EXPERIMENTAL STUDY

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Anatomic compatibility of femoral intramedullary implants: a cadaveric study

Ömer Sunkar BİÇER[1], Gazi HURİ[2], Mustafa TEKİN[1], Akif MİRİOĞLU[1], Ahmet AYDIN[3], İsmet TAN[1]

[1]*Çukurova University Faculty of Medicine, Department of Orthopaedics and Traumatology, Adana, Turkey*
[2]*Hacettepe University Faculty of Medicine, Department of Orthopaedics and Traumatology, Ankara, Turkey*
[3]*Çukurova University Faculty of Engineering and Architecture, Department of Biomedical Engineering, Adana, Turkey*

Objective: The purpose of this study was to describe the morphology of the proximal and diaphysis of femur, distribution of neck version, neck-shaft angles, and radius of anterior curvature in a Turkish population to compare with that of femoral intramedullary implants.

Methods: Using 84 cadaveric femora, three-dimensional (3D) modeling was performed with a light scanner, data were transferred to Solidworks 2013 software (Solidworks, Waltham, MA, USA) to determine the variability in the femoral length (FL), neck version, neck-shaft angle (NSA), and anterior bow. Three independent observers' measurements were tested with a reliability analysis and then evaluated using Cronbach's alpha value, after which they were compared with the neck-shaft angles, and the radii of curvature (RAC) of intramedullary femoral nails, as stated on the official manufacturer websites.

Results: Mean FL, femoral neck anteversion (FNA), and NSA had ranges of 346.1–454.1 mm, -11.3–40.4°, and 105.9–149.0°, respectively, and RAC was between 1.0 and 1.2 m. The correlation coefficient and 95% confidence intervals (CI) were 0.89 (CI 0.849–0.928), 0.86 (CI 0.799–0.904), and 0.85 (95% CI 0.785–0.898) for FL, FNA, and NSA, respectively. FNA was <10° in 32 femora (37.6%) and >14° 38 (44.7%). NSA was between 130° and 135° in 40 femora (47.1%), and RAC ranged from 0.5 to 1.5 m in 76 femora (91.6%), <1 m in 38 (45.8%), and >1.5 m in 7 (8.4%).

Conclusion: FNA and NSA show a wide distribution, mostly out of the range of intramedullary implants. There is a need for implants that are compatible with a range of NSAs and versions, so that they are suitable for use with a variety of morphologies.

Keywords: Anatomy; femur; intramedullary nail; light scanner.

Femoral neck anteversion (FNA) and neck-shaft angle (NSA) have to be reconstructed in the treatment of femoral neck, pertrochanteric, and subtrochanteric fractures. Concurrent diaphysis fractures of the femur are treated by the same intramedullary implants, providing fixation of both proximal and diaphysis fractures of the femur. The hypothesis of this study was that femur morphometry may present different features compared with those of anatomic femoral intramedullary implants.

Correspondence: Ömer Sunkar Biçer, MD. Çukurova Üniversitesi Tıp Fakültesi, Ortopedi ve Travmatoloji Anabilim Dalı, Adana, Turkey.
Tel: +90 322 – 338 67 67 e-mail: omersunkar@yahoo.com

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Mismatch of femoral intramedullary nail radius of anterior curvature (RAC) with the human femur has been reported by various authors.[1–3] Recon screws or blades fixing the neck have fixed NSAs and versions, with slight differences between commercially available intramedullary implants. Cutout of a recon screw-blade or a relative rotational deformity of the lower extremity may be a consequence of a fixed NSA or femoral neck version. Trying to place the recon screw or blade in the femoral head centrally with a tip–apex distance less than 20 mm may cause oblique rather than transverse placement of the distal screws. In other cases, it may cause external rotation and consequent out-toeing in high FNA. The angle of curvature of the femoral implant may also cause problems such as anterior broaching.[3–6]

The aim of this study was to describe the morphology of the proximal and diaphysis of the femur and show the distribution of femoral neck version, NSAs, and RAC for comparison with those of femoral intramedullary implants.

