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Original Research

Do Cementless Stems Match Any Hip? A Description of Anthropometric Measurements of the Proximal Femur in Colombia

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ABSTRACT

Background: Leg length discrepancy following hip arthroplasty causes dissatisfaction to the patient; thus, preoperative planning and implant selection is critical. The purpose of this study was to measure the articular-trochanteric distance (ATD) and femoral neck length (FNL) in our population and compare them to those of 3 of the most used uncemented stems.

Methods: In this cross-sectional study, 401 hip radiographs of healthy adults were collected between January and July 2022. The vertical ATD and FNL were measured. A linear regression model was used to identify the relationship between these measurements and age, sex, and height. A logistic regression model was used to assess the matching of native hips with the neck length of the stem.

Results: Mean age was 60 years, and 74.56% were women. In 94.3% of hips, the ATD was negative, 3.73% neutral, and 2% positive. In our population, 0.25% of FNL were shorter than POLARSTEM (Smith & Nephew, UK), 10.72% shorter than MetaFix stem (Corin, UK), and 11.97% shorter than Corail stem (DePuy Synthes, USA). In the logistic regression analysis, matching for the POLARSTEM was associated with age but not with sex or height. Conversely, for MetaFix and Corail, stem matching was associated with sex and height.

Conclusions: Anthropometric hip measurements vary among individuals, and variables such as age, sex, and height must be considered during preoperative planning and implant selection to avoid leg length discrepancy. Additional studies, including different implants, are required to guide surgeons in selecting a femoral stem that best matches the patient's native hip.

Introduction

Leg length discrepancy (LLD) after total hip arthroplasty (THA) is a contributor to dissatisfaction in the patient, with a prevalence varying from 1% to 27%. On average, discrepancies of 17 mm have been described [1,2]. Differences >10 mm are perceived by 50% of patients, affecting clinical and functional outcomes by altering hip biomechanics [3,4].

One of the causes of postoperative discrepancy is a mismatch between the prosthetic neck length and the corresponding measurement in the native or contralateral hip. It is more frequent in individuals with short necks and varus hips (negative articular-trochanteric distance [ATD]); even with the appropriate neck osteotomy, limb lengthening may occur if the prosthetic neck is longer than the native femoral neck length (FNL) [5]. Moreover, as LLD might be multifactorial [6], spine alignment, pelvic tilt, altered anatomy of the contralateral hip or the ipsilateral limb, muscle contractures (hip, knee, ankle), or trauma sequelae must be also considered in order to avoid LLD [7,8].

Several authors have described that preoperative planning and intraoperative assessment of the FNL and ATD is critical to avoid lengthening [2,9,10]. In patients with severe osteoarthritis, severe

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joint space loss, and a flattened femoral head, standardized data of proximal femoral anatomy based on the local population might be useful, especially when the contralateral side is also affected [10,11]. Furthermore, the limited availability of prosthesis designs across different contexts may limit the options to reproduce native hip anatomy [12].

Characterizing the anthropometric measurements of the proximal femur within a specific population can help to identify an implant that restores more accurately the native anatomy, thereby preventing alterations to hip joint mechanics and ensuring effective limb-length restoration [2,5]. The purpose of this study was to determine variations in FNL and ATD within our specific population. Furthermore, we aim to compare these measurements with those of the most used femoral uncemented stems and assess optimal stem compatibility for restoring LLD, based on these findings.

Material and methods

A cross-sectional analytical study was performed, including anteroposterior pelvic radiographs of patients aged 18-80 years, that required diagnostic images for any reason. Images were obtained prospectively between January and July 2022 in an academic hospital. Patients with any pathology that alter hip anatomy or who had undergone previous surgery around the hip were excluded. A total of 401 pelvis radiographs were selected using a non-probabilistic sequential method. One author measured ATD and FNL in each radiograph, and the senior author validated the measurements.

Age, sex (assigned at birth), height, weight, and body mass index were obtained from the medical records. Data of 401 patients (802 hips) were analyzed. The mean age was 60.1 years (range: 18-80), 74.6% (95% CI: 70.1-78.6) of patients were women, mean height was 161.6 cm (standard deviation [SD]: 8.2), and mean body mass index was 28 kg/cm^2 (SD: 18.7). Of all patients, 43.4% (95% CI: 38.6-48.3) were overweight, and 22.7% (95% CI: 18.8-27.1) were obese (Table 1).

