A 45-degree radiographic method for measuring the neck shaft angle and anteversion of the femur: a pilot study

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ABSTRACT

Purpose. To propose a novel method to measure the neck shaft angle and anteversion of the femur using anteroposterior and 45° oblique radiographs.

Methods. Three human subjects were used to verify the 45° oblique method. The true neck shaft angle and anteversion of the femur were determined using computed tomography. The true values were compared with the values derived by the 45° oblique method after correcting the distortion using a formula.

Results. With the true values based on computed tomography as references, the neck shaft angle and anteversion of the 3 subjects deviated +0.82° to +4.66° and -2.14° to +2.55° in lateral 45° oblique radiographs, respectively, whereas the corresponding values in medial 45° oblique radiographs were +0.98° to +5.93° and -10.09° to +1.58°. The lateral 45° oblique method resulted in smaller range of deviation and were more accurate.

Conclusion. This 45° oblique method is useful in surgical planning, especially for femoral derotational osteotomy in children. This new method enables easy calculation of the true neck shaft angle and anteversion, with low radiation exposure.

Key words: bone anteversion; femur neck; radiography

INTRODUCTION

Neck shaft angle and anteversion of the femur are common measurements for studies involving correlations with congenital hip dislocation, slipped capital femoral epiphysis, risk of osteoarthritis, femoral neck fracture, and instability of the hip.1-3 They are also used for diagnosing paediatric in-toeing or out-toeing gait, as well as for patient selection and surgical planning for derotation osteotomy of the femur and total hip replacement. Based on the anteroposterior radiographs of the hip, the anteversion of the femur ranges from -14.63° to 35.90°, with a mean of 9.73° and standard deviation of 9.28°, whereas the neck shaft angle ranges from 105.65° to 146.29°, with a mean of 129.23° and standard deviation of 6.24°.5 However, depending on the position of the
subjects, error may ensue. Thus, the biplanar and the Dunn axial radiographic methods are proposed for more accurate measurement, but are not popular owing to difficulty achieving special positioning, biased results, and high radiation exposure (in the axial method). Clinical measurements correlate poorly with radiographic measurement in terms of the anteverision. Ultrasonography enables accurate and reproducible measurements, but is operator dependent and may be biased. Computed tomography is also accurate and reproducible, but entails high radiation exposure, which is undesirable in children. We therefore propose a novel method to measure the neck shaft angle and anteverision of the femur based on trigonometry, using anteroposterior and 45º oblique radiographs. The subject maintains the same position while the X-ray beam is directed at an angle of 45º to the anteroposterior film. This ‘45º oblique method’ can be used in patients with cerebral palsy even if muscle contracture resists manipulation.

MATERIALS AND METHODS

The neck shaft angle is the angle between the femoral shaft axis and the femoral neck axis, whereas the anteverision is the inclination of the femoral neck axis with reference to the transcondylar plane (Fig. 1). The 45º oblique method was first verified in a sawbone model, with a known neck shaft angle of 135º and anteverision of 20º. An anteroposterior and a 45º oblique (medial and lateral) radiographs of the sawbone were taken. As the 45º oblique radiographs were actually distorted, the true neck shaft angle and anteverision were derived using a formula.

The 45º oblique method was then verified in 3 subjects. Subjects were positioned supine on the radiographic table. The knees were flexed 90º and the legs hanged perpendicularly over the table end to avoid femoral rotation. The transcondylar plane of the femur was parallel to the table, and anteverision was measured. Anteroposterior and 45º oblique (medial and lateral) radiographs of the hip were taken (Fig. 2). The true neck shaft angle and anteverision were derived using the formula, and the results were compared with those determined using computed tomography, in which the anteverision was measured using the axial oblique plane (parallel to the femoral neck axis) and the transcondylar plane.

The formula was based on trigonometry. When the femur rotates along its shaft axis, the neck shaft angle eventually becomes a straight line in the anteroposterior view. Therefore, by knowing the 2 neck shaft angles in an anteroposterior view and in a 45º oblique view, the true neck shaft angle and anteverision can be derived.