Materials and methods

A total of 96 dry right and left femora were obtained from the anatomy department after the approval of the Institutional Review Board. Neither the age nor the gender of the cadavers was known to the authors. The study included 84 intact femora (52 left, 32 right). The femora were vertically fixed on a rotating platform with paste and scanned with a 3D high-precision light scanner (David Structured Light Scanner, SLS-2, Koblenz, Germany). The device consisted of a digital camera and a receiver with a light scanner. Three-dimensional imaging of objects with 8 sequences of photographs against a well-contrasted background was provided by rotating the platform in 45° intervals until that platform had been fully rotated. Extrusion and intersection of the silhouettes provided data which were used to measure distances and angular relations. The data were exported in standard 3D file formats (OBJ, STL, PLY) to Solidworks 2013 software (Solidworks, Waltham, MA, USA). The OBJ format was used in the measurements.

Femoral NSA, femoral neck version, femoral anterior bow, femoral length (FL), femoral neck length (FNL), and both horizontal and vertical femoral offsets (HFO, VFO) were independently measured by 3 observers.

The caput-collum-diaphyseal (CCD) angle or femoral NSA was defined as the angle between the anatomic axis of the femur and the longitudinal axis of the neck, which passes through the center of the perfect fit circle drawn around the head of femur on the coronal plane. Anteversion (AV) was measured on the cephalocaudal view as the angle which is formed by the longitudinal axis of the neck with reference to the posterior condylar axis. RAC was measured on the sagittal plane, on a circular arc which was drawn with 3 points on the anterior surface (proximal, middle, and distal). FL was defined as the distance between the fossa piriformis to the most distal point on the intercondylar notch on the anatomic axis of the femur. VFO was the distance from the center of rotation of the femoral head (the center of the best fit circle on the femoral head) to the transverse line drawn at the most proximal point of the trochanter minor perpendicular to the anatomic axis of the femur. HFO was the distance between the center of rotation of the femoral head to the line perpendicular to the long anatomic axis of the femur, and FNL was the length of the femoral neck axis between the center of rotation of the femoral head to the anatomic axis of the femur.[7] All data were evaluated using Solidworks 2013 software (Figures 1a, b).

Statistical analysis was performed using SPSS software (version 17.0, SPSS Inc., Chicago, IL, USA). Continuous variables with normal distribution were stated as mean±standard deviation ($p>0.05$ in Kolmogorov-Smirnov test or Shapiro-Wilk [$n<30$]), and if the continuous variables did not conform to normal distribution, they were stated as median values. Comparisons between observer measurements were applied using the paired t-test for normally distributed data, and the interobserver correlation method was used for interobserver comparisons. Correlations between parameters were evaluated using the Pearson correlation test. Pearson correlation coefficients were interpreted as either excellent relationship ($r\geq0.91$), good ($0.90\leq r\geq0.71$), fair ($0.70\leq r\geq0.51$, weak ($0.50\leq r\geq0.31$; little or none ($r\leq0.3$). Compatibility between the femoral measurements was tested with a reliability analysis and then evaluated using Cronbach's alpha value. Values of $p<0.05$ were considered statistically significant.

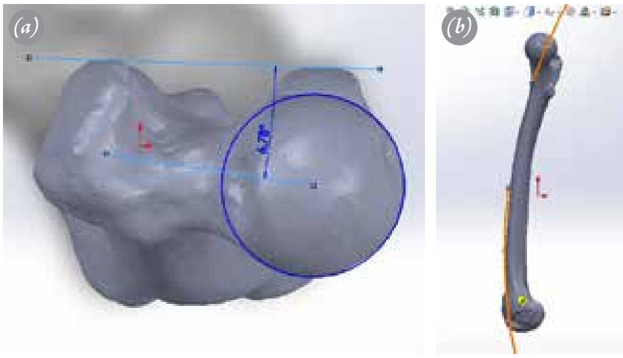

Fig. 1. **(a)** Estimation of femoral neck anteversion. **(b)** Estimation of radius of anterior curvature. [Color figures can be viewed in the online issue, which is available at www.aott.org.tr]

Table 1. Study parameters.

