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ORIGINAL ARTICLE

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The comparison of femoral curves and curves of contemporary intramedullary nails

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Abstract The aim of this study was to evaluate both the cortical and the medullary anterior bowing of the femur, and to compare these measurements with current intramedullary nails to assess the adequacy of their design. *Methods*: Lateral digital radiographic views of left femurs of 104 normal subjects (18–68 years old) were obtained. Radii of cortical and medullary curvatures of femurs were calculated using these images. The values obtained were compared to the radius of curvatures of ten different intramedullary nails. *Results*: Medullary bowing was between 114 and 1,389 mm (mean: 722 mm, SD: 230 mm) and the cortical bowing was between 109 and 1,666 mm (mean: 770 mm, SD: 267 mm). For males, these values were 114–1,389 mm (mean: 722 mm, SD: 230 mm) and 109–1,666 mm (mean: 770 mm, SD: 267 mm), respectively. For females, they were 114–1,389 mm (mean: 722 mm, SD: 230 mm) and 109–1,666 mm (mean: 770 mm, SD: 267 mm), respectively. The differences between genders were not significant. Cortical and medullar bowing was strongly correlated with age ($r = -0.269$, $p < 0.006$ and $r = -0.234$, $p < 0.017$, respectively). These significances were produced by females only. Radii of curvatures of intramedullary nails ranged between 150 and 300 cm and were higher than the mean cortical (77 cm) and medullary (72.2 cm) bowings. *Conclusion*: The difference between the curves of femur and the contemporary femoral nails implicates the inadequacy of the design of such nails for the Caucasian race living in Anatolia. Therefore, such nails should be revised accordingly to prevent the above-mentioned complications.

Keywords Anthropometry · Femoral curve · Femur · Fracture · Intramedullary nail

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Introduction

Femur is one of the bones in humans that exhibit ethnic, racial, and gender differences [2, 5, 6, 10, 16, 18, 19]. Several basic and clinical studies were conducted to explore these variations [5, 16, 18, 19]. Clinical anthropological studies have dealt with the compatibility of femoral prostheses and osteosynthesis materials with the femur [3, 9, 12–14, 17]. Several other studies were conducted to determine the compatibility of femoral medulla with intramedullary nails. Intramedullary nailing is currently accepted as the gold standard in the treatment of diaphyseal femur fractures [4, 8, 15, 20].

If there is a mismatch between the radii of curvature of the intramedullary nails and the anterior bowing of femur, and if this mismatch does not get compensated with the medullary breadth, several problems may arise. Angular defects [11, 20], iatrogenic fractures [4, 20], and penetration of the distal anterior femoral cortical bone [1, 12] are among the major problems. Inadequacy of contact at the fracture line, which may negatively affect fracture healing [14], difficulty in removing the tightly inserted nail [3, 11, 12, 20], or difficulties in implementing locking screws as a result of stretching or bending of the nail [3, 12] are additional problems in intramedullary nailing. The above-mentioned problems have led manufacturers to diversify the radii of anterior bowing of the nails in order to improve nail-medulla matching (Fig. 1). Different values for anterior femoral bowing were suggested for different populations [5, 6, 16, 19, 20]. However, there are still significant differences between femoral bowings and the anterior bowings of the current nails.