The ATD (Fig. 1a, line E-C) was defined as the vertical distance between the center of rotation of the femoral head and the tip of the greater trochanter and presented in millimeters. The position of the center of rotation in relation to the tip of the trochanter was also described qualitatively as: *neutral* when the center of rotation is at the same level with the tip of the trochanter, *negative* when the tip of the trochanter is positioned proximally to the center of rotation (coxa vara), and *positive* when the tip is located distally (coxa valga). The FNL (Fig. 1b, line C-D) was defined as the distance between the center of rotation of the femoral head and the most prominent and proximal portion of the lesser trochanter. These measures were obtained with the iQ-VIEW/PRO - DICOM Viewer (RADiQ IMAGE Information Systems, Rostock, Germany).

In Colombia, there are approximately 45 different femoral stems available from 20 manufacturers that have received approval by the local regulatory authority for implantation. At our institution, 3 different uncemented stems are preferred for their exceptional performance and survival rates. According to the 2021 National Joint Registry (UK), the Corail stem (DePuy Synthes, Warsaw, IN, USA) presents a 10-year survival rate of 97%, 97.7% for the MetaFix stem (Corin, UK), and 96.3% for the POLARSTEM (Smith & Nephew, UK) [13]. Each stem provides different options for femoral neck offset and head lengths. For the Corail stem, the shortest FNL is 39 mm [14], 32 mm in the POLARSTEM [15], and 38.5 mm in the MetaFix stem [16].

Table 1
Demographic characteristics of patients included in the study.

Variable	Mean	SD
Age (years)	60.1	14.3
BMI (kg/cm^2)	28	18.8
Height (cm)	161.6	8.2
Weight (kg)	71.1	14.8
Variable	**n (N = 401)**	**% (CI)**
BMI category		
Normal	136	33.9 (29.4-38.7)
Overweight	174	43.4 (38.6-48.3)
Obesity	91	22.7 (18.8-27.1)
Gender		
Female	299	74.6 (70.1-78.6)
Male	102	25.4 (21.4-29.9)

Data analysis

The assessment of the data distribution was performed using Q-Q plots. Quantitative variables with a normal distribution were reported using means for central tendency and SD as a measure of dispersion. Qualitative variables were reported using absolute and relative frequencies with their respective confidence intervals. The *chi*-squared test for 2 independent samples was used to compare qualitative variables between groups, while the parametric statistical Student's *t*-test was used to compare quantitative variables. A linear regression model was performed to identify the relationship of ATD and FNL with age, sex, and height. A logistic regression model was performed to assess the association between the prosthesis neck length (PNL) and the following variables: age, sex, and height. Thus, PNL was dichotomized according to the information provided by manufacturers: POLARSTEM <32 mm, MetaFix stem <38.5 mm, and Corail stem <39 mm. Given the baseline characteristics of the study population for each of the analyzed prostheses, measurements from the left and right hips were combined, increasing the sample and power. A significance level of .05 (*P*-values) was considered. The data were analyzed using the STATA 17 program (StataCorp LP, College Station, TX).

Institutional review board approval

Approval was granted for the development of the present research by the institutional review board. Radiographs were collected prospectively, and patients provided consent for use of images and clinical data. Confidentiality and appropriate consent were assured and supervised by the institutional review board.

Results

The mean vertical ATD for the left hip was −8.27 mm (SD: 4.23) and −8.31 mm (SD: 4.28) for the right. Qualitatively, 93.5% (95% CI: 90.6-95.5) of left hips had a negative ATD, and 94.3% (95% CI: 91.5-96.2) of the right hips were negative. The mean FNL in left hips was 45.1 mm (SD: 5.36) and 45.1 mm (SD: 5.45) for the right (Table 2).

Based on these results, 0.25% (95% CI: 0.03-0.1) of the hips were shorter than the neck length of the POLARSTEM (32 mm), 10.7% (95% CI: 8.03-14.2) were shorter than the MetaFix stem (38.5 mm), and 12% (95% CI: 9.12-12.5) were shorter than the Corail stem (39 mm).

According to the bivariate analysis, there were no statistically significant differences in the mean FNL ($P = .54$) or the ATD ($P = .70$) between left and right hips. The mean ATD showed a statistically significant difference by sex ($P < .05$), but no difference was found for the mean FNL (Table 3).