Group	O1 (n=85)		O2 (n=85)		O3 (n=85)	
	Mean±SD	Median (Min–Max)	Mean±SD	Median (Min–Max)	Mean±SD	Median (Min–Max)
FNSA (°)	132.0±6.4	135.0 (109.3–149.0)	128.2±6.5	128.8 (107.3–145.0)	130.6±7.0	130.9 (105.9–147.4)
AV (°)	13.1±8.0	12.3 (-11.3–32.2)	11.8±8.5	10.8 (0.0–40.4)	13.2±7.6	12.4 (0.0–32.4)
RAC (m)	1.0±0.3	1.0 (0.5–2.9)	1.2±0.3	1.1 (0.6–3.0)	1.2±0.4	1.2 (0.6–3.2)
FL (mm)	397.9±22.8	395.6 (346.1–449.3)	400.6±31.1	398.8 (352.3–453.3)	404.6±22.4	401.7 (348.3–454.1)
VFO (mm)	56.0±7.0	55.7 (38.9–74.5)	45.3±6.0	46.1 (32.9–57.5)	46.4±6.0	47.1 (32.0–61.1)
HFO (mm)	40.8±5.6	41.5 (26.4–53.7)	38.7±6.0	38.7 (28.1–52.6)	40.6±6.2	41.2 (24.5–54.5)
FNL (mm)	53.3±6.4	53.2 (39.0–70.5)	49.7±6.7	50.2 (35.9–62.3)	53.8±6.1	55.0 (36.6–67.2)

SD: Standard deviation; FNSA: Femoral neck-shaft angle; AV: Anteversion; RAC: Radius of anterior curvature; FL: Femoral length; VFO: Vertical femoral offset; HFO: Horizontal femoral offset; FNL: Femoral neck length.

Results

The present study demonstrated good interobserver agreement for the morphological measurements. All values of femoral NSA, AV, RAC, FL, VFO, HFO, and FNL are presented in Table 1. There was a positive correlation between FL with both VFO and HFO ($p<0.05$). RAC of the femora ranged from 1.0 to 1.2 m. The correlation coefficient and 95% confidence intervals (CI) were 0.89 (CI 0.849–0.928), 0.86 (CI 0.799–0.904), and 0.85 (95% CI 0.785–0.898). FNA was <10° in 32 femora (37.6%) and >14° in 38 (44.7%) femora. NSA was between 130° and 135° in 40 femora (47.1%), and RAC ranged from 0.5 to 1.5 m in 76 femora (91.6%), <1 m in 38 (45.8%), and >1.5 m in 7 (8.4%), as shown in the scatter graphs (Figures 2–4).

Discussion

The aim of this study was to evaluate the compatibility

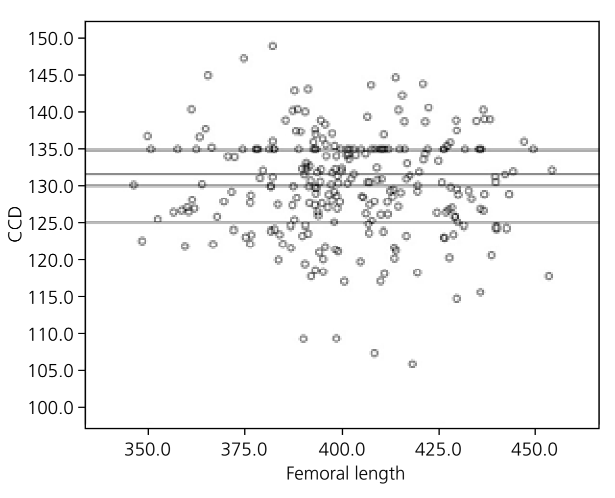

Fig. 3. Scatter graph showing the distribution of femoral neck shaft angle (FNSA) of the cadaveric femora, compared with long intramedullary femoral nails with 125°, 130°, 132°, and 135° caput-collum-diaphyseal (CCD) angle.

