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Original Article

Radiological Assessment of Femoral Rotation: A Cadaveric Study
股骨旋轉的放射學評估：屍體標本研究

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ABSTRACT

Purpose: To define how the lesser trochanter can be used in an objective manner to assess the femoral rotation in plain radiograph.
Methods: Eighteen pairs of cadaveric femurs from Chinese individuals were used in this study. For each femur, radiographs were taken in the following positions with reference to the anatomical trans-epicondylar axis: neutral position; 5°, 10°, 15°, and 20° internal rotation; and 5°, 10°, 15°, and 20° external rotation. Lesser-trochanter index, which was defined as the width of lesser trochanter divided by the remaining width of the proximal femur, measured at the level of its most prominent point, which was perpendicular to the anatomical axis of the proximal femur, was obtained on a Picture Archiving Communication System workstation in every radiograph. Statistical analyses were performed by using a statistical software R (R language, version 2.12.0).
Results: The lesser-trochanter index showed positive correlation with increasing external rotation of femur: correlation coefficient = 0.75 ($p < 0.00001$). Analysis-of-variance test showed that the lesser-trochanter indexes of Group 1 (20° and 15° internal rotation), Group 2 (10° internal rotation to 10° external rotation), and Group 3 (15° and 20° external rotation) had statistically significant differences ($p < 0.00001$). Receiver operating characteristic curves were used to determine the cutoff value of lesser-trochanter index to distinguish the three groups. By using the lower cutoff value as 0.17, we can distinguish Group 2 from Group 1 with a sensitivity of 0.85 and a specificity of 0.65. By using the upper cutoff value as 0.28, we can distinguish Group 2 from Group 3 with a sensitivity of 0.80 and a specificity of 0.73.
Conclusion: The lesser-trochanter index can be used as a method to assess the rotational alignment of femur in plain radiograph. It is simple, objective, not affected by the factor of magnification, and can be applied to both long and short films.

中 文 摘 要

目的: 如何客觀地在X線片以小轉子用作股骨旋轉的評估。
方法: 本研究把18對中國籍的屍體股骨進行分析。我們對每條股骨在以下位置拍取X 線片：中立位置（與上髁間軸平衡）、5°，10°，15°，20°內旋位置、與及5°，10°，15°，20°外旋位置。我們在每張X線片上測量小轉子指數。小轉子指數的　厘定方法是：在在小轉子最突出的一點並與股骨近端解剖軸成正角的水平，把小轉子的闊度除以股骨近端的剩餘闊度° 每張X線片都在PACS工作站進行量　度，並以統計分析軟件R（版本2.12.0）對數據進行分析。
結果: 小轉子指數與股骨外旋呈正相關的關係，相關係數 = 0.75（p值<0.00001）。 ANOVA 分析表明，第1組（20°和15°內旋）的小轉子指數，第2組（10°內旋至10°外 旋）的小轉子指數和第3組（15°和20°外旋）的小轉子指數有顯著注差異（p <0.00001）。我們並以ROC曲線來找出用以區分 3組的小轉子指數數值。透過使用0.17小轉子指數作為分野，我們可以把第2組從第1組分別出來，敏感　度 = 0.85，特異性 = 0.65。透過使用0. 28小轉子指數作為分野，我們可以把 第2組從第3組分別出來，敏感度 = 0.80，特異性 = 0.73。
結論: 小轉子指數能用作股骨旋轉的X線評估，這方法不但簡單，而且客觀，並不受; 放大因素所影響，因此適用於長和短的X線片中。

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Introduction

Correct lower limb alignment is essential in many orthopaedic surgeries, such as total-knee replacement and high tibial osteotomy, and the margin of error is low.[1,2] Standing long film is the gold standard to assess the lower limb alignment, and it is important for both preoperative planning and postoperative assessment. However, because an anterolateral bowing occurs naturally in the shaft of femur, the femoral axis obtained from a two-dimensional anteroposterior (AP) radiograph is affected by the rotation of femur at the time of radiographic assessment. The angle between the mechanical axis and the anatomical axis of the femur will vary with different rotations of the femur. This effect had been well illustrated by Jiang and Insall,[3] who found a variation of 2.5° between the positions of 20° internal rotation and 20° external rotation. This finding was also echoed by other authors.[4,5] This can result in pitfalls in the use of femoral intramedullary guides in total-knee replacement. This issue is particularly important in Chinese patients who have more significant femoral bowing.[6,7]

The standard procedure to control the rotation of the femur while taking the AP radiograph of the lower limb is to place the patella facing forward. In real practice, it is difficult, especially in obese patients; patients with knee deformities, such as flexion contracture and coronal deformity; and patients with subluxed or dislocated patella. Therefore, we need a better way to assess the lower limb rotational alignment in AP radiograph. The appearance of the lesser trochanter is commonly used to assess the femoral rotation, but there are no objective criteria on that, and it has not been validated as an accurate assessment tool. In this cadaveric study, we try to define how the lesser trochanter can be used in an objective manner to assess the femoral rotation in the radiograph.