Table 4 shows the results of the linear regression model for the assessment of the relationship between FNL and age, sex, and

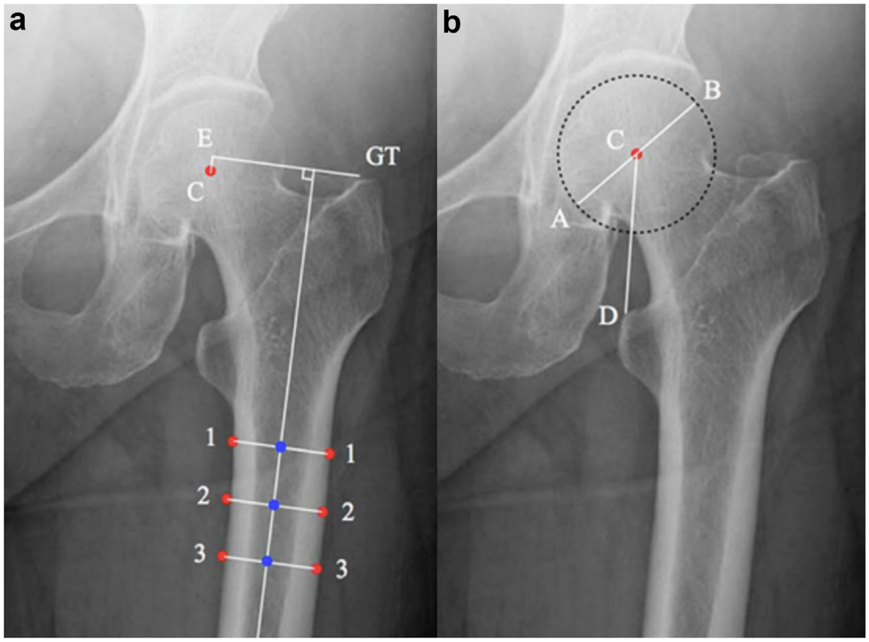

Figure 1. Radiographic measurements of the hip. (a) Measurement of vertical ATD, line C-E and (b) measurement of FNL, line C-D.

height. In summary, for right hips, with each year increment in age, the mean FNL increased by 0.044 mm ($P < .05$), and for every 10 mm increase in height, the FNL increased 0.32 mm ($P < .05$). Similar results were found for the left hip.

In the logistic regression analysis, stem matching was defined as the odds ratio (OR) of the PNL being longer than the FNL, considering the variables of age, sex, and height. In brief, age was associated with POLARSTEM matching, while sex and height were associated with MetaFix and Corail matching (Fig. 2). Furthermore, it was observed that with each year increment in age, the likelihood of POLARSTEM matching increased by 6% (OR 0.94; 95% CI: 0.91-0.98). For the MetaFix stem, the likelihood for the stem not matching adequately was 2.4 (95% CI: 1.24-4.62) for female patients. Conversely, with every 10-mm increase in height, there was an 11% higher likelihood of achieving a better prosthesis matching. For Corail, female patients had 2.6 times higher odds of the prosthesis not matching appropriately (OR 2.6; 95% CI: 1.39-4.89); nonetheless, for every 10-mm increase in height, there was a 12% higher likelihood of achieving a more accurate match (Table 5).

Table 2
Anthropometric measures.

ATD category	Mean	SD
ATD (mm)		
Left	−8.27	4.23
Right	−8.31	4.28
FNL (mm)		
Left	45.1	5.36
Right	45.1	5.45

ATD category	n (N = 401)	% (95% CI)
Left hip		
Neutral	17	4.24 (2.64-6.72)
Negative	375	93.5 (90.6-95.5)
Positive	9	2.24 (1.68-4.67)
Right hip		
Neutral	15	3.74 (2.62-6.23)
Negative	378	94.3 (91.5-96.2)
Positive	8	2 (1.0-3.94)

Discussion

Restoration of hip biomechanics during THA requires careful preoperative planning and implant selection. To avoid LLD, the ATD and FNL of the native hip must be reproduced accurately [17]. Nonetheless, hip anatomy might vary among individuals, as evidenced in the present study. We found statistically significant differences in mean ATD by sex, as well as in FNL by age and height.

