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An innovative method for measuring the femoral arch

Dong Ren[a], Tianci Wang[b], Ming Li[c], Yueju Liu[a], Yajie Huang[b], Pengcheng Wang[a,*]

Abstract

A mismatch between the femoral bow and intramedullary nails causes a series of complications. Previous investigations have sought to determine the curvature of the femur using the radius of the femoral bow. However, the radius of the curvature is affected by femur length. To eliminate the influence of femur length, we instead used an angle to indicate femoral curvatures.

Forty patients with intertrochanteric fractures who underwent a surgical procedure at our institution were enrolled in this study. We conducted a lateral X-ray of the contralateral femur before operation. We drew a triangle in the X-ray images using Digimizer software. The tangent values of the acute angle were used to indicate femoral curvature. The tangent values were then compared with the dimensions of currently used nails.

The average tangent value of the femurs was 0.0835 ± 0.0147, as measured from the inner cortex and 0.0798 ± 0.0150, as measured from the outer cortex. The tangent values were related to sex, with males having straighter femurs than females, and there was no obvious correlation between tangent values and age or femur length. Tangent value is a reliable method with a high intersurveyor consistency; femur curvatures were significantly greater than the curvatures of currently used nails.

Abbreviations: CT = computed tomography, IMN = intramedullary nail, ROC = radius of the curvature.

Keywords: femoral anterior curvature, femoral fracture, femoral intramedullary nail, tangent value

1. Introduction

The intramedullary nail (IMN) technique was first applied for the treatment of trochanteric fractures in 1940.[1] This technique gradually became preferred by orthopedic surgeons and was increasingly used in recent years.[2,3] Long IMNs have advantages over short nails for treating unstable fracture types. Kijima et al[4] investigated failure rates according to area classifications, and they found that short nails should be considered for fractures extending above the trochanter, while long nails should be considered when fractures extend to the subtrochanteric part. The use of long IMNs is a standard technique for treating femoral diaphysial fractures,[5] where a nail must be inserted from the proximal cavity into the distal medullary cavity.[6]

Mismatches between femoral bows and IMNs increase the difficulty of nail insertion,[7] cause perforation of the anterior cortex,[8,9] and change femoral angulation for the treatment of a femoral shaft fracture. This problem drew our attention and impelled us to explore the relationship between femoral curvature and IMNs.

Previous investigations have reported on the curvature of the femur and have found correlations between femoral curvature and age, sex, race, and body weight. Schmutz et al[10] analyzed 3D morphologic bone data from 90 human femurs and calculated an average radius of the curvature (ROC) of 885 mm, with Caucasian subjects (974 mm) having a larger radius than Asian subjects (787 mm), they also found a weak-to-moderate correlation between subject height and ROC. Maratt et al[11] conducted a retrospective review analyzing computed tomography (CT) scans of 3922 femurs of 1961 patients, the mean anterior ROC of the femurs was 145 cm, and they found a moderately strong positive correlation between femoral length and ROC.

In the past few decades, the radius of the femoral bow has been widely used to express the curvature of the femur. However, previous studies found that ROC was related to height and therefore femur length, which makes the radius of the femoral bow an inaccurate representation of femoral curvature. The aim of this study was to establish an innovative method (Tan α) to describe femur anterior curvatures. α is the acute angle of the isosceles triangle in a femur bow, it will be introduced in detail in the following section. We sought to determine the average Tan α of people from Hebei Province of China, and to investigate correlations of Tan α with age, sex, and femur length. Tan α was then compared with the dimensions of the currently used IMN.

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2. Methods

2.1. Subjects and materials

This study was approved by the ethics committee of The Third Hospital of Hebei Medical University (2018–007-1). Forty consecutive patients with trochanteric fractures who underwent a surgical procedure in the Department of Geriatric Orthopedics in our hospital between January 25, 2017 and May 3, 2018, with a minimum age of 65, were enrolled in this study. All patients were from Hebei Province, China. Patients with evidence of pathological fracture, open fracture, contralateral lower limb fracture, a femoral or pelvic implant, and those unwilling to join our study were excluded from this study. Patient data, including sex and age, were recorded within 24 h of admission. Femoral curvature is thought to be roughly the same in both legs,[12] therefore, because it was difficult to measure the injured femur directly owing to the deformity of the femur caused by the fracture, we conducted a lateral X-ray of the contralateral femur instead.