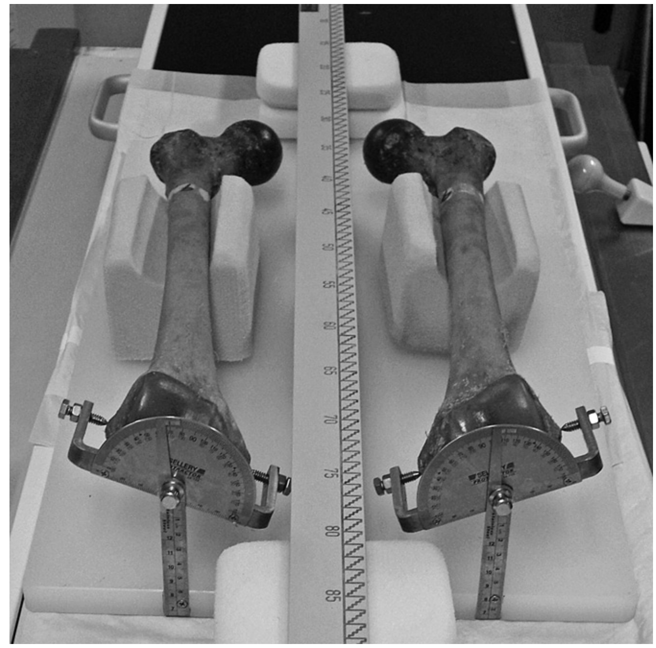

Figure 1. Setup of the study.

Methods

Eighteen pairs of cadaveric femurs from Chinese individuals were used in this study. All of them were dry anatomic specimens with no soft-tissue attachment. The medial and lateral epicondyles were located, and the anatomical transepicondylar axis was defined. The cadaveric femurs were fixed onto a stand in which the angle of rotation could be adjusted with the aid of a goniometer (Figure 1). The base of the stand was made of radiolucent plastic material; it can accommodate two femurs at the same time. The proximal shaft of the femur was supported by foam, whereas the distal femur was clamped at the medial and lateral femoral epicondyles; therefore, the angle of rotation can be adjusted with reference to the transepicondylar axis. A ruler was placed at the level of femur shaft as calibre. For each specimen, nine radiographs were taken in the following positions with reference to the transepicondylar axis: neutral position; 5°, 10°, 15°, and 20° internal rotation; and 5°, 10°, 15°, and 20° external rotation, in which the neutral position was defined as parallel to the transepicondylar axis (Figure 2). Thus, a total of 162 radiographs were taken. The instruments applied in the study include the digital radiograph system SIREGRAPH D2M by SEMENS (Germany), the measurement software Radworks system by General Electric Healthcare (UK) and the Picture Archiving Communication System workstation.

Lesser-trochanter index, which was defined as the width of lesser trochanter divided by the remaining width of the proximal femur, measured at the level of its most prominent point, which was perpendicular to the anatomical axis of the proximal femur, was obtained on a Picture Archiving Communication System

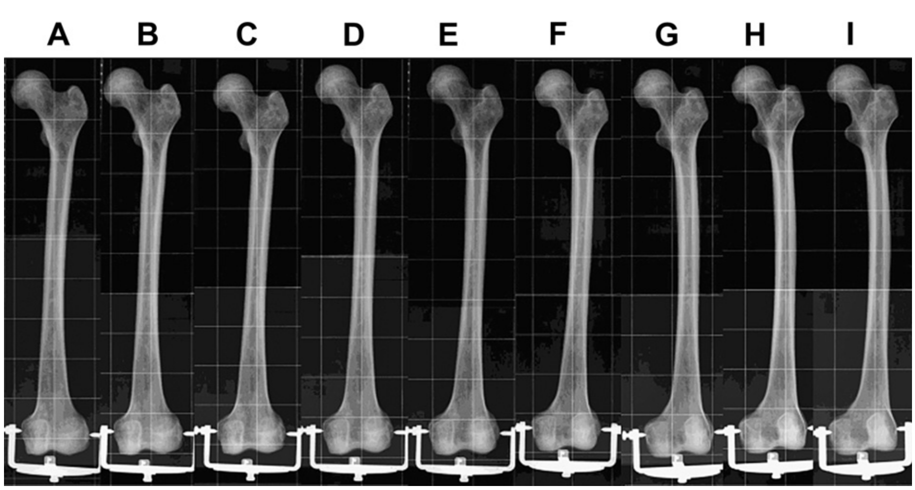

Figure 2. Nine standard anteroposterior radiographs of left femur taken from 20° IR to 20° ER, which demonstrated the changes in appearance of the lesser trochanter. (A) IR 20°; (B) IR 15°; (C) IR 10°; (D) IR 5°; (E) neutral; (F) ER 5°; (G) ER 10°; (H) ER 15°; and (I) ER 20°. ER = external rotation; IR = internal rotation.