In Figure 1b, \( \theta \) represents anteverision:

\[
\cos \theta = \frac{a}{d}
\]

\[
a = \cos \theta \times d
\]

The neck shaft angle in the anatomical position and in 45º rotation of the femur are defined as \( \alpha_y \) and \( \alpha_x \), respectively. In Figure 1a,

\[
\tan(180^\circ - \alpha_y) = \frac{a_1}{b}
\]
\[
\tan(180°-\alpha_1) = \frac{\cos\theta \times d}{b}
\]
\[
\tan(180°-\alpha_2) = \frac{d}{b}
\]

whereas
\[
\tan(180°-\alpha_2) = \frac{a_2}{b}
\]
\[
\tan(180°-\alpha_2) = \frac{\cos(\theta+45°) \times d}{b}
\]

Combining the 2 equations:
\[
\tan(180°-\alpha_1) = \tan(180°-\alpha_2)
\]
\[
\frac{\tan(180°-\alpha_1)}{\cos\theta} = \frac{\tan(180°-\alpha_2)}{\cos(\theta+45°)}
\]
\[
-\tan\alpha_2 = \frac{\tan\alpha_1}{\cos(\theta+45°)}
\]
\[
-\tan\alpha_2 = \frac{\tan\alpha_1}{\cos\theta \cos 45° - \sin\theta \sin 45°}
\]
\[
\frac{2\tan\alpha_2}{\sqrt{2}} = \frac{1 - \tan\theta}{\sqrt{2} \tan\alpha_1}
\]
\[
\tan\theta = 1 - \frac{2\tan\alpha_2}{\sqrt{2} \tan\alpha_1}
\]

Figure 2 Subject is lying supine on the table with both knees flexing 90° and the legs hanging perpendicularly. The X-ray beam is projected (a) anteroposteriorly and (b) in a lateral 45° oblique direction.

Figure 3 (a) Lateral 45° oblique projection of the X-ray beam distorts the radiographs. (b) The light grey line represents the true femoral neck axis. The medium grey line represents the femoral neck axis projected on the anteroposterior radiograph. The dark grey line represents the femoral neck axis projected on the lateral 45° oblique radiograph. The 2 triangles represent extractions from the anteroposterior and lateral 45° oblique radiographs. \(\alpha\) denotes neck shaft angle in the anteroposterior radiograph, and \(\beta\) denotes neck shaft angle in the lateral 45° oblique radiograph.
In the equation, when \( d \) is equal to \( a \), \( \alpha_t \) is the true neck shaft angle (after eliminating the anteversion), and \( a_t \) represents \( a \) in 0° anteversion:

\[
\tan(180°-\alpha_t) = \frac{a_t}{b} \\
\tan(180°-\alpha_t) = \frac{d}{b} \\
-\tan\alpha_t = \frac{\tan(180°-\alpha_t)}{\cos\theta} \\
-\tan\alpha_t = -\tan\alpha_t \frac{1}{\cos\theta} \\
\tan\alpha_t = \frac{\tan\alpha_t}{\cos\theta}
\]

Instead of rotating the femur 45°, the femur remained in the same position and lateral and medial 45° oblique radiographs were taken. The neck shaft angle in 45° oblique radiographs was distorted, and hence another formula was needed to calculate the real angles.

In Figure 3b, \( \beta \) represents the neck shaft angle in 45° oblique radiographs:

\[
\tan(180°-\beta) = \frac{\sqrt{2B^2}}{A} \\
-\tan\beta = \frac{\sqrt{2\times B}}{A} \\
-\tan\beta = \frac{B}{\sqrt{2}} \frac{1}{A}
\]

whereas, \( \alpha \) represents the neck shaft angle in an

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**Figure 4** The neck shaft angle is (a) 139° on the anteroposterior radiograph, (b) 135° on the lateral 45° oblique radiograph, and (c) 143° on the medial 45° oblique radiograph.

