RESEARCH ARTICLE

The Distribution of Caput-Collum-Diaphyseal (CCD) Angles in the Iranian Elderly Population: Implications for Proximal Femoral Nail Design

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Abstract

Objectives: Proximal femoral nails (PFNs) are widely used in managing unstable proximal femur fractures. These implants are designed with fixed femoral neck-shaft angles in different sizes, based on anthropometric studies of the Western population. In this study, we aimed to evaluate the Caput-collum-diaphyseal (CCD) angle in the Iranian population and determine whether any design modification for PFNs is needed for this population.

Methods: In this retrospective study, we evaluated patients who underwent hip and pelvic radiography at our hospital between 2015 and 2023. The CCD angles were measured on AP pelvic and hip radiographs. The mean CCD angle of the Iranian population was calculated. Correlation analysis was also conducted to evaluate the CCD angle in different age and sex groups.

Results: The CCD angle was evaluated in 1040 patients with a median age of 72 (range 60-99) in this study. The mean CCD angle in the Iranian population was 130.6 ± 5.9 (range: 115.4-149). 117 (11.3%) of the patients had Coxa Vara or Coxa Valga. The CCD angles did not differ significantly between men and women. We observed a significant correlation between the patient’s age and the CCD angle. It was found that 20.35% of our population’s CCD is not covered by the most commonly available Western PFN designs.

Conclusion: This study's findings demonstrated that the Iranian population's mean CCD angle is higher than in Western countries. Therefore, future PFN designs should consider the CCD angles of the specific populations.

Level of evidence: III

Keywords: Caput-collum-diaphyseal angle, Implant design, Iranian population, Neck shaft angle, Proximal femoral nail

Introduction

Proximal femoral fractures are common among elderly patients, with an incidence rate of approximately 489 per 100,000 for head and neck fractures and 304 per 100,000 for intertrochanteric fractures in individuals over 65 years old in the United States.[1] In recent decades, there has been a growing trend toward using intramedullary nails (IMNs) for the surgical treatment of unstable proximal femoral fractures.[2-4] Proximal femoral nails (PFNs) were introduced in 1997 to enhance the internal fixation of unstable proximal femoral fractures.[5] The choice of implant design for PFNs is crucial for restoring the native anatomy of the proximal femur.[6,7]

The caput-collum-diaphyseal (CCD) or femoral neck-shaft angle is the angle between the femoral head and the femoral body. It plays a crucial role in knee and hip biomechanics and in diseases of the knee and hip.[8] Anatomical studies have demonstrated variation of the CCD angle among different populations.[9-11] The CCD angle of the PFN should be close to the patient's native CCD angle. Therefore, the implant designs should account for the interpersonal

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differences of CCD angles [10,12]

PFNs are designed with a fixed CCD degree, and most have CCD angles between 125 and 135, based on the global average neck-shaft angle.[13,14] Most manufacturers of intramedullary implants offer two or more options for implant CCD angles to help surgeons accommodate anatomical variations in patients.[13] However, there are some limitations to using a PFN with a specific CCd angle in patients with less or higher angles.

Most implants are designed based on anatomical data from Western populations, and anatomical variations in the Iranian population have not been accounted for. In this study, we aimed to measure the CCD angles in the Iranian population and to investigate the mismatch between available PFN designs and the native anatomy of Iranian patients.

Materials and Methods

Study Design

A retrospective study was conducted on Iranian patients aged 60 years or older who underwent hip and pelvic radiographic evaluations at our hospital between January 2015 and January 2024. Exclusion criteria were designated as a history of the spine, pelvic or lower extremity surgery, history of pelvic or lower extremity fractures or current fractures in the lower limbs, paraplegia or hemiplegia, inflammatory arthritis, infectious arthritis, a discrepancy of leg length, history of DDH or Legg–Calvé–Perthes disease, hip OA, connective tissue disorders, malignancy, and those with non-standard or low-quality radiographs. The ethics committee of our institution reviewed and approved this study under code XXX (Blinded). This study was conducted in accordance with the Declaration of Helsinki and institutional ethics guidelines. Written informed consent was obtained from the patients to use clinical data. Patient records and radiologic images were accessed in February 2024.