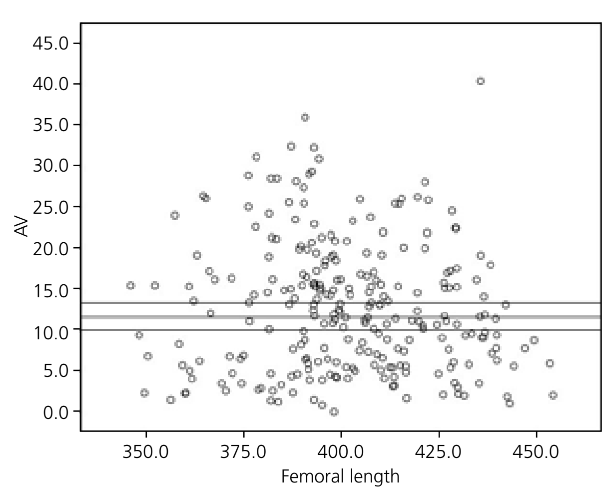

Fig. 2. Scatter graph showing the distribution of femoral neck anteversion (AV) of the cadaveric femora, compared with long intramedullary femoral nails with 10°, 12°, and 14° femoral neck AV.

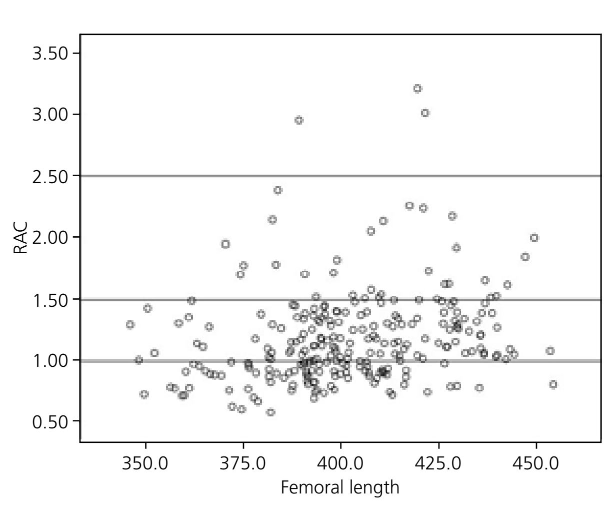

Fig. 4. Scatter graph showing the distribution of radii of anterior curvature (RAC) of cadaveric femora with the RAC of long intramedullary femoral nails.

of femoral intramedullary implants with the morphometric features of Turkish femora.

Mechanical and electronic micro calipers have been used previously in direct morphometric studies. The use of computer software provides data in direct radiography or computed tomography (CT).[8] Digital photography was used for morphometric evaluation of femora by Toogood et al.[9] In this study, a 3D light scanner was used.

Data collected by CT may be used in 3D modeling, but providing a standard setting in every patient may be challenging.[10] Laser scanners may be used in quantitative evaluation, and the use of light or laser scanners may be preferred for the surface analysis of dry bones with less radiation.[11,12]

The results of the current study demonstrated that the femoral NSAs in 40 (47.1%) of the femora were 130–135°, within the range of the CCD angle of the femoral intramedullary nails (one 125°, and five 130°, 135° options). However, the range was quite wide, with the lowest and highest femoral NSA measurements being 105.9° and 149.0°, respectively. The fixed femoral NSA of the nails, which may cause "cutout through the femoral head," questioned the efficacy of providing a tip–apex distance of "20 mm" in fixing pertrochanteric and neck fractures of the femur, especially in the remaining 44 femora (52.9%) with femoral NSAs <130° or >135°.[13] Unnanuntana et al.[14] reported a similar average femoral NSA in their study (133.8°), compared with 123–125.8° in previous studies.[13,15,16]