2.2. X-ray imaging

Conventional X-ray has a limited visual field, which is insufficient to show the whole femoral structure, therefore, a radiographic stitching system[13] was used to obtain a complete image of the femur. The leg of each patient was postured by 2 of the authors dressed in lead clothes, with the assistance of the patient's dependents. To obtain standard lateral X-ray images, we rotated the leg until both posterior edges of the femoral condyle coincided on a lateral view.

2.3. X-ray analysis

The X-ray images were then imported into Digimizer software, which was used by 3 orthopedists to draft a geometric figure of each image. The final values for each patient were the means of the 3 results obtained by the associate professors.

A computer-based graphical anatomic study[10] of the femur suggested that the antecurvature of the femoral arch can be approximated by a circular arch. We drew 3 lines on each image, which were at the level of the distal edge of the lesser trochanter, the proximal margin of the femoral condyle, and midway between the 2 lines above. The 3 midpoints of these lines were then determined (Fig. 1), which have been used to determine the femoral ROC in previous studies. These lines formed an isosceles triangle, and the femoral curvature was expressed as the tangent value of the acute angle of the triangle instead of using the traditional method. Values for the ROC as the traditional measurement were calculated and were compared with the results of our new method. We simplified radii to R and used the following equation according to the Pythagorean theorem: $R^2 = (R - Z_3E)^2 + Z_1E^2$. The radii were calculated by mathematical methods. Femur length (defined as segment AB) was also measured as an independent value, together with age and sex. All the measurements were performed according to the inner and outer cortical surface, respectively.

All measurements were expressed in the units of the Digimizer software. To obtain actual lengths, we measured the ruler in the X-ray image at the same time, and using proportional scaling, we determined the actual lengths of femurs and the radius of the 3-point arch.

All measurements and calculations were completed before surgery, and we chose the appropriate length of long nails according to the tangent value and femur length of the patient. Because inserting long nails requires a longer time than inserting short nails, we chose short nails for patients suffering from heart failure, respiratory failure, and other complications that may increase risks as the operation time is extend, these risk factors were estimated together by the anesthesiologists and surgeons.

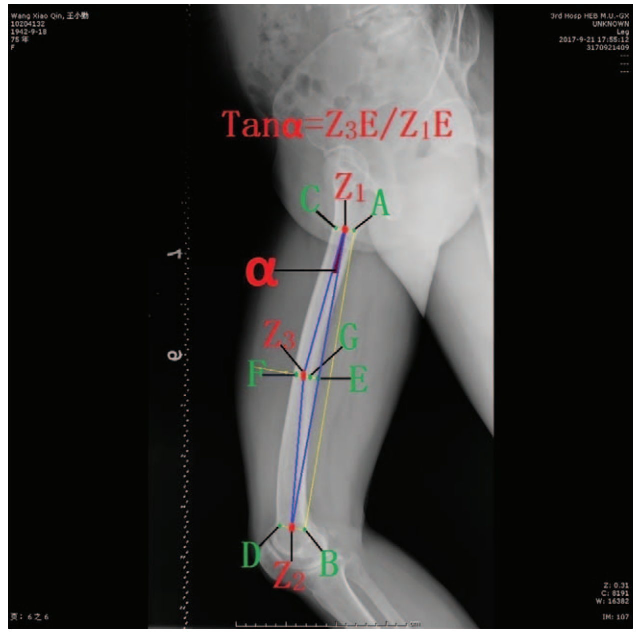


Figure 1. Measurement of lateral femur X-ray image using Digimizer software. The mapping process was as follows: Point A: The posterior inner cortex, lower edge of the lesser trochanter. Point B: The posterior inner cortex and a starting point of the femoral condyle. Point C: Draw a vertical line for AB through A, called line a. Point C is the intersection of line a and the anterior inner cortex. Point D: Draw a vertical line for AB through B, named line b. Point D is the intersection of line b and the anterior inner cortex. Z_1: Middle point of line AC. Z_2: Middle point of line BD. E: Middle point of Z_1Z_2. Point F: Draw a vertical line of AB through E, named line c. Point F is the intersection of line c and the anterior inner cortex. Point G: The intersection of line c and the posterior inner cortex. Z_3: Middle point of FG. Tan $\alpha = Z_3E/Z_1E$.

