A method for measuring the anteversion angle of the stem from a plain axial radiograph after total hip arthroplasty

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Abstract

The anteversion angle of the stem is one of the important parameters in total hip arthroplasty (THA), and computed tomography (CT) is frequently employed for its measurement. We developed a simple calculation formula to determine the angle of anteversion of the stem from a plain axial radiograph alone (the axial view method), and investigated its usefulness by comparing the results with those obtained by CT (CT method).

The mean angle of anteversion of the stem was determined to be 23.9° by the axial view method and 24.2° by the CT method. Thus, there was no statistically significant difference in the mean angle measured between the two measurement methods. The difference in the measured anteversion angle between the axial view method and the CT method, ranged from −18° to +9°, with a mean difference of 6.4°. There was a good correlation of the angles measured by the two methods, with a correlation coefficient of 0.788.

Thus, it was concluded that the axial view method of calculation of the angle of anteversion of the stem, in which the angle is determined from a plain axial radiograph obtained after THA, is a simple and clinically useful method.

Introduction

Total hip arthroplasty (THA) is one of the most revolutionary techniques in the history of orthopedic surgery. The surgery allows dramatic improvement in the quality of life (QOL) and activities of daily living (ADL) of the patients, by ameliorating pain and increasing the range of movement (ROM) of the hip joint. THA has been widely adopted in various countries worldwide, saving the lives of a progressively increasing number of patients. On the other hand, postoperative complications, have been increasingly recognized, including dislocation, infection, abrasion and loosening. Dislocation leads to reduced function of the artificial joint, and ultimately decreases the patient’s QOL, as it increasingly causes deterioration of the artificial joint, resulting in frequent dislocation. When the angle of anteversion of the stem is increased excessively, impingement of the cup stem is likely to occur, and the possibility of damage to the polyethylene liner and dislocation is increased. The angle of anteversion of the stem is one of the most important predictive parameters of the postoperative condition of the implant. Numerous reports have been published on the use of computed tomography (CT) for its measurement. In actual clinical settings, however, routine CT may not always be feasible. Therefore, we attempted to determine the angle of anteversion of the stem by a simple method.
from a single plain axial radiograph (the axial view method).

When the angle of anteversion (or retroversion) of the femoral neck is to be measured by plain roentgenography, two roentgenographic films are generally required, because there are two unknowns, the collodiaphyseal angle of the neck and the angle of anteversion. However, when the anteversion angle of stem is to be measured after THA, only one roentgenogram, obtained by a pre-selected technique, is sufficient, because the collodiaphyseal angle of the component used is known. In general, two radiographs of the hip joint are obtained after THA in each patient, i.e., a frontal view and a lateral view. An axial view may also be obtained for observing the cup and its periphery. Although important information can be obtained from the plain radiograph, an axial view rather than a frontal view is thought to reflect information more accurately, because the angle of anteversion of the stem is approximately 20° in many cases, being 45° or lower in the majority.

Therefore, we developed a formula, using which we calculated the actual angle of anteversion of the stem from the virtual angle of anteversion as measured from the plain axial radiograph obtained after THA. The angle was also measured by CT (CT method), and a comparative analysis of the results was conducted.