Demographics and Radiological Evaluations

Age and gender were recorded for all patients. All patients' anteroposterior (AP) radiographs of the hip and pelvis were obtained according to standard protocols at a distance of 100 cm. The hips were in a 15-30° internal rotation position. All radiographs were taken by the same technician and were analyzed on a computer radiography system (Picture Archive and Communication Systems (PACS)). two orthopedic surgeons measured radiographic variables, and the mean angle was. The mean angle and the mean angle measure were used for analysis. Inter-rater reliability was assessed using a two-way mixed-effect intraclass correlation coefficient (ICC). The caput-collum-diaphyseal (CCD) angle was measured on AP pelvic and hip patients' radiographs.[15] We determined the neck axis by joining the center of the femoral head to the midpoint of the base of the femoral neck. The shaft axis was determined by connecting the midpoints of two horizontal lines drawn between the edges of the lateral and medial cortices, with the proximal line positioned just below the lesser trochanter [Figure 1]. The angle between these two lines was recorded as the CCD angles [Figure 1].[15] Coxa Vara, Normal, and Coxa Valga were defined as CCD angles <120, 120-140, and >140, respectively. Patients' age was categorized into decades.

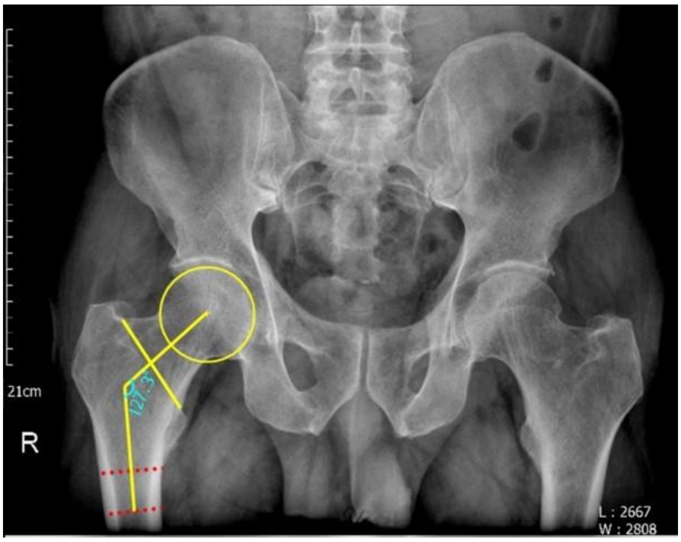

Figure 1. Measurement method of CCD Angle in AP radiograph

Statistical Analysis

Statistical analysis was performed using SPSS statistical software version 29 and GraphPad Prism version 9.5. The Kolmogorov-Smirnov test was used to check the normality of the variables. One-way ANOVA and the students' t-test were used to analyze normally distributed continuous variables. In addition, we used the Kruskal–Wallis and Mann-Whitney U test for analyzing not normally distributed continuous variables. The Pearson Chi-Square test was used for categorical variables analysis, and Spearman and Pearson's correlation tests assessed associations between the variables. Regression models were built to evaluate independent predictors of the CCD angle as the dependent variable. ROC curve analysis was used to determine cut-offs for the variables. Patients with CCD angles within the normal range were assigned to the control group, and those with Coxa Valga or Coxa Vara to the case group. P values less than 0.05 were considered statistically significant.

Results

Finally, 1040 patients, with a median age of 72 (range 60-99), were enrolled in this study. We evaluated 479 (46.1%) males and 561 (53.9%) females [Table 1]. The patients' mean CCD angle was 130.6 ± 5.9 (range: 115.4-149). Regarding the CCD angle, 117 (11.3%) patients have a Coxa Vara or Coxa Valga angle, and 923 (88.7%) have a normal CCD angle. The number of abnormal CCD angles did not differ significantly between genders (P=0.820) [Table 2]. The interrater reliability (ICC) of CCD angles measured by two orthopedic surgeons was 0.85 (95% CI=0.76-0.91), indicating good agreement.