2.4. IMN analysis

The radii of curvature of IMNs were provided by the manufactures, and we chose a 35-cm Smith–Nephew nail as the model nail. Three points were selected on corresponding circles for the nails at both ends and the midpoint of the arch. The tangent value (Tan β) of the acute angle of the isosceles triangle represented the nail curvature. Tan β was mathematically calculated from the 3-point circle using the same method used for X-ray images (Fig. 2), and these values were then compared with Tan α values.

2.5. Data analysis

Statistical analysis was performed using SPSS 21.0 (IBM Corp. 2012). We used Shapiro–Wilk test to determine whether the data followed normal distribution or not. The data that followed normal distribution are presented as the mean ± standard deviation (SD). The data that did not follow normal distribution are presented as median (upper quartile, lower quartile). Intergroup correlation coefficients (ICCs) were used to check for consistency among the 3 surveyors. Correlations between

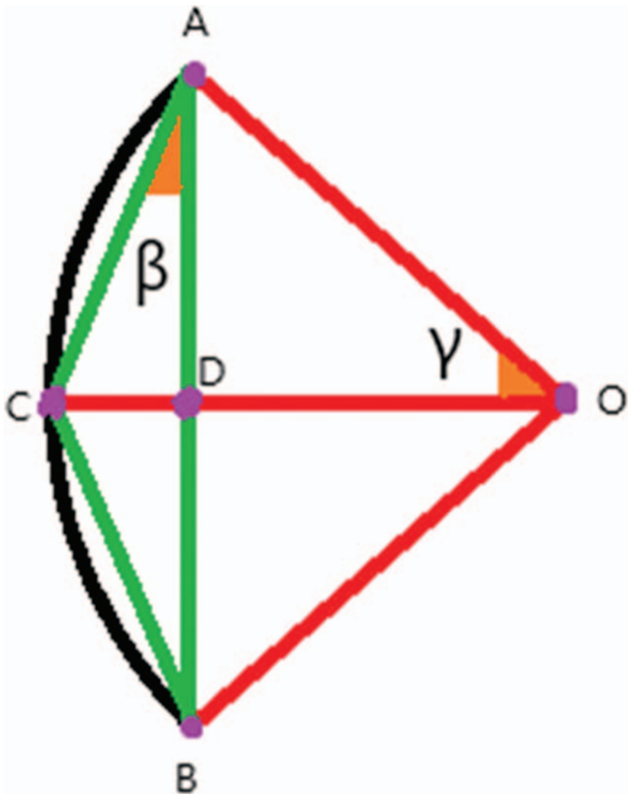


Figure 2. Diagram of the model nail measurement. This is the sketch map of intramedullary nail, arc AB represents the length of the nail, segment OA represents the radius of arch, length of arc AB and segment OA was provided by the manufacture. The calculation process is as follows: Arc AC = arc AB/2. γ = arc AC × 360°/2Π × segment OA. Cos γ = segment OD/segment OA. Segment CD = segment OA − segment OD. AD = √[(segment OA)^2 + (segment OD)^2]. Tan β = segment CD/segment AD.

dependent variables (tangent value from the inner and outer cortex) and independent variables (age, sex, and femur length) were determined using multivariate linear regression analysis. The correlation between our new method and the traditional method was analyzed by Spearman correlation analysis. The robustness of the data was assessed by the coefficient of variance between the 3 different observers and the standard error of mean between the observations by individuals. $P < .05$ was considered statistically significant.

3. Results

The average age of our sample population was 80.03 ± 7.89 years, ranging from 65 to 99, and the majority of patients (75%) were female. All 40 patients were Chinese and from Hebei Province.

There was high consistency among the 3 surveyors (Table 1). The ICC of the tangent value was 0.954 for the inner cortex and 0.990 for the outer cortex. The difference was statistically significant ($P < .001$). For inner cortex, the coefficient of variance between the 3 different observers was 0.030, For outer cortex, the coefficient of variance between the three different observers was 0.023. For inner cortex, the standard error of mean between the observations by individuals was 0.0024. For outer cortex, the standard error of mean between the observations by individuals was 0.0018.