Tian et al. [18] assessed the relationship between the ATD and the femoral head diameter and determined that the difference between male and female patients was also statistically significant. And similar to what was observed in our study, Wang et al. in an analysis of 194 hip radiographs identified that the distance between the greater trochanter and the femoral head was related to sex but not to age [19].

Moreover, vertical ATD might differ according to the geographic location. In the study by Panichkul et al. in Thailand, 75% of their population had a positive ATD, 15% were negative ATD, and 10% were neutral. In the studies by Antapur in the United Kingdom [17] and Unnanuntana in the United States [20], a negative ATD was reported in 82% and 76% of the population, respectively. Notably, in our study, 93.5% of the population had negative ATR. Kumar et al., in 2020, reported that the mean vertical distance between the center of rotation and the greater trochanter was 9.20 mm [21], while in our study, this distance ranged from −8.24 to −8.33 mm and was

Table 3
Results of bivariate analysis by gender and laterality.

Measure	Mean (SD)	95% CI	Mean (SD)	95% CI	P
	Right		Left		
ATD	0.98 (0.23)	0.95-1.00	0.98	0.95-1.00	.70
FNL	45.1 (5.43)	44.6-45.7	45.1 (5.36)	44.5-45.6	.54
Measure	Male		Female		
ATD					
Right	−8.24 (4.75)	−9.17 to −7.30	−8.33 (4.75)	−8.80 to −7.86	<.05
Left	−8.17 (4.55)	−9.07 to −7.28	−8.30 (4.12)	−9.07 to −8.77	<.05

Table 4
Results of linear regression analysis for FNL by age, height, and gender.

Variable	Coefficient	*P*	% CI
Right hip			
Height	0.322	.000	0.245-0.400
Age	0.044	.013	0.009-0.079
Gender			
Female	0.086	.904	−1.319 to 1.4923
Left hip			
Height	0.179	.000	0.245-0.393
Age	0.039	.023	0.005-0.074
Gender			
Female	0.054	.938	−1.327 to 1.437

different among sex, as previously described. Nonetheless, larger multicenter studies are required to confirm these findings.

The differences found in our analysis for FNL by age and height are similar to what has been reported previously by Prins et al. in their analysis in over 1500 native hips with advanced osteoarthritis [11]; however, these results may not be completely comparable as our population was composed of healthy individuals. Nonetheless, identifying the measurements of the proximal femur in normal hips might be useful as a reference for hip reconstruction when the native anatomy of both hips has been altered by osteoarthritis or different conditions [8]. We found an 0.32-mm increase in FNL for every 1-cm increase in height, and an 0.044-mm increase for every year increment in age, and both were statistically significant. Hence, each case must be analyzed individually.

Modern modular components allow to reconstruct proximal femoral anatomy through extended necks and femoral head lengths. However, limb lengthening can occur if the resulting length is longer than the native hip (47). In our population, 0.25% of patients had shorter necks than the POLARSTEM, 10.72% were shorter than the MetaFix, and 11.97% were shorter than the Corail uncemented stem. Therefore, if the PNL is longer than the native FNL, the prosthetic head length must be selected carefully, as longer heads may exacerbate this discrepancy.

Successful restoration of proximal femur measurements provides appropriate muscular balance around the hip joint [17,22]. Changes in leg length and femoral offset [23] and lateralization or any displacement of the center of rotation of the hip [24,25] modify the impact of abductor muscle moment arms, which can trigger alterations in gait and strength [4] and contribute to both real and perceived length discrepancies [6,22].

Appropriate selection of implants is cornerstone, although available stems might not always accommodate to native anatomy in terms of FNL and ATD; stem geometry, press-fit, and design are out of the scope of the present study. In the logistic regression analysis to assess stem appropriateness, it was found that based on the FNL of the native hip and the stem, matching for the POLARSTEM was associated with age but not with sex or height. Conversely, for MetaFix and Corail, stem matching was associated with sex and height, where female patients had 2.4 and 2.6 times, respectively, the likelihood of having the FNL lengthened with the use of these stems. Alternatively, the POLARSTEM was more likely to be an appropriate match for older patients, while MetaFix and Corail stems appear better suited for men and taller patients (11% likelihood of matching for every 1-cm increase in height for Metafix and 12% for Corail). To our knowledge, this is the first study that aims to provide an alternative consideration in preoperative planning to prevent leg lengthening after THA [26].