In 82.3% of the femora, FNA was determined as either <10° or >14° (range: -11.3–40.4°). Of the 6 different intramedullary implants, 5 had standard 10°, 12°, and 14° AV measurements, while 1 had 0° AV (the neck AV of the proximal femoral intramedullary nails was 0°, and it was 10–14° in long nails). A high AV of the neck would cause either oblique distal locking or, when transverse locking was obtained, external rotation with consequent out-toeing in recon screw or blade use. Insisting on transverse distal locking in 40° AV would cause external rotation of approximately 30° with the use of nails with proximal recon screws or blades.

RAC of 76 femora (91.6%) in the current study was found to be between 0.5 and 1.5 m. Only 8 (8.4%) had RAC >1.5 m, and the long femoral nails of different brands (Table 2) had RAC of 1, 1.5, and 2.5 m. Buford et al. studied 19 cadaveric femora using 3D polygonal reconstruction. However, RAC of the femora was measured on the anterior cortex of the femora in the current series, so as to be able to compare with the intramedullary devices. The medullary cortex would be a more appropriate reference for RAC, but Buford et al. stated that there was no significant difference.[2] RAC of the femora in the current series was highly compatible with the reports of both Buford et al. and Egol et al.[1,2] In a study by Harma et al.,[17] mean RAC was reported as 0.77 cm (cortical) and 72.2 cm (medullary). A mismatch of the anterior curvature of the femoral intramedullary implants with the average femora was reported in similar studies. The possibility of anterior broaching was implicated for the clinical relevance of the study. Scolaro et al.[3] also stated that RAC of the femoral intramedullary implants did not match the average femur, and they suggested a technique to avoid anterior broaching. However, 91.6% of RAC in the current series were found to be compatible with the currently available intramedullary implants.

Fixation of both proximal and shaft fractures of the femur requires implants properly designed according to the NSA and the anterior curvature of the femoral shaft, which may help in reducing the fracture as well as achieving fixation. The potential complication of using a high CCD angle blade to fix a pertrochanteric fracture with a low NSA is cutout through the femoral head. Use of recon screws or blades with fixed AV angles will result in external rotation and out-toeing in a hip with high AV. These complications may be prevented by preoperative templating and compatible implants.

The weaknesses of this study were that neither the age, the gender, or the dominant side of the cadavers were known to the authors. However, even if some specimens

Table 2. Technical specifications of currently available femoral intramedullary nails.*

	A_1	A_2	A_3	B	C_1	C_2
CCD (°)	125, 130, 135	132	130	135	130, 135	130
Anteversion (°)	0	10	10	14	12	12
RAC (m)	1.5	1	1	2.5	1.5–2.5	1.5–2.5
Nail length (mm)	300–460	240–400	300–480	275–475	300–500	300–500, 360–440
Blade/Recon	Blade	Recon	Recon	Recon	Recon	Recon

CCD: Caput-collum-diaphyseal angle; RAC: Radius of anterior curvature.

*Obtained from companies' websites.

were from the same subject, the data would still be valuable when evaluated independently. The present study determined morphometric parameters from a discrete Turkish population. Wider series and clinical studies may provide more information about the morphology of Turkish femora. The parameters were compared with the data provided from the official websites of the manufacturers. Three-dimensional modeling with CT scanners may be planned to evaluate the position of proximal recon screws, blades, and distal screws to ascertain the compatibility of the implants applied on cadaveric femora.

Conclusion

The results of this study demonstrate that the femoral neck AV and NSAs of femora may be out of the range of intramedullary femoral implants. Fixed anteversion and CCD angles of recon screws or blades may cause version, varus-valgus, or rotational errors in fixing fractures with intramedullary femoral implants. Therefore, there is a need for implants that are compatible with a range of NSAs and versions, so that they are suitable for use with a variety of morphologies.

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Conflicts of Interest: No conflicts declared.

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