For the inner cortex, the average femur tangent value was 0.084 ± 0.0147, and the ROC was 1556.707 (1373.554, 1903.258). For the outer cortex, the average tangent value was 0.080 ± 0.0150, and the ROC was 1612.328 (1362.294, 2082.786). The mean femur length measured from the inner and outer cortices was 31.724 ± 2.063 cm and 31.369 ± 1.947 cm, respectively. Spearman correlation analysis showed that Tan α was negatively correlated with the radius of curvature. The correlation coefficient was −0.776 for the inner cortex and −0.856 for the outer cortex ($P < .001$).

Multivariate linear regression analysis demonstrated that the tangent values of the femurs were related to sex (Figs. 3 and 4), with males having straighter femurs than females for both inner cortex ($P = .009$) and outer cortex ($P = .001$), and there was no relationship between tangent values and age ($P = .742$ for inner cortex, $P = .747$ for outer cortex) (Figs. 5 and 6) or femur length ($P = .146$ for inner cortex, $P = .486$ for outer cortex) (Figs. 7 and 8).

Mathematical calculations showed that Tan β = 0.044, it was significantly lower than the value of Tan α. This finding indicates that the model nails we chose were straighter than the average femoral curvature.

4. Discussion

We previously defined the tangent value as a new estimation of femoral curvatures in a finite analysis study.[14] It was a subsequent research. Previous studies have investigated the curvature of the femur by means of ROCs, but this method ignores the impact of femur length. The importance of this method is represented in the following example: 2 people have the same femur curvature but a different femur length, which means 1 is significantly taller than the other. Using the traditional method, the taller person has a larger ROC, which leads to the conclusion that the femur of the taller person is straighter, which is an obviously incorrect conclusion. The use of an angle to express femur curvatures allows us to determine the correct result by avoiding the impact of femur length. As another example, if we scale up a relatively short femur by a factor of 2, the ROC becomes twice as large but the femoral curvature does not change. In contrast, the value of Tan α is maintained, which makes this angle a better choice than femur length to express femoral curvature. No gold standard for determining femoral

Table 1

ICC analysis of different observers.

	Surveyor 1	Surveyor 2	Surveyor 3	Mean ± SD	ICC	P
Tan α(inner cortex)	0.0833 ± 0.0163	0.0829 ± 0.0146	0.0842 ± 0.0152	0.0834 ± 0.0147	0.954	<.001
Tan α(outer cortex)	0.0800 ± 0.0153	0.0796 ± 0.0150	0.0797 ± 0.0153	0.0798 ± 0.0150	0.990	<.001

There was high consistency among the three surveyors.
ICC = intergroup correlation coefficient.