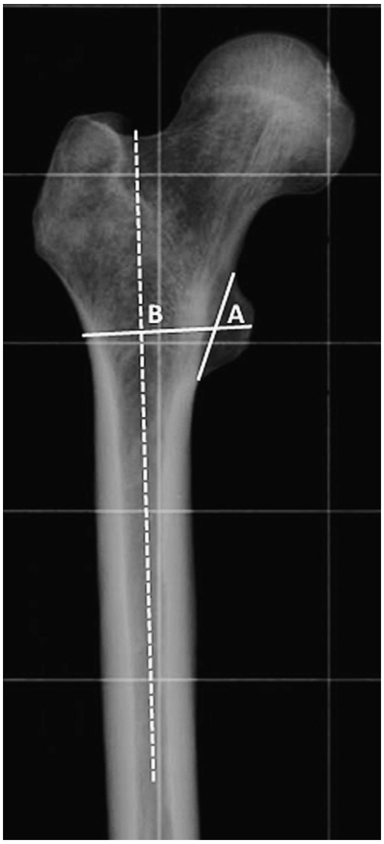

Figure 3. Lesser-trochanter index = *A*/*B*.

workstation in every radiograph (Figure 3). The anatomical axis of the proximal femur was defined by joining two midpoints of the canal, one at 5 cm and the other at 10 cm distal to the most prominent point of lesser trochanter. A single observer performed all the measurements to eliminate the interobserver error.

Statistical analyses were performed by using a statistics software R (version 2.12.0) by the R Developement Core Team. Correlation between the lesser-trochanter index and femoral rotation was calculated. We then divided the data into three groups: Group 1 (20° and 15° internal rotation); Group 2 (10° and 5° internal rotation, neutral position, 5° and 10° external rotation); and Group 3 (20° and 15° external rotation). The reason why we divided the data into three groups as earlier was that a previous study showed that the rotation of 10° internally and externally had a small effect on the axial alignment measurement of the lower limb.[8] However, 15° of external foot rotation was found to result in 3.5° more measured varus alignment, compared with 15° of internal foot rotation.[9] Therefore, femoral rotation from 10° internal rotation to 10° external rotation is acceptable for the measurement of axial alignment of femur. The mean value, range, and quartile range of the lesser-trochanter index for the three groups were calculated. Comparisons among different groups were made by analysis-of-variance test. Receiver operating characteristic curves were used to determine the cutoff value of lesser-trochanter index to distinguish the three groups. Differences were regarded as statistically significant when p values were less than 0.05.

Results

The lesser-trochanter index showed strong positive correlation with increasing external rotation of femur, (correlation coefficient = 0.75, $p < 0.00001$). The mean values and the ranges of

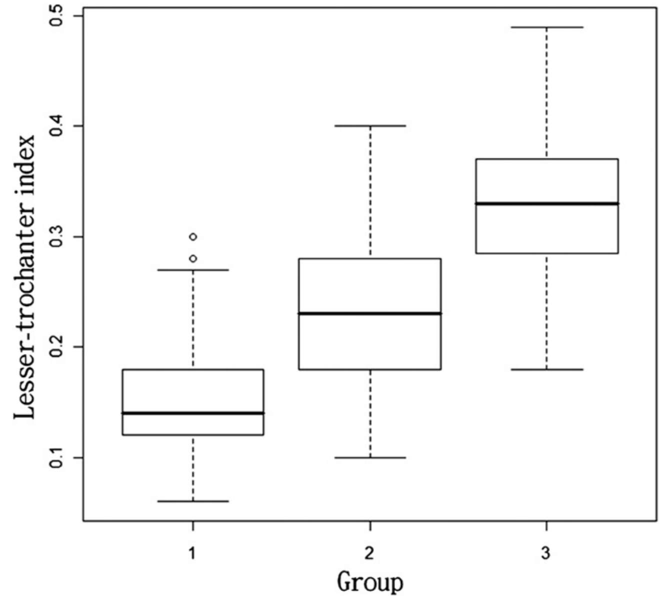

Figure 4. Box plots of the lesser-trochanter indexes of the Groups 1, 2, and 3.

lesser-trochanter indexes for the three groups were as follows: (1) Group 1: 0.15 (0.06–0.30); (2) Group 2: 0.24 (0.10–0.40); and (3) Group 3: 0.33 (0.18–0.49). The quartile ranges of the lesser-trochanter index for the three groups were as follows: (1) Group 1: 0.12–0.18; (2) Group 2: 0.18–0.28; and (3) Group 3: 0.29–0.37 (Figure 4). We confirmed that the lesser-trochanter indexes of the three groups were in normal distribution, and the analysis-of-variance test showed that the lesser-trochanter indexes of Groups 1, 2, and 3 had statistically significant differences ($p < 0.00001$). By using receiver operating characteristic curves, we found that, to distinguish Group 2 from Group 1, the optimal cutoff value was 0.17,