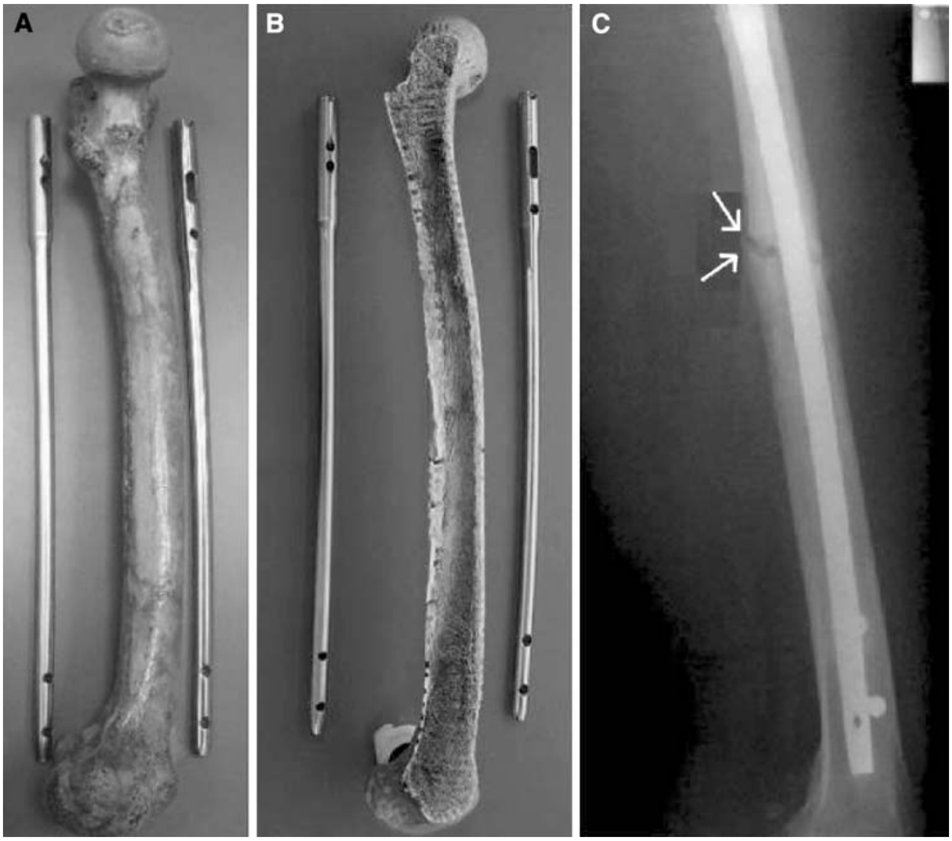

Fig. 1 External (**a**), and sectional (**b**) comparison of the anterior femoral bowing with two intramedullary femoral nails having separate anterior bowings. Radiologic appearance of inadequate contact due to a similar mismatch resulting in delayed union at the posterior of the middiaphyseal fracture

The aim of this study was to evaluate both the cortical and the medullary anterior bowing of the femur, and to compare these measurements with current intramedullary nails to assess the adequacy of their design.

Materials and methods

One hundred and twelve healthy volunteers (54 males and 50 females) with no systemic illness, and congenital or traumatic pelvic or lower extremity disorder were the subjects of the study. All of them were informed about the study and their written consents were obtained. The study was approved by the local human research ethics committee. The age of the subjects ranged between 18 and 68 and equal number of subjects were recruited for every 10-year period.

Lateral digital radiographic views of both lower extremities were obtained using computed tomography (CT) scanner (Secura, Philips, Best, The Netherlands). During each scanning, subjects were given a supine position, and a sponge pillow was put beneath their right hips to keep them 40–45° flexed. This method prevented proximal overlapping of the right and left femurs. Radiographic views were copied on video films on which measurements were performed. Eight out of 112 subjects were excluded from the analysis because of their technically inadequate images. As a result, 104 subjects were taken into the final analysis.

During the scanning process, the left femur was closer to the detector array of the scanner and was relatively free of magnifying effects. Therefore, only the left femur was measured. Femoral curvature was accepted as an arch, and the radius of the imaginary circle to which this arch might belong was calculated both from the posterior cortex and from the medulla (Fig. 2). Three points that formed the posterior cortical arch were defined as follows: Proximally, the lower edge of the lesser trochanter (P); distally, where the widening of the condyle begins (D); at the middle, the half distance between these two points (M). For the medullary arch, the closest points in the middle of the medullar cavities to the above-mentioned reference points were taken into consideration. After the determination of these reference points, the line connecting proximal and distal points (PD) was traced. The distance between P and D and the shortest distance between PD line and the point M (Mm) were measured. The radius of the imaginary circle to which this PMD arch belongs (namely the length of the hypotenuse of the triangle CmD) was calculated using the formula $a^2 = b^2 + c^2$ (Fig. 2).

The values obtained after the formula given above were compared to the radii of curvatures of ten different commercially available intramedullary nails (1—AUN: AO, Mathys, Bochum, Germany; 2—Universal: Synthes, Paoli, PA, USA; 3—Russel-Taylor: S&N Richards, Memphis, TN, USA; 4—Uniflex: Biomet, Warsaw, IN, USA; 5—AIM: Ace-De Puy, Warsaw, IN, USA;