A strength of this study was the comprehensive analysis of a representative sample of anthropometric measurements and the most used hip prostheses in Colombia. The lack of standardization in pelvis radiograph acquisition introduces random error; however, this was mitigated by the sample size and not affecting the validity of the estimator or the width of the confidence interval. Another limitation of this study was that we did not include measurements for the neck-shaft angle [27] or the femoral offset, which are also very important anatomical and mechanical parameters to consider during THA [28]. Furthermore, given the use of the ATD has been debated [10,17,29], recent studies conclude that it is a reliable parameter for preoperative planning and recommend templating hips to match the contralateral ATD [18,21]. As it was observed in this study, differences between sides are not statistically significant. Finally, our objective was to measure the FNL in native hips and compare it with the PNL of the most-used stems, as an indirect estimate of their compatibility in terms of leg length restoration during THA. However, we did not consider the effect of head length, acetabular component position, and neck cut length on limb length in our analysis; therefore, further studies that include these variables are encouraged.

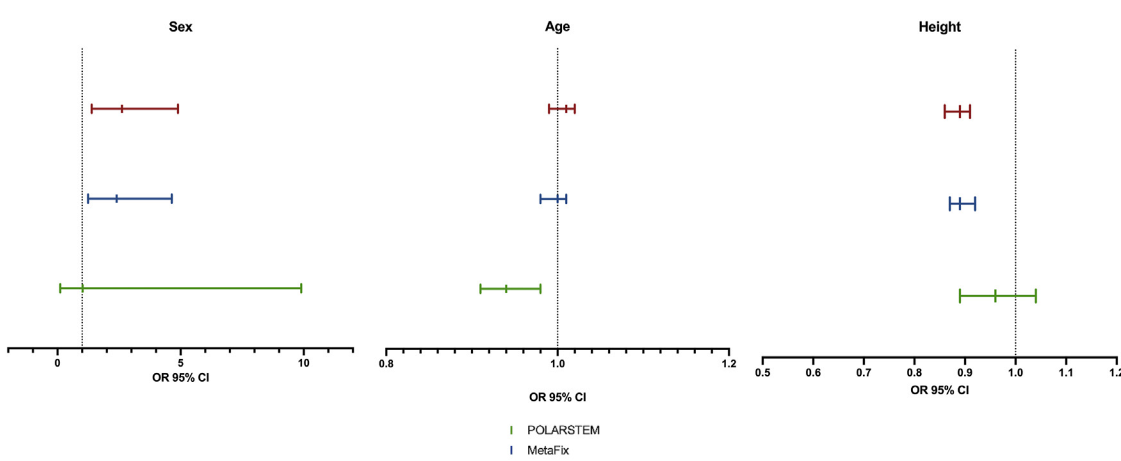

Figure 2. Odds ratio (OR) illustration of the relationship between the 3 analyzed stems with variables sex, age, and height.

Table 5
Femoral stem matching: prosthesis neck length (PNL) by age, height, and female gender.

Variable	POLARSTEM PNL: <32 mm	MetaFix PNL: <38.5 mm	Corail PNL: <39 mm
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Female	1.02 (0.11-9.90)	2.40 (1.24-4.64)[a]	2.62 (1.39-4.89)[a]
Height	0.96 (0.89-1.04)	0.89 (0.87-0.92)[a]	0.89 (0.86-0.91)[a]
Age	0.94 (0.91-0.98)[a]	1.00 (0.98-1.01)	1.01 (0.99-1.02)

[a] *P*-value < .05.

Conclusions

Based on these results, variables such as age, sex, and height must be considered during preoperative planning and implant selection to avoid LLD or modifications to abductor muscle lever arms. The availability of a diverse range of modular implants nowadays allows for an extent of individualization in hip arthroplasty surgery that yields excellent functional and satisfaction outcomes. Additional large population studies, incorporating a broader range of implants, are necessary to confirm these findings and guide surgeons in selecting a femoral stem that best matches each patient's hip measurements.

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Conflicts of interest

The authors declare there are no conflicts of interest.
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CRediT authorship contribution statement

María Camila Canencio Salgado: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Diego Martínez-Villaba:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **María Bautista:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis. **Omar Alejandro Amado Pico:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Formal analysis, Data curation, Conceptualization.

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