| Femur       | Neck shaft angle | Difference from true value | Anteversion | Difference from true value |
|-------------|------------------|----------------------------|-------------|---------------------------|
| Sawbone     |                  |                            |             |                           |
| True value  | 135.00°          | -                          | 20.00°      | -                         |
| Lateral 45° oblique | 132.08°      | -2.92°                     | 20.74°      | +0.74°                    |
| Medial 45° oblique | 132.14°      | -2.86°                     | 20.45°      | +0.45°                    |
| Subject 1   |                  |                            |             |                           |
| True value  | 136.00°          | -                          | 6.00°       | -                         |
| Lateral 45° oblique | 138.68°      | +2.68°                     | 8.55°       | +2.55°                    |
| Medial 45° oblique | 138.75°      | +2.75°                     | 7.58°       | +1.58°                    |
| Subject 2   |                  |                            |             |                           |
| True value  | 131.00°          | -                          | 25.00°      | -                         |
| Lateral 45° oblique | 135.66°      | +2.66°                     | 22.86°      | -2.14°                    |
| Medial 45° oblique | 136.93°      | +5.93°                     | 15.58°      | -9.42°                    |
| Subject 3   |                  |                            |             |                           |
| True value  | 128.00°          | -                          | 8.00°       | -                         |
| Lateral 45° oblique | 128.82°      | +0.82°                     | 6.54°       | -1.46°                    |
| Medial 45° oblique | 128.98°      | +0.98°                     | -2.09°      | -10.09°                   |
Figure 5  The true neck shaft angle (upper value) and anteverision (lower value) are derived using the neck shaft angle measured in the anteroposterior and lateral 45° oblique radiographs. When medial 45° oblique radiographs are used, the positive/negative signs of derived true anteverision are reversed and the true neck shaft angle remains the same.
anteposterior radiograph after conversion from 45° oblique radiographs:

\[
\tan(180°-\alpha) = \frac{B}{A} \\
-tan\alpha = \frac{B}{A} \\
-tan\alpha = -\frac{\tan\beta}{\sqrt{2}} \\
tan\alpha = \frac{\tan\beta}{\sqrt{2}}
\]

Therefore, the formulae to calculate anteversion in medial and lateral 45° oblique radiographs, respectively, are

\[
\tan\theta = 1-\left(\frac{2}{\sqrt{2}\tan\alpha_i} \times \frac{\tan\beta}{\sqrt{2}}\right) \\
\tan\theta = 1-\frac{\tan\beta}{\tan\alpha_i}
\]

and

\[
\tan\theta = \frac{\tan\beta}{\tan\alpha_i} - 1
\]

The lateral 45° oblique radiographs are recommended, as the elongated femoral neck enables easier measurement of the neck shaft angle (Fig. 4).

The formula to calculate the true neck shaft angle is:

\[
tan\alpha_T = \frac{\tan\alpha_i}{\cos\theta}
\]

RESULTS

With the true values based on computed tomography as references, the neck shaft angle and anteversion of the 3 subjects deviated +0.82° to +4.66° and -2.14° to +2.55° in lateral 45° oblique radiographs, respectively, whereas the corresponding values in medial 45° oblique radiographs were +0.98° to +5.93° and -10.09° to +1.58° (Table). The lateral 45° oblique method resulted in a smaller range of deviation and were more accurate. A crossing table is shown for easy calculation of the neck shaft angle and anteversion, using the 45° oblique radiographic method (Fig. 5).

DISCUSSION

In the 45° oblique radiographs, the femur is distorted, but the centre of the femoral neck and the centre of the femoral shaft can be easily identified, as the distortion did not change the ratio of the centre position. This 45° oblique method is useful in surgical planning, especially for femoral derotational osteotomy in children. It can be used to detect occult femoral neck fracture and equivocal hip dislocation where positioning of patients is difficult owing to pain. Computed tomography should be reserved for selected patients owing to the high radiation dose. This new method enables easy calculation of the true neck shaft angle and anteversion, with low radiation exposure. This pilot study was limited by the small sample size. Further large-scale studies are necessary to evaluate its accuracy as well as intra- and inter-observer reliability.

ACKNOWLEDGEMENT

The authors thank Mr Kok Wah Lim for his verification of formula.

DISCLOSURE

No conflicts of interest were declared by the authors.

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