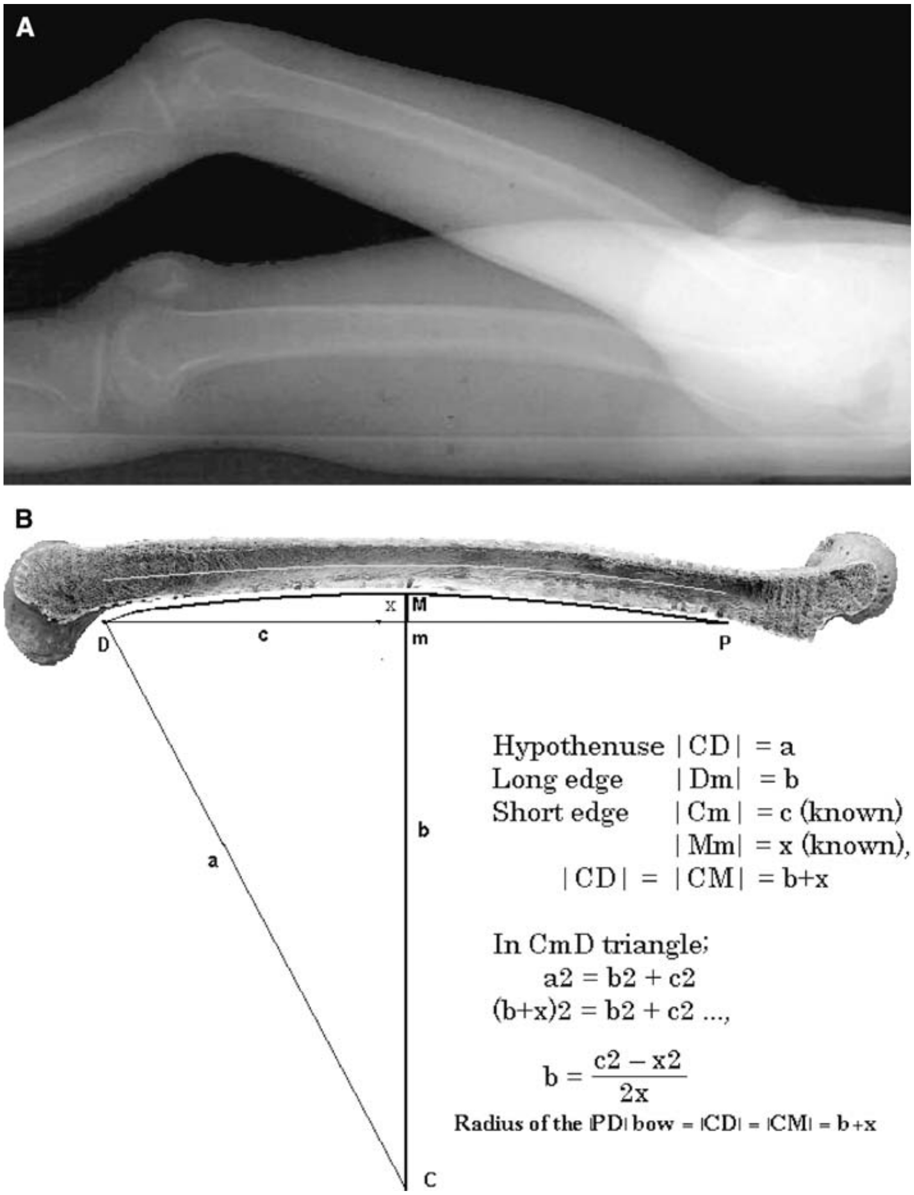

Fig. 2 The right hip 45° flexed, the left hip in extension, the lateral scout graph obtained with the left hip in extension (**a**). Calculation of anterior femoral bowing (**b**): *P* proximal point, on the lower edge of the lesser trochanter; *D* distal point, immediately above the flare of the condyles; *M* midway between the proximal and distal points

6—C75: Hipokrat, Izmir, Turkey; 7—Morris: Treu-Instrumente, Tuttlingen, Germany; 8—IMC: Tıpsan, Izmir, Turkey; 9—T2: Howmedica-Osteonics, Rutherford, NJ, USA; 10—SHO: Howmedica-Osteonics, Rutherford, NJ, USA). The values for the nails were retrieved from the product data, the relevant scientific literature, and our actual measurements on the nails we use. Radii of curvatures were found to be 150 cm for the first, 189 cm for the second, 230 cm for the third, 250 cm for the fourth, 280 cm for the fifth and the sixth, 290 cm for the seventh and the eighth, 295 cm for the ninth, and 300 cm for the tenth nail.

Results

When all subjects were considered, the calculated radius of the medullary arch (medullary bowing) was between 114 and 1,389 mm (mean: 722 mm, SD: 230 mm). The calculated radius of the cortical arch (cortical bowing), on the other hand, was between 109 and 1,666 mm (mean: 770 mm, SD: 267 mm) (Table 1; Figs. 3 and 4).