Correlation analysis showed a possible association between patient age and CCD angle (P=0.012, R=0.078, 95% CI=0.015 to 0.140). A regression analysis confirmed this correlation, examining the relations between gender and age and the CCD angle, and the results showed that, contrary to gender, age significantly affected the CCD angle (p=0.004, R=0.008, B=0.056, 95%CI=0.018 to 0.095). However, logistic regression showed no statistically significant effect of age on the prediction of non-normal-range CCD angle (P=0.346). The ROC curve analysis did not yield a significant result for proposing an age cut-off to predict non-normal CCD angles (P=0.274). Comparing categorical age with CCD angle did not show a statistical difference between age decade and CCD angle (P=0.112) [Table 3].

Table 1. Demographic Characteristics of Patients. (The p-values are obtained by chi-square test for non-continuous and t-test for continuous variables.)

Variables	Male	Female	Total	P Value
Total, N (%)	479 (46.1)	5611 (53.9)	1040 (100)	
Age ± SD[2], y	72.14 ± 8.96	73.84 ± 9.67	73.06 ± 9.38	0.007
Categorical age:				
60-69 (Sexagenarian), N (%)	213 (44.5)	213 (38)	426 (41)	
70-79 (Septuagenarian), N (%)	153 (31.9)	164 (29.2)	317 (30.5)	
80-89 (Octogenarian), N (%)	90 (18.8)	145 (25.8)	235 (22.6)	0.012
90-99 (Nonagenarian), N (%)	23 (4.8)	39 (7)	62 (6)	
CCD[1] ± SD, degree	130.69 ± 6.07	130.66 ± 5.81	130.67 ± 5.93	0.849

[1] CCD: Caput-collum-diaphyseal
[2] SD: standard deviation

Table 2. Patients in the Coxa Vara, Coxa Valga, and Normal Range groups, and the CCD angles, were compared using an independent t-test.

CCD[1] angle groups	Male		Female		Total		P Value
	N (%)	*Mean ± SD[2]*	*N (%)*	*Mean ± SD*	*N (%)*	*Mean ± SD*	
Coxa Vara	23 (4.8)	118.09 ± 1.30	25 (4.5)	118.48 ± 0.94	48 (4.6)	118.29 ± 1.13	0.375
Coxa Valga	34 (7.1)	143.20 ± 2.41	35 (6.2)	143.27 ± 2.48	69 (6.6)	143.23 ± 2.43	0.782
Normal range	422 (88.1)	130.37 ± 4.46	501 (89.3)	130.38 ± 4.33	923 (88.8)	130.37 ± 4.38	0.992

[1] CCD: Caput-collum-diaphyseal
[2] SD: standard deviation

Table 3. Mean ± SD of CCD angles for different age decades between males and females. The CCD angles were compared within each age group using an independent t-test, and ANOVA was used to compare the four groups.

Age Groups	Male	Female	Total	P Value	P Value
60-69 (Sexagenarian)	130.29 ± 5.77	129.90 ± 5.48	130.10 ± 5.62	0.317	0.112
70-79 (Septuagenarian)	130.92 ± 6.50	130.76 ± 5.82	130.84 ± 6.15	0.812	
80-89 (Octogenarian)	131.14 ± 5.67	131.67 ± 5.96	131.47 ± 5.85	0.312	
90-99 (Nonagenarian)	130.98 ± 7.35	130.59 ± 6.57	130.73 ± 6.81	0.826	

Further evaluation revealed that the prevalence of coxa Vara and Coxa Valga, and the normal range CCD angle, were statistically different between patients of different ages (P=0.015). The mean age of patients with Coxa Vara, Coxa Valga, and Normal range CCD was 71.25 ± 9.25, 75.62 ± 8.45, and 72.96 ± 9.43, respectively. Although the age of patients with a normal range CCD angle was not statistically different from that of patients with coxa Vara (P=0.599), the age of patients with coxa Valga was statistically different from that of patients with coxa Vara (P=0.022) and from that of patients with a normal range CCD angle (P=0.035). Also, the relationship between age categories and Coxa Valga, Coxa Vara, and Normal range has been shown in [Table 4] (P=0.075).