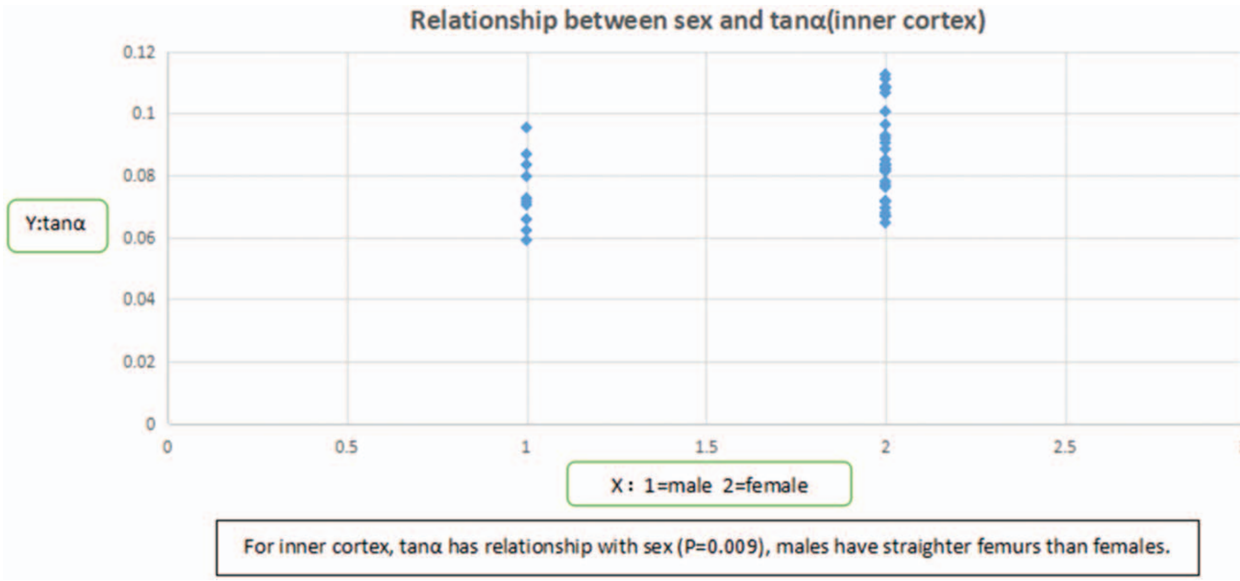


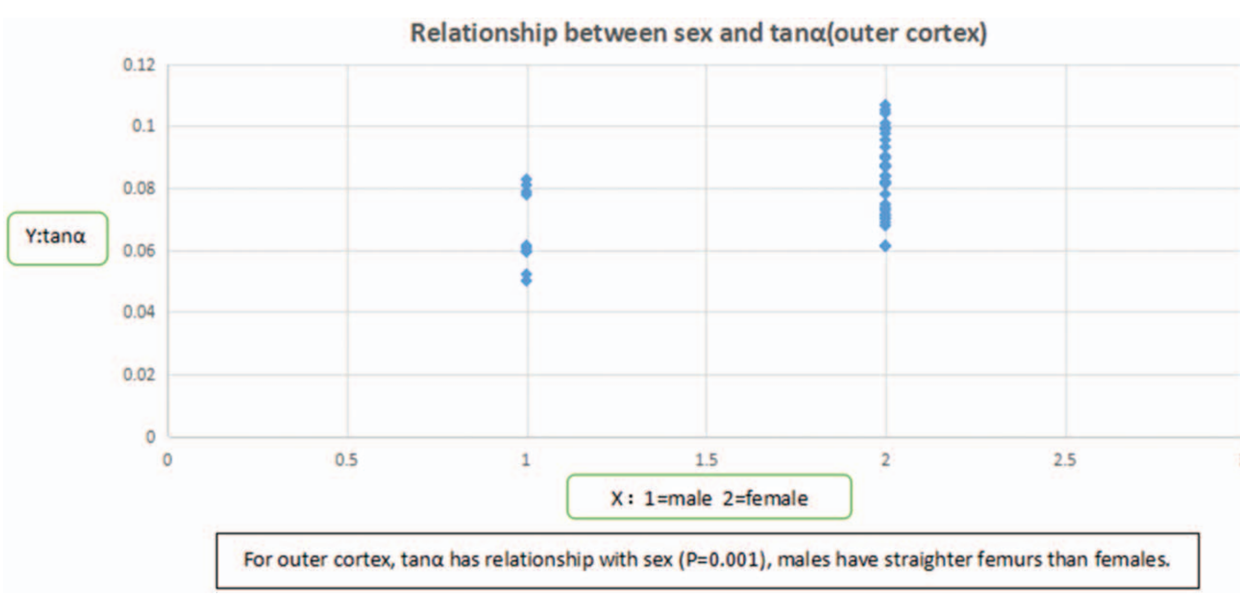
Figure 3. XXX.

curvature has yet been established, but we think that using this angle is a better method than using ROC.

The ROC (1664.194 for the inner cortex and 1734.937 for the outer cortex) in this study was slightly higher than previously reported values (range 1090–1523),[11,12,15–17] which might be due to the small sample size and the fact that our samples were from a small area (Hebei Province in China). Notably, the patients in our study were older than 65 years, and a previous study suggested that age has an impact on femoral curvature[18]; therefore, the age in our study may have contributed to the differences. In addition, this was a prospective study, and the whole sample group consisted of consecutive intertrochanteric fracture patients in a geriatric orthopedics department rather than samples from a database or museums, which might also have had an impact on the results.