For males, the calculated radius of the medullary arch (medullary bowing) was between 114 and 1,389 mm (mean: 722 mm, SD: 230 mm). The calculated radius of the cortical arch (cortical bowing), on the other hand, was between 109 and 1,666 mm (mean: 770 mm, SD: 267 mm) (Table 1). For females, the calculated radius of the medullary arch (medullary bowing) was between 114 and 1,389 mm (mean: 722 mm, SD: 230 mm). The calculated radius of the cortical arch (cortical bowing), on the other hand, was between 109 and 1,666 mm (mean: 770 mm, SD: 267 mm) (Table 1). The difference between gender types regarding medullary or cortical bowings was not statistically significant

Table 1 Descriptive statistics for the left medullary and cortical femoral bowings

Parameter	Sex	*n*	Minimum	Maximum	Mean	SD
Medullary bowing (mm)	All	104	113.74	1389.37	722.37	229.58
	Male	50	113.74	1389.37	692.63	219.30
	Female	54	113.74	1389.37	749.91	237.41
Cortical bowing (mm)	All	104	108.75	1665.68	769.79	267.31
	Male	50	117.82	1665.68	759.34	269.58
	Female	54	108.75	1665.68	779.47	267.35

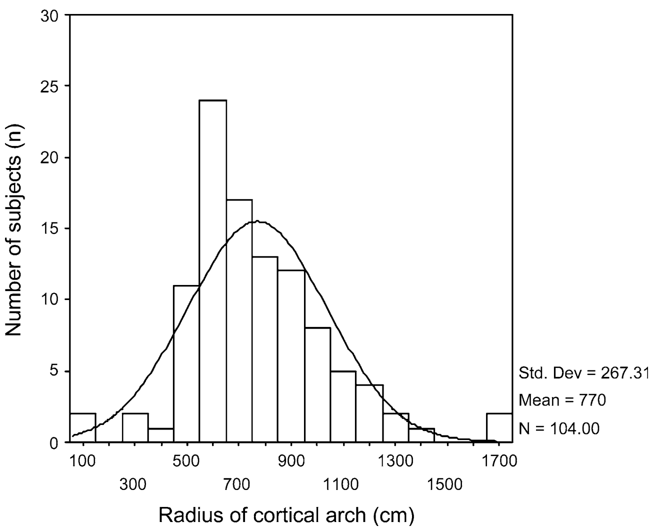

Fig. 3 Histogram showing the actual and normal distributions of the radius of medullary arch

($p = 0.205$ and $p = 0.705$, respectively) (Table 1; Figs. 5 and 6).

Cortical and medullar bowing was strongly correlated with the age of the subjects (Pearson's moments correlation coefficients, $r = -0.269$, $p < 0.006$ and $r = -0.234$, $p < 0.017$, respectively). When considering different gender types, these significances were produced by females ($r = -0.401$, $p < 0.003$ and $r = -0.403$, $p < 0.003$, respectively), and not by males.

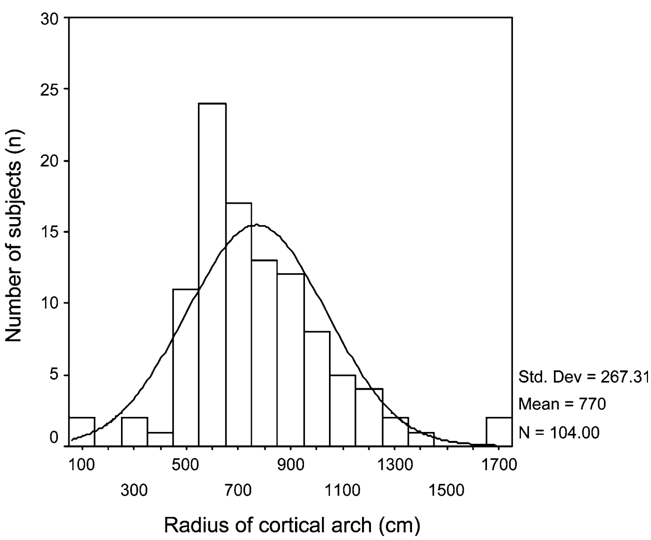

Fig. 4 Histogram showing the actual and normal distributions of the radius of cortical arch

Radii of curvatures of ten different intramedullary nails that were introduced in the "Materials and methods" section ranged between 150 and 300 cm. These values were higher than the mean cortical (77 cm) and medullary (72.2 cm) bowings. The longest radius for medullary bowing was 138 cm and this radius was shorter than the nail which has the shortest radius (AUN: AO, Mathys, Bochum, Germany, 150 cm). Accordingly, femurs of the subjects were more curved than the commercially available nails.