Although the patients are mainly within the normal range, 11.3% have a CCD angle outside the normal range (120°-140°) [Figures 2, 3]. If we consider the acceptable range of CCD angles covered by each implant to be ±5 °, the most commonly available western PFN designs (125°, 130°, 135°) can cover 88.7% of Iranian patients [Table 5, Figure 2]. However, considering the acceptable range of CCD angles for each implant to be CCD ± 2.5°, these designs can cover 79.65% of Iranian patients [Figure 4]. Therefore, considering a coverage range of CCD±5 ° and CCD±2.5 °, 11.30% (4.7% coxa vara, 6.6% coxa valga) and 20.35% (8.22% coxa vara, 12.66% coxa valga) would be out of the range covered by the currently designed PFN CCD angles, respectively.

Table 4. CCD angles in patients in the Coxa Vara, Coxa Valga, and Normal Range groups. A one-way ANOVA was used to compare the CCD angles across groups.

Age groups	Coxa Vara		Coxa Valga		Normal range		P Value
	N (%)	*Mean ± SD*	*N (%)*	*Mean ± SD*	*N (%)*	*Mean ± SD*	
60-69 (Sexagenarian)	21 (4.9)	118.07 ± 1.24	18 (4.2)	142.73 ± 2.08	387 (90.8)	130.16 ± 4.38	<0.001
70-79 (Septuagenarian)	18 (5.7)	118.35 ± 1.02	27 (8.5)	142.32 ± 1.74	272 (85.8)	130.53 ± 4.49	<0.001
80-89 (Octogenarian)	5 (2.1)	119.10 ± 0.71	19 (8.1)	145.01 ± 2.57	211 (89.8)	130.54 ± 4.05	<0.001
90-99 (Nonagenarian)	4 (6.5)	118.20 ± 1.30	5 (8.1)	143.25 ± 3.25	53 (85.5)	130.50 ± 5.13	<0.001
Total	48 (4.6)	118.29 ± 1.13	69 (6.6)	143.23 ± 2.43	923 (88.8)	130.37 ± 4.38	<0.001
P Value	0.256		0.007		0.671		