Subjects and Methods

1. Comparison between the axial view method and the CT method

This prospective study was conducted on 18 hip joints for which total hip arthroplasty (THA) had been conducted during the period from 1999 to 2001, consisting of 3 hip joints of male patients and 15 hip joints of female patients, and all the patients had osteoarthritis of the hip. The patients ranged in age from 62 to 77 years, with a mean of 69 years. The Bi-Metric® stem (Biomet Inc. (Warsaw, IN, USA)) was used in 12 cases, and the MetaSUL® stem (Sulzer Orthopedics Ltd. (Oerlikon, Zurich, Switzerland)) in 6. The collodiaphyseal angle of the stem was 135° in the case of the Bi-Metric® stem, and 130° in the case of the MetaSUL® stem. Since the MetaSUL® stem already shows a 9° anteversion, correction for this degree of anteversion was applied when the angle was measured by the CT method. The angle of anteversion of the stem was measured by the axial view method, as well as the CT method as control for comparison, in all patients. In the axial view method, the anteversion angle of the stem was calculated from a plain axial radiograph obtained after THA, using the formula described below. In the CT method, the direction of CT scanning was consistent with the femoral axis for obtaining image slices of the region extending from the hip joint to the femoral condyle. Then, the angle subtended by a line connecting the posterior margins of the internal and external condyles of the femur as the baseline with the stem base was defined as the angle of anteversion of the stem, or \( \theta_c \) (Fig. 1). The measurement by imaging was conducted within one month of surgery in all patients. We did X-ray after having got an agreement of exposure from all patients. Correlation between the anteversion angles measured by two methods was tested using Person's correlation coefficient.

2. Preparation of a calculation formula

The use of the axial view method was confined to cases in which the stem axis was inserted consistently with the femoral axis. The angle at the time when the stem was anteriorly rotated around the stem axis was defined as the angle of anteversion of the stem. For the plain axial radiograph, the patient was instructed to lie down in the supine position to keep his femoral bones parallel to the imaging table and hang his legs down vertically from the table to allow the affected limb to

Fig. 1. The angle of anteversion of the stem, \( \theta_c \), measured by the CT method

(2)
adopt the parallel-neutral position. The film was set such that it was in a plane parallel to the neck of the stem at 0°-anteversion, that is, corresponding to the collodiaphyseal angle (Fig. 2).

The actual angle of anteversion of the stem was defined as $\theta_a$, the virtual angle of anteversion on a plain axial radiograph as $\theta$, the collodiaphyseal angle of the stem as $\theta_n$, and the length of the stem neck as $L$ (Figs. 3a, b). The collodiaphyseal angle of the stem, $\theta_n$, varied with the device used.

The relationship between the image on an axial radiograph and the position of the stem during imaging is shown (Fig. 4). The base of the stem neck was regarded as the origin of the coordinate axes; the $X$ axis was set in the body axial direction, the $Y$ axis, crossing the $X$ axis at right angles, was set in the frontal plane, and the $Z$ axis was set in the direction vertical to the frontal plane. When the stem neck was present in the $X$-$Y$ plane, the angle of anteversion of the stem was defined as $0^\circ$. When the stem was rotated anteriorly around the $X$ axis by the angle of anteversion, $\theta_a$, it
was projected on the film as the virtual angle of anteversion, $\theta_l$.

The relationship between the virtual length of the stem neck, denoted by $r$ and projected on the $Y-Z$ plane when the angle of anteversion was $\theta a$, and the $Z$-axis component, denoted by $h$, was expressed as follows:

$$h = r \times \sin \theta a$$  (Fig. 5).

The following relation can be expressed for the virtual stem neck as projected on an axial radiograph;

$$\tan \theta f = h / N$$  (Fig. 6),

where $N$ represents the component on the $X-Y$ plane, and $h$ represents the $Z$-axis component.

Based on the relationship between the stem projected on the $X-Y$ plane, i.e., the frontal plane, and the film surface plane (Fig. 7), the stem neck $N$ on the film surface was divided into two parts, $N1$ and $N2$, for drawing diagrams, and the relationship formulae were expressed as follows:

$$N1 = L \times \cos^2 (\pi - \theta n)$$
$$N2 = r \times \cos \theta a \times \sin (\pi - \theta n)$$
$$N = N1 + N2$$

Taking into consideration the above relationships, the relationship between the virtual angle of anteversion, $\theta l$, and the actual angle of anteversion of the stem was expressed as follows:

$$\tan \theta l = \sin \theta a \times \sin \theta n / (\cos^2 \theta n + \sin^2 \theta n \times \cos \theta a).$$

Figure 8 shows the relationship between $\theta l$ and $\theta a$. It was represented by a curve that varied with the collodiaphyseal angle of the stem. The presence of even one diagram allows easy determination of the true angle of anteversion from the virtual angle of anteversion seen on a plain axial radiograph.