Discussion

In the presence of an uncompensated mismatch between the curve of a femoral nail and the femoral medullary bowing, serious problems may arise. An iatrogenic fracture may develop during the insertion of the nail [8, 20], or the tip of the nail may rip the distal anterior cortex of the femur [1, 12]. Moreover, as a result of the mismatch, angulations on the sagittal plane cause inadequate contact of the fracture ends, which in turn leads to union problems [14]. Particularly in fractures arising in the femoral isthmus, rotational misalignments due to the forced advancement of the "jammed" nail may occur [11, 20]. The insertion process may become difficult as an inappropriately curved nail leans against the medullary wall [3, 11, 12, 20]. Withdrawal of such a nail may eventually become difficult or even impossible because of the dynamic leaning and friction with the medullary wall. The use of interlocking nails may lead to a variety of additional consequences. The nail is stretched due to the effect of the medullary curvature, the parallelism between the guiding tools used for placing the locking screws, and the nail pricks which have to be in a parallel arrangement are missed, and therefore the interlocking screws cannot hit the pricks on the screw [12].

The above-mentioned complications of a mismatched nail necessitate investigating the compatibility of intramedullary nails and femoral medulla. Several researchers studied this problem. These studies yielded different suggestions for the ideal point of entry [4, 8, 11, 20], and for intramedullary nail designs having varied anterior

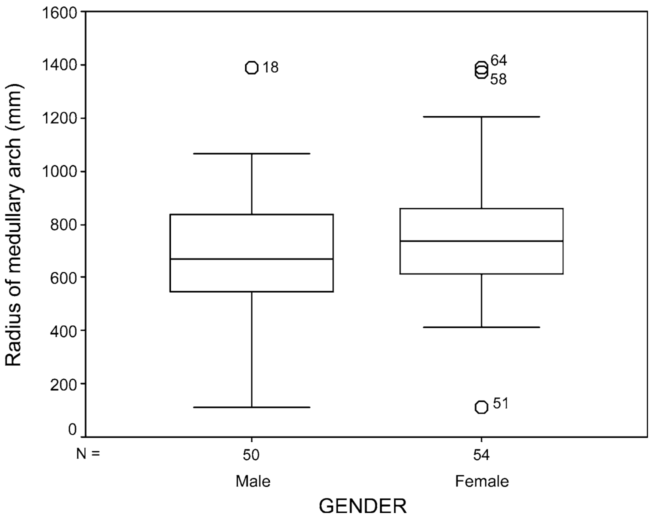

Fig. 5 Box plot showing the distribution of the radius of medullar arch in the males and in the females

curves [3, 7, 8, 11, 20]. The mean radius of anterior bowing of the femur was also investigated in the past. This value was found to be 144 cm by Harper and Carson [8], 109 cm by Johnson and Tencer [11] and Zuber et al. [20], 138 cm by Gonzalez et al. [7], and 120 cm by Egol et al. [3]. In our study, the mean medullary bowing was 72 cm, and the mean cortical bowing was 77 cm. Both results are remarkably different than the above-cited values, indicating that the femurs of our study population were more curved. This may be due to the naturally existing racial differences reported in many studies. To give an example, Walensky [19] in his extensive study on Whites, Blacks, American-Indians, and Eskimos showed that Blacks had less anterior curvature than Whites. According to that study, American-Indians exhibited greater anterior curvature than American-Whites and -Blacks, and the Eskimo femora were more closely related to American-Indians.

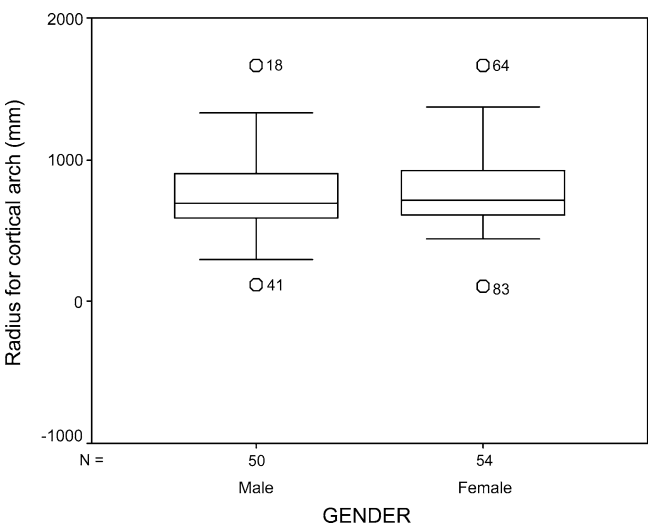

Fig. 6 Box plot showing the distribution of the radius of cortical arch in the males and in the females

The difference between the curves of the femur and the femoral nails that we use in current clinical practice implicates the inadequacy of the design of such nails for at least the Caucasian race living in Anatolia. Therefore, such nails should be re-designed accordingly to prevent the above-mentioned complications.

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