The curvature of the nails was also expressed by an angle, Tan $\beta = 0.0438$, which was much lower than Tan α (0.0835 for the inner cortex and 0.0798 for the outer cortex); a previous study[12] compared the ROC of femurs and nails and obtained the same result. This finding occurred because early nails were designed for a 3-point contact fixation. A previous investigation[19] indicated that an increase in nail curvature may reduce the risk of anterior cortical penetration distally. In the past few decades, long nails have been designed with a decreased ROC, but they remain straighter than femurs, which is probably because a highly curved nail is more difficult to insert, and thus further research needs to be conducted on the process of nail insertion.

IMN manufactures never stop improving their products. Initially, long IMNs of different lengths had the same ROC; however, with further research on anterior femoral curvature as



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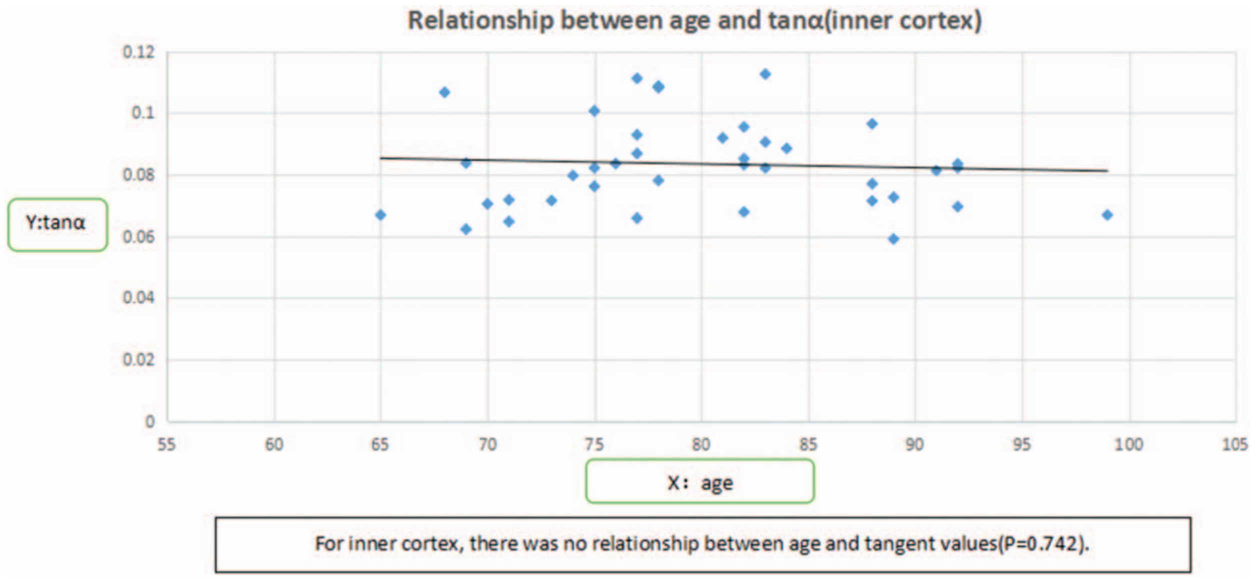


Figure 5. XXX.

described above, an obvious correlation between femur length and ROC was found.[10,11] Therefore, long IMNs were then designed with different ROCs according to femur length. In 2015, Chapman et al[20] found an extremely large degree of variability in the overall curvature of femurs, with the highest degree of femoral curvature found in the distal shaft. In addition, Smith–Nephew recently changed their nails, with the nail curvature becoming more gradual from the proximal end to the distal end.

There are limitations to this study. Despite being an innovative and new method to describe femoral curvature, our study is limited by its relatively small sample size. Another limitation is that we used X-ray images rather than CT to measure the femur arch. Although Kenneth[11] found that X-ray has a good correspondence with CT imaging in the study of femur curvature, error may arise in choosing the points because the edge of the cortex is not as clear as that on CT images. But CT it is too much radiation to scan the whole femur of the patience, and X-ray as a more convenient measurement method to conduct, has its own advantages, and it is a relatively low cost method as well. Our analysis showed that a 0.00066 variance (approximately 0.9%) in Tan α was caused by a 1-mm displacement in the transverse direction, and a 0.00048 variance (approximately 0.66%) in Tan α was caused by a 1-mm displacement in the vertical direction. We may have obtained more precise results by averaging the results from 3 separate measurements, but errors may still be present.