**Results**

Figure 9 shows the relationship between the angle of anteversion of the stem measured by the axial view method and that measured by the CT method. The difference between the two tended to decrease with increasing angle of anteversion of the stem. However, there was a reasonably close correlation between the angles measured by the two methods, with a correlation coefficient ($r$) of 0.788. The mean angle of anteversion measured by the axial view method was $23.9 \pm 12.9^\circ$, and that measured by the CT method was $24.2 \pm 12.8^\circ$: the difference between the two was not statistically significant. The error between the angle of anteversion measured by the axial view method and that measured by the CT method, that is, $\theta a - \theta l$, ranged from $-18^\circ$ to $+14^\circ$, with a mean absolute error of $6.4 \pm 3.2^\circ$. 

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Figure 4. Relationship between the axial view on the film during imaging and the stem (3D stereoscopic film)

Figure 5. $Y-Z$ plane

Figure 6. Stem on axial view

Figure 7. $X-Y$ plane
When considered by the type of device used, the error \((\theta_a - \theta_v)\) ranged from \(-18^\circ\) to \(+7^\circ\) ((mean, \(-5.12^\circ\)), with a mean absolute error of 7.12\(^\circ\) when the MetaSUL\textsuperscript{®} stem was used, and from \(-10^\circ\) to \(+14^\circ\) (+2.20\(^\circ\)), with a mean absolute error of 7.00\(^\circ\) when the Bi-Metric\textsuperscript{®} stem was used. When the MetaSUL\textsuperscript{®} stem was used, the angle of anteversion of the stem measured by the axial view method was significantly lower than that measured by the CT method. There were no significant differences in the angles measured by either method between the two sexes.

**Discussion**

Many factors, including the size of the implant, position of the implant setup, and soft tissue imbalance, have been reported to influence the incidence of dislocation after THA\textsuperscript{67}. For evaluation after THA it is important to accurately determine the setup position of each implant. During the surgery, the stem is inserted with reference to the angle (exterior open angle, anterior open angle) of the cup set up on the shelf side and the preoperative angle of anteversion of the femoral neck. When the angle of anteversion of the stem becomes excessive, impingement of the cup stem is likely to occur, and the possibility of damage to the polyethylene liner and dislocation is also increased. The position of the implant setup after THA is thus an important factor, and CT is frequently used to evaluate this parameter. Measurement methods by 3D-CT and ultrasonography have also been reported\textsuperscript{8,9}. In the clinical setting, however, various restrictions preclude the routine use of CT. We obtain lateral view radiographs by the axial view method after THA, for the purpose of checking the side of the cup\textsuperscript{10}, but the use of the formula described in

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**Fig. 8.** Relationship between \(\theta_v\), the virtual angle of anteversion of the stem on an axial radiograph, and \(\theta_a\), the actual angle of anteversion of the stem

**Fig. 9.** Relationship between the angle of anteversion of the stem measured by the axial view method and that measured by the CT method
the present study also facilitates calculation of the angle of anteversion from an axial radiograph alone, which is very useful in the clinical setting. Comparison of the angle of anteversion of the stem measured between the axial view method and the CT method revealed a reasonable correlation between the two. There was, nevertheless, a difference in the angle of anteversion measured between the axial view method and the CT method; the maximum difference was 18° and the mean difference was 6.4±3.2°. This difference should not be ignored. Some reasons for the difference have been considered: error of rotation on the body axis (X axis) induced by actual inconsistency, in the axial radiograph, of the line connecting the posterior margins of the internal and external condyles of the femoral bone (baseline on CT), with the parallel position of the legs when they are hung down the side of the imaging table9; the femoral bone not parallel to the imaging table10; error of rotation on the sagittal plane induced by the inconsistency of the axis of the inserted stem with the femoral axis; error of distortion on imaging by dispersion of the irradiated x-ray beam and the distance between the film and the light source11; error of setting up induced by different positions of the film.