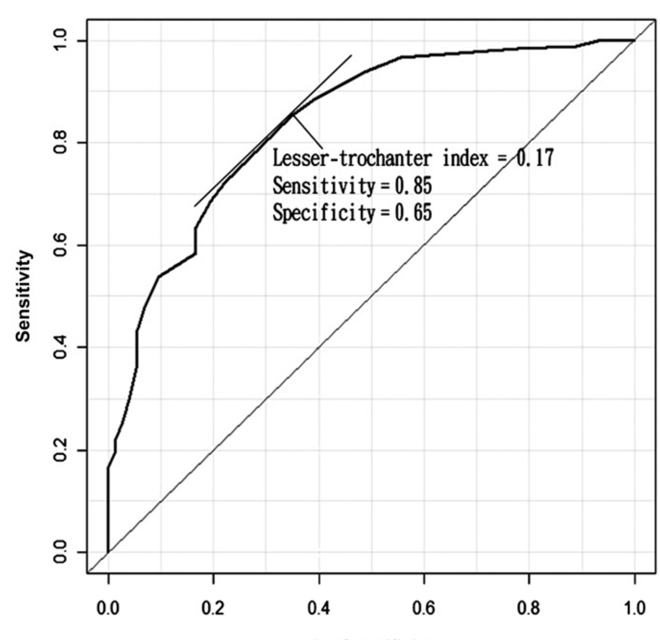

Figure 5. Receiver operating characteristic curve to determine the lower cutoff point of acceptable rotation by using data of Groups 1 and 2.

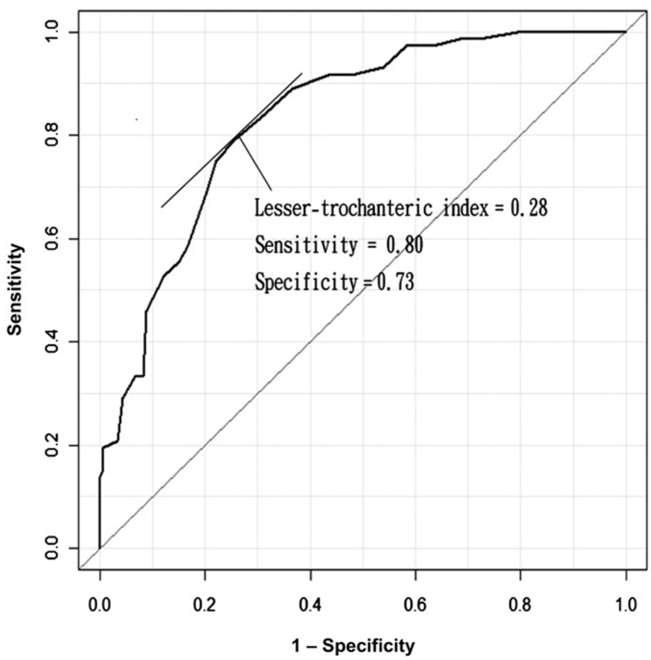

Figure 6. Receiver operating characteristic curve to determine the upper cutoff point of acceptable rotation by using data of Groups 2 and 3.

with a sensitivity of 0.85 and a specificity of 0.65 (Figure 5). To distinguish Group 2 from Group 3, the optimal cutoff value was 0.28, with a sensitivity of 0.80 and a specificity of 0.73 (Figure 6).

Discussion and Conclusion

We found that the lesser-trochanter index could be used as a method to assess the rotational alignment of femur. Furthermore, from our results, if the lower limb radiograph is being used for the measurement of axial alignment of femur and clinical use of preoperative planning of knee alignment surgeries, we must be very cautious if the lesser-trochanter index is <0.17 or >0.28 because error may result owing to malrotation.

The merits of the lesser-trochanter index are that it is simple and objective. It is not affected by the factor of magnification because we are not measuring the exact dimension but a ratio instead; hence, it can be applied to both conventional films and digital films easily. Also, because all the landmarks used are located in the proximal femur, it can be applied to both long films of the lower limb and short films, which only showed the proximal femur.

The limitations of our study include the relatively small sample size and the potential measurement error when finding the lesser-trochanter indexes. Also, the interobserver and intraobserver errors were not measured in this study. Moreover, because all the measurements were done with the cadaveric femur parallel to the table, it may not be applied to situations where the hip is in flexed position, such as hip flexion contracture or ipsilateral knee flexion contracture. Other limitations when applying the index include history of old femur fracture and torsional deformity of femur.

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