Both Tan α and the radius of curvature were measured from the inner and outer cortices. Technically, the inner cortex is closer

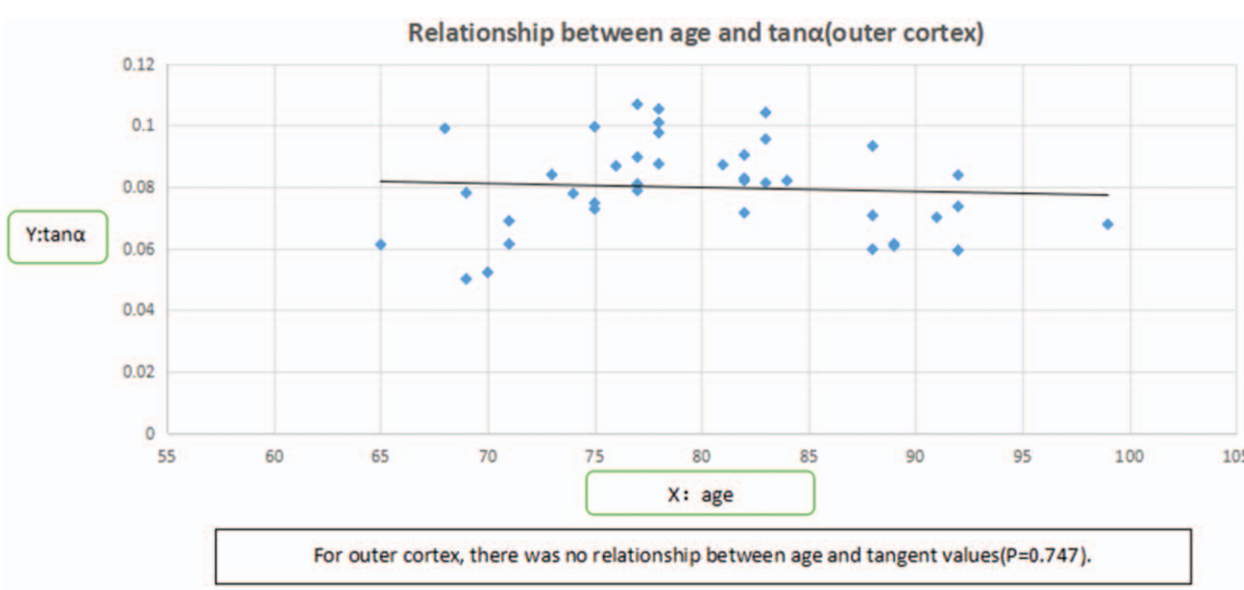
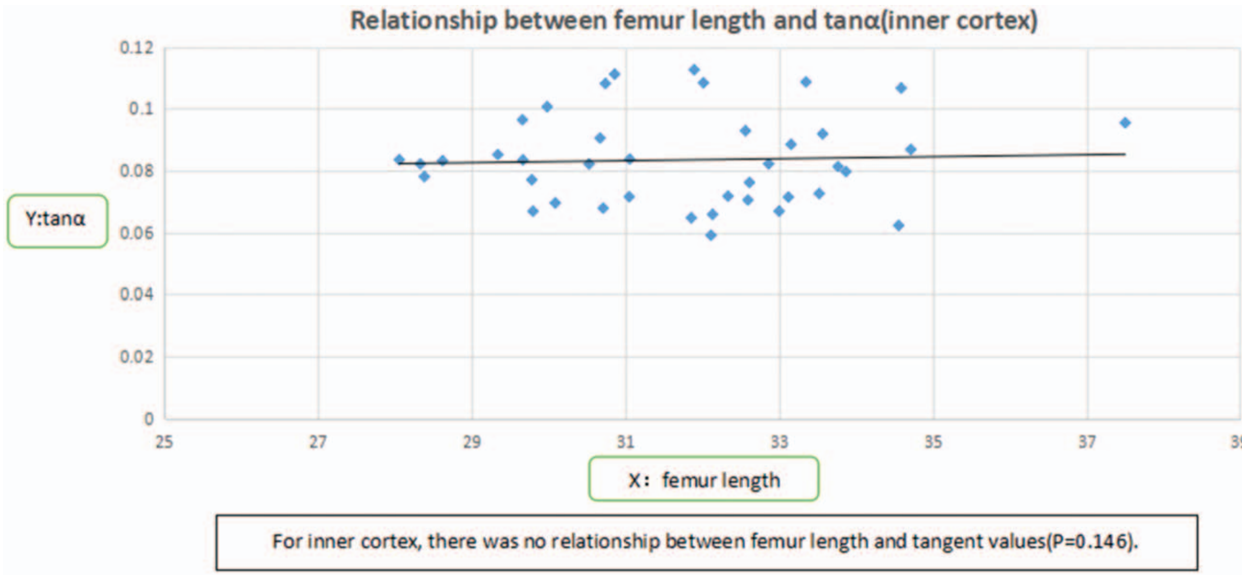


