adult population to determine the variability of shape parameters and their potential implications for preoperative planning of cementless THA.

MATERIALS AND METHODS

A retrospective analysis was conducted of the results of CT angiography of the lower limbs in 111 patients performed between 2017–2019 at the Department of Diagnostic Imaging and Interventional Radiology of the Independent Public Clinical Hospital No. 1 of the Pomeranian Medical University in Szczecin. All the patients presented with symptoms of lower limb ischemia as a result of atherosclerotic changes in the arterial circulatory system.

The results of 12 patients with a history of documented injuries and surgeries of the lower limbs, with congenital and developmental orthopaedic defects (developmental hip dysplasia or juvenile femoral head exfoliation) with symptoms of OA, with uneven lower limb rotation and internal rotation of the lower limbs less than 10° were excluded.

A statistical analysis was ultimately performed on the CT angiography results of the lower limbs of 99 patients (58 men and 41 women) aged 42–79, with an average age of 61. There was no statistically significant difference in age between women and men.

Computed tomography protocol and measurements

Computed tomography scans were obtained with a slice thickness of 0.6 mm. Patients were positioned supine, with both lower limbs in approx. 15° internal rotation to compensate for natural anteversion. Measurements were taken in centimetres (to 1 decimal place, i.e. accurate to 0.1) and degrees (accurate to 1°).

The images were analysed using Syngovia software, which employed multiplanar reformatted and maximum intensity projection views.

Measured parameters included:

- relative and absolute femoral length,
- neck-shaft angle,
- CFI (was defined by Noble et al. [11]),
- Dorr classification (A–C),
- angle of varus deformity of the femur, angle of posterior convexity of the proximal femur, angle of anterior convexity of the middle part of the femur.

Two radiologists performed independent assessments, with consensus resolution for discrepancies.

Statistical analysis

Statistical analysis was performed using the licensed Statistica 13.0 software (StatSoft, Inc. Tulsa, OK, USA). The Shapiro–Wilk test was used to assess the normality of the distribution of the studied variables. The homogeneity of variance was tested using Levene's test. Means, standard deviations, medians, coefficients of variation, frequencies, and percentages were used to present the characteristics of the group. The differences between women and men were assessed using the Mann–Whitney U-test or the Student's t-test, while the differences between Dorr types were assessed using the Kruskal–Wallis test or 1-way analysis of variance. The X^2 test was used to analyze qualitative data, and Yates' correction was used if there was a low number of cases in a subgroup. The correlation coefficient was assessed using Spearman's rank test. A significance level of $p \leq 0.05$ was adopted. Power analysis of the study was 80%.

To assess the variability of femoral bone structure, a measure of dispersion was used, namely the coefficient of variation calculated from the quotient of the standard deviation and the arithmetic mean of the variable, with a value below 25% considered low variability, 25–45% as average variability, above 45–100% as strong variability, and above 100% as very strong variability.

RESULTS

General morphology

No significant differences were observed between the right and left femurs (Tab. 1). The mean relative length was 44.6 ±3.0 cm, neck-shaft angle was 27.3 ±5.0°, and CFI was 4.53 ±0.59. According to Dorr, type B morphology was the most common (68%), followed by type A (19%) and C (13%).

TABLE 1. Morphometric parameters of right and left femur (n = 99)

Parameter	Right (mean± SD)	Left (mean± SD)	p
Relative femoral length (cm)	44.57 ±2.99	44.68 ±3.05	0.798
Absolute length (cm)	42.68 ±2.94	42.65 ±2.99	0.941
Neck-shaft angle (°)	127.27 ±5.05	127.97 ±4.89	0.328
Canal flare index	4.53 ±0.59	4.47 ±0.63	0.457
Varus bowing (°)	2.44 ±2.94	2.46 ±2.96	0.826

SD – standard deviation

Sex- and age-related differences

Men had significantly longer femur ($p < 0.001$) but comparable CFI and neck-shaft angles. Type B predominated in both sexes (Tab. 2). Age correlated positively with CFI ($r = 0.38$; $p = 0.03$), indicating canal widening with age.