With regard to error of the angle at which the film is set up, it was confirmed in a preliminary experiment that the error is approximately 1° when the film is set up at a varus and valgus of approximately 5–6°; this is considered to be within the acceptable range. The angle of anteversion measured by the axial view method was lower than that measured by the CT method; this could have been induced by error of rotation on the body axis (X axis) measured during derotation, since the femoral bone is a position of internal rotation when the x-ray is taken with the legs hanging down from the edge of the imaging table, because of the anatomical varus of the leg. With regard to the difference in the error (βa–βc) between the two measurement methods depending on the device used, the angle of anteversion of the stem tended to be significantly lower with the MetaSUL® stem than with the straight-type stem, namely, the Bi-Metric® stem. When the angle of anteversion in the case of MetaSUL® was measured in an axial view, the virtual angle tends to be underestimated, because the stem already shows anteversion of the neck, even before it is set up.

For improvement of the accuracy of the measurements, it is necessary to conduct imaging studies in experimental models under various conditions, in order to investigate the factors that might influence the magnitude of error between the angle determined by the axial view method and that measured by the CT method, to determine the extent of such influence, and to allow further innovations and improvements.

**Conclusion**

We obtained a calculation formula for determining the actual angle of anteversion of the stem from the virtual angle of anteversion of the stem determined from a plain axial radiograph obtained after THA. The use of the formula allows simple and accurate measurement of the angle of anteversion of the stem from a plain axial radiograph alone, which is highly useful in the clinical setting.

**References**

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THA 術後単純 X 線軸写像を用いたステムネック前捻角計測法の検討

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【要旨】 全人工股関節置換術 (以下 THA) は、その普及に伴い顕著、摩耗、緩みなどの術後合併する問題点が明らかになってきた。ステム前捻角は THA 術後インプラント設置状態を知る上で重要なパラメータの一つであり、その計測には CT が使用される場合が多い。我々はステム前捻角を単純 X 線軸写像のみから計算式を用いて簡便に求め (以下軸写法)、CT 計測結果と比較検討した。

本法でのステム前捻角は、大腿骨内外頚の後継を基準線としステムがステム軸を中心に前方へ回転したときの角度とした。単純 X 線軸写像は、深部平行中間位とし、フィルムはステム前捻角 0 度の時にフィルムとステムネックが平行となる様に設置しフィルム面に垂直に X 線を入射した。ステム前捻角を \( \theta_a \)、軸写像上の見かけの前捻角を \( \theta_l \)、ステム頸体角を \( \theta_n \)、ステムネック基部を座標原点と設定し、ステムが前捻角 \( \theta_a \) だけステム軸周りを前方向へ回転したとき、フィルム上に見かけの前捻角 \( \theta_l \) が投影される。各座標面上での作図より関係式を求めると、見かけの前捻角 \( \theta_l \) とステム前捻角 \( \theta_a \) との関係は、

\[
\tan \theta_l = \sin \theta_a \times \tan \theta_n / (\cos^2 \theta_n + \sin^2 \theta_n \times \cos \theta_a)
\]

となる。

THA 後の男性 3 股、女性 15 股、計 18 股を対象として、CT からもステム前捻角 \( \theta_c \) を計測し (以下 CT 法)、比較検討した。

ステム前捻角の平均値は、軸写法で 23.9±12.9 度、CT 法では 24.2±12.8 度であり、統計学的に有意差は認めなかった。軸写法と CT 法でのステム前捻角の差 \( \theta_a-\theta_c \) は、-18 から+9 度、差の絶対値平均は 6.4 度であった。軸写法では CT 法に比べて、ステム前捻角が大きくなるに従いやや値がなる傾向があるものの、相関係数 0.788 と良好な相関を認めた。

本法は、THA 術後の単純 X 線軸写像のみからステム前捻角を算出できる簡便な方法であり、臨床用有用である。

<Key words> Anteversion angle, 全人工股関節置換術, 単純 X 線軸写像