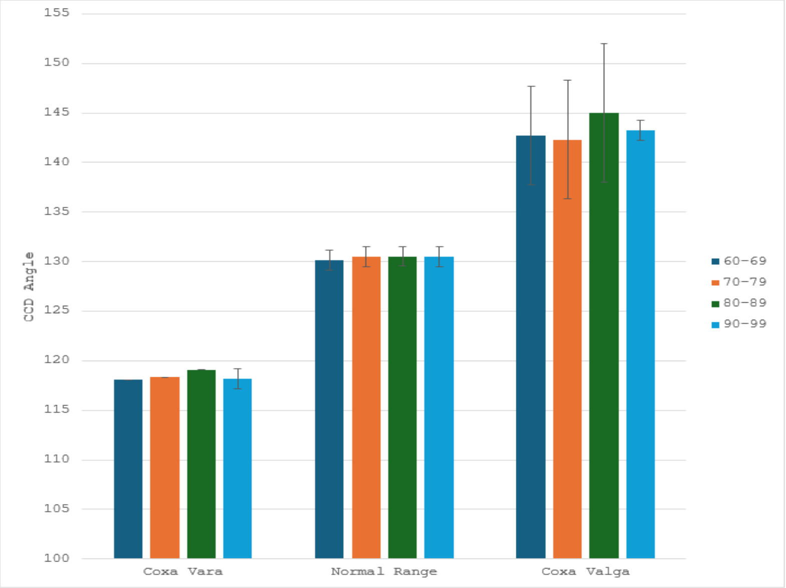

Figure 2. CCD angles in different age groups

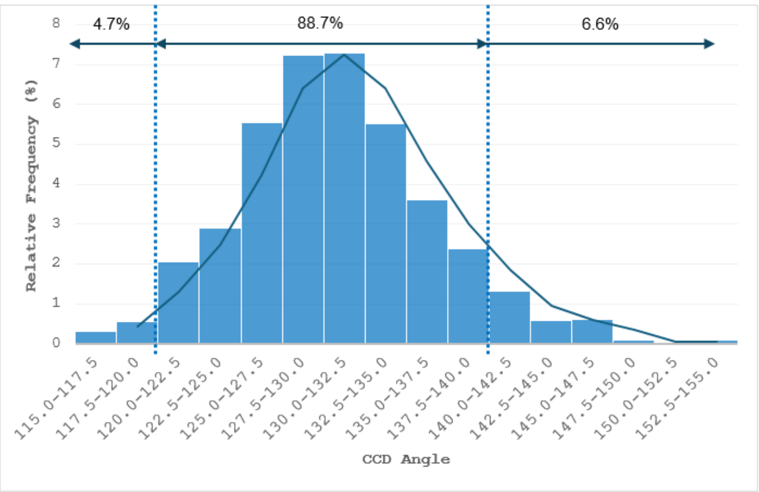

Figure 3. Frequency distribution of different CCD angles

Table 5. Parameters of Western Nails.

Variables	Gamma 3 (Stryker)	PFNA (Synthes)	Trigen Intertan (Smith & Nephew)	Kanghui (Medtronic)
Proximal diameter (mm)	15.5	17	15.25, 16.25	16.5
M-L angle (degree)	4	6	4	5
CCD[1] angle (degree)	125, 130, 135	125, 130, 135	125, 130	130
Distal Diameter (mm)	10, 11, 13, 15	10, 11, 12	10, 11.5, 13	9.5, 10, 11, 12

[1]CCD: Caput-collum-diaphyseal

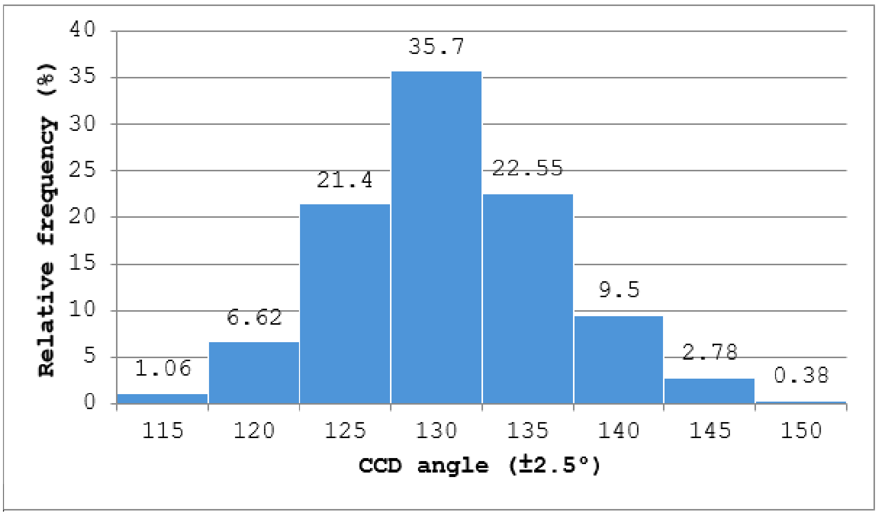

Figure 4. Frequency distribution of different CCD angle groups

Discussion

The mean CCD angle in our Iranian study population was 130.6 ± 5.9, ranging from 115.4 to 149. The PFNs are designed with a fixed CCD angle based on anthropometric studies of Western populations, which show most have CCD angles between 125 and 135 degrees. Our findings demonstrated that the CCD angles of 20.35% of patients are out of the range covered by currently designed PFNs.