Figure 6. XXX.



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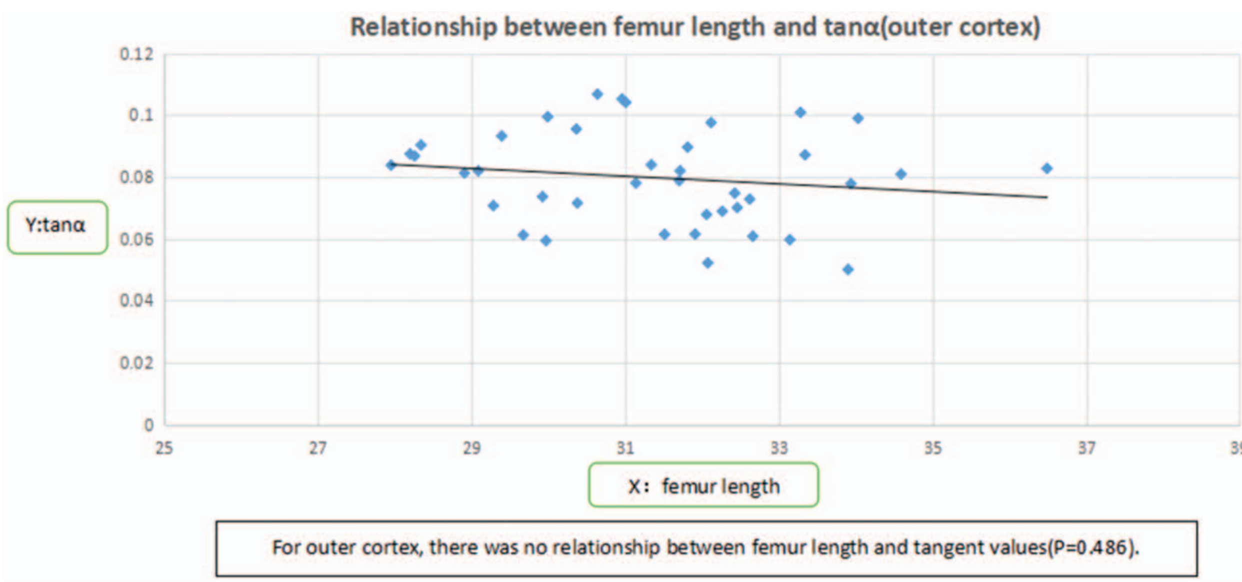

Figure 8. XXXX.

to the actual medullary canal, but the inner cortex surface is difficult to distinguish in some segments, while nearly all parts of the outer cortex surface are clear. Although some researchers choose the midpoint between 2 points measured at the inner and outer surfaces, we calculated these 2 results separately and found that they differed only slightly from each other (0.0835 vs. 0.0798).

5. Conclusion

The tangent value of femurs is a reliable method with a good intersurveyor consistency; the average tangent value of femurs measured from the inner cortex was 0.0835 ± 0.0147 and was 0.080 ± 0.0150 measured from the outer cortex. There was a correlation between tangent values and sex, with males having straighter femurs than females, and no obvious correlation was found between tangent values and age or femur length. The model nail we chose was significantly straighter than the average femoral curvature.

Author contributions

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