TABLE 2. Dorr classification and morphometric parameters by sex

Parameter	Women (n = 41)	Men (n = 58)	p
Dorr A/B/C (%)	21.9/63.4/14.6	17.2/70.7/12.1	0.594
CFI	4.48 ±0.59	4.57 ±0.60	0.730
Neck-shaft angle (°)	128.4 ±4.9	126.5 ±5.0	0.058

CFI – canal flare index

DISCUSSION

This CT-based morphometric study demonstrated high inter-individual variability in proximal femoral geometry without significant side-to-side asymmetry. These results confirm the validity of using measurements of the femur on the opposite side to create a preoperative template, which is consistent with the reports of Noble et al., who found symmetrical limb geometry in healthy adults [12].

Clinical implications for stem selection

The examination of both femurs in 99 patients did not reveal any significant differences between the right and left lower limbs. This result is of great practical importance. The lack of differences in the structure and dimensions of both femurs allows this knowledge to be used as a basis for planning extensive reconstructive surgery after injuries leading to bone defects or the need to implant post-resection prostheses used in bone tumors requiring extensive resection. Similar results to those presented in the study were obtained by Ferràs-Tarragó et al. based on CT examinations, but these were carried out on only 15 healthy volunteers [13].

The predominance of Dorr type B morphology (68%) in this Polish population is consistent with results from other European cohorts [14]. Type B offers the most predictable environment for cementless stem fixation because it maintains adequate cortical support and a favorable shape. On the contrary, type C "stovepipe" femur presents wide canals with thin cortices, increasing risk of micromotion and poor initial stability, which may require cemented fixation or customized stems. A CFI around 4.5 in our study corresponds to the "normal" category (3–5), indicating balanced flare.

The results of other studies suggest that CFI <3 predicts difficulty in achieving press-fit fixation, while values >5 may lead to proximal mismatch and stress shielding. Thus, individualized assessment of CFI can guide implant selection.

Anatomical variation and ethnic context

Morphological differences among populations are well established. Mahaisavariya et al. found significantly smaller CFI and narrower canals in Asian cohorts, necessitating thinner, tapered stems [15]. Our mean CFI (4.5) aligns with European norms [16], confirming that standard stem designs are appropriate for this population. Such population-specific data are essential as global implant systems are often designed using Western anthropometry.

Age- and sex-related trends

The positive correlation between age and CFI observed in our study reflects age-related endosteal resorption and cortical thinning. Similar findings by Dorr et al. suggest that bone remodelling leads to widening canals and decreased bone density, particularly in postmenopausal women [17]. Although women often require smaller implants, our study found no significant differences in CFI or Dorr distribution between the sexes, which is consistent with Yeung et al.'s report [18].

Femoral bowing and surgical accuracy

Femoral curvature (bowing) affects stem alignment and stress transfer. Excessive anterior or varus bowing increases the risk of cortical perforation or malalignment in long stems. Our results (mean varus bowing ≈2.4°, posterior ≈20°) fall within the expected ranges reported by Khanuja et al. [19]. Awareness of sagittal curvature is particularly relevant for navigated THA, as it allows for precise stem positioning and helps to avoid intraoperative complications.

Clinical relevance of 3D imaging

Traditional radiography offers limited accuracy for assessing complex femoral geometry due to projectional distortion. Computed tomography-based 3D reconstruction provides quantitative evaluation of cortical thickness, bowing, and canal morphology, improving preoperative templating accuracy [20].

Studies comparing 2D and 3D templates [21] have shown up to a 15% reduction in prosthesis component dimensioning errors when using 3D methods. Our findings reinforce the value of integrating CT-based planning, particularly for patients with atypical anatomy or prior deformities.

Limitations

Our study did not consider the impact of biomechanical factors, such as body weight (including potential obesity) and physical activity. As the study group consisted of patients with lower limb atherosclerosis, it is essential to consider the mobility limitations these subjects may experience due to intermittent claudication.

Future studies should consider including these factors and investigating the possible correlation between the studied indicators and bone mineral density.

CONCLUSIONS

1. Proximal femoral morphology demonstrates considerable interindividual variability but symmetrical geometry between limbs.
2. Dorr type B morphology predominates in both sexes, indicating favorable conditions for cementless fixation.
3. The CFI increases with age, reflecting cortical thinning and canal widening.
4. Computed tomography-based 3D evaluation provides accurate morphologic data that enhances preoperative planning and optimizes stem selection in cementless THA.

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