In a cross-sectional study in the northern part of Iran that investigated the CCD angle among the patients with femoral neck and intertrochanteric fractures, it was reported that the mean CCD angle of the 120 patients was 131.97±5.11.[16] A study investigating the correlation between BMI and proximal femoral geometry in 635 patients demonstrated a mean femoral neck-shaft angle of 131.16±5.96 in an Iranian population.[17] We evaluated a higher number of patients and included patients from a tertiary referral center in Tehran to represent the Iranian population. The mean femoral neck-shaft angle in our study was 130.6 ± 5.9 in 1040 patients, which was close to the values reported in the abovementioned studies conducted in other parts of Iran.

An anatomical study by Gilligan et al. was conducted on a global database of 8000 femora from 101 countries to assess variations in femoral neck-shaft angles across populations. Their results showed a global mean neck-shaft angle of approximately 127 degrees.14 Also, the femoral neck-shaft angle was evaluated in an extensive population-based study in Germany based on MRI data from over 3,000 adults, and the researchers found the average CCD angle was 127° (range of 114°-140°). Additionally, they identified several factors associated with CCD angle variation, including inverse relationships with age, BMI, and waist circumference.18 Our study found that the mean CCD angle in the Iranian population was higher than that in Western countries. Also, we observed a correlation between the age and the CCD angles of our population.

Boese et al. showed that the mean CCD angle for male and female adults was 129.6° and 131.9°, respectively, and that the difference between the sexes was significant.[19] However, most studies reported no significant difference between genders.[14,20,21] In our population, the CCD angle did not differ significantly between males and females.

Proximal femoral nails (PFNs) are available in the market with CCD angles of 125, 130, and 135 degrees [Table 5]. A retrospective study found that fixing unstable intertrochanteric fractures with an implant's CCD angle smaller than the native CCD angle was associated with greater varus reduction and greater fracture displacement.[22] A finite element analysis was performed to determine what implant designs should be used for a patient with native CCD angles between the available PFN designs. It was found that utilizing implants with a CCD angle of 125 in the fixation of unstable intertrochanteric fractures with a native CCD angle of 127 resulted in a more mechanically stable construct compared to using implants with a CCD angle of 130.[23]

To the best of our knowledge, the literature has not yet provided a clear answer to the question of the optimal range of CCD angle covered by a PFN implant. However, it is clear that a narrower range better suits the patient's proximal femur biomechanics and can more closely restore the patient's anatomy. On the other hand, a narrower acceptable range necessitates the design of more implants, thereby increasing manufacturers' costs. We considered two acceptable ranges and examined our population accordingly. Considering a range of CCD ±5 °, the most commonly available western PFN designs (125°, 130°, 135°) [Table 5] can cover 88.7% of Iranian patients. Considering a ±2.5 ° range for CCD, these designs can cover 79.65% of Iranian patients. Therefore, at least (CCD±5 °) 11.30% (4.7% coxa vara, 6.6% coxa valga) and at most 20.35% (8.22% coxa vara, 12.66% coxa valga) will not be covered by the currently designed PFN CCD angles, respectively. As a result, from a cost-effectiveness perspective, we recommend that Iranian manufacturers allocate around 20% of their PFN products to patients with CCD angles in these extreme ranges by designing PFNs with CCD angles of 120 ° or 140°. We suggest that conducting similar studies in other countries can also help manufacturers tailor their PFN production to the distribution of CCD angles in the community.

The results of our study aid in designing and developing PFNs with new CCD angles to match the hip anatomy of the Iranian population. However, our study had some limitations. The study was conducted at a single referral center, whereas multi-center studies can better reflect the Iranian population. The study focuses on elderly patients (60-99 years), which may not reflect the CCD angles of younger individuals.

Conclusion

Our study's findings demonstrated that the Iranian population's mean CCD angle is higher than that of Western populations. We also observed that the CCD angle is correlated with age but not different between men and women. Local PFN manufacturers should consider differences in CCD angle distribution in the Iranian population, as approximately 20% of Iranian patients fall outside the range covered by current PFN designs.

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