Measurement of the Acetabular Cup Anteversion on the Simulated Radiographs

Running title: Anteversion angle of the acetabular cup

Abstract

Widmer reported a protractor for measuring the anteversion of acetabular cups on radiographs but with limited percision. We intended to improve its precision by trigonometric mathematics. We measured the anteversion of the acetabular cups on 336 simulated radiographs using aforementioned two methods. The anteversion measured by Widmer's protractor ranged from 7° to 41° (mean ± SD =28.0° ± 9.8°), and our methods, 5° to 51° (27.7° ±13.2°). The mean ± SD of error by Widmer's protractor was 5.2 ± 2.5°, and our protractor, 0.8° ± 0.8° (Student's t-test, $p<0.0001$). The inter-observer study showed the difference between measurements less than 2°, for each method. Therefore the smaller error of our method than that of Widmer's implicated a potentially precise measurement of the anteversion.

Level of Evidence: Diagnostic study, level II.

Introduction

The anteversion of acetabulum is important for function after total hip arthroplasty. It is linked to stem anteversion and functional range of motion in the hip with intra and extra articular impingement and their respective effects on wear, impingement, and instability. Previously reported methods can be classified into three groups, the computer tomography methods[1,2], the trigonometric methods[3,4,5,6,7,8], and the protractor methods[9,10,11]. Olivecrona et al.[2] measured the orientation of the acetabular cups on the CT images in 10 patients. Their results showed that the anteversion angles ranged from 0° to 52° with an error of 2.9°, whereas the inclination angle ranging from 30° to 65° with an error of 1.5°.

With trigonometric method, the anteversion angles of the acetabular cups were measured using calculation equations (Appendix A). Liaw et al.[10] applied this trigonometric method to measure the anteversion of the acetabular cups and got the mean ± SD of error with 1.2° ± 0.57°. Additionally, Liaw et al.[10] used his own protractor method to get the mean ± SD of the error of 0.96° ±0.74°. These protractor methods are more convenient than the others since they do not require a calculator or computer.

Furthermore, Liaw et al.[10] incorporated the inverse trigonometric function into his own protractor. In practical, the most common disadvantages are to find the ends of long axis and short axis. Fabeck[9] applied direct measurement using a protractor that was designed without any incorporation of trigonometric function. However, the examiner usually has difficulty in following the long arc of the circles during the measurement. Widmer[11] invented his own protractor through his linear regression equation. The user can apply for direst measurement without the need of finding the ends of the long axis first. Widmer[11] mentioned that the only disadvantage is its imprecision that was due to oblique radiographic projection on various acetabulum abduction angles and the adoption of a linear regression equation. He did not recommend the usage of his own protractor if highly precise measurements are needed.

The study aims to investigate the relationship curve mathematically and to eliminate the error caused by oblique projection. The measured angles and the precision error will be compared with those of the Widmer's[11] results.

Materials and Methods

At the given distance of 105 cm from x-ray tubes to subjects, Widmer[11] found a relationship between anteversion and the short axis (S) and the total length (TL) of the projected cross-section of the cup along the short axis by linear regression.

Anteversion= 48.5*(S/TL)-0.3

In our methods, we investigated the mathematical relationship between radiographic version β and S/TL-ratio is shown in Equation (1). The detailed deduction process was shown in Appendix A.

$$\beta = \sin^{-1}(S / l) = \sin^{-1}((S/TL\text{-ratio})/(2-(S/TL\text{-ratio}))) \qquad (1)$$

To eliminate the error caused by oblique projection, we applied the Equation (2). The detailed deduction process was shown in Appendix B.

$$\beta = \tan^{-1}(\tan(\tan^{-1}(\tan(\sin^{-1}((S/TL\text{-ratio})/(2-(S/TL\text{-ratio}))))\csc\gamma) + 5.46^{\circ})\sin\gamma) \qquad (2)$$

Through Equations 2 we reproduced Widmer's[11] results that were shown in Fig. 1 and Table 1. The results were quite the same as the data shown by Widmer[11].

We further used the mathematic model to calculate the error of Widmer's[11] linear regression equation (Fig. 2), and improved the precision by the following two methods.

First, we applied the protractor on the hip-centered radiographs that eliminated the error caused by oblique projection. If we used the radiograph centered on the symphysis pubis for measurement, we corrected by Equation 2.

Second, we improved the precision by a mathematic model. Widmer's[11] method used linear regression method to approximate the curve. The precision was good in linear region of the whole curve, but bad in the non-linear region. The mathematic model fully approximated the curve, thus improved the precision.

Base on these two points, we developed our protractor through Equation 1 (Fig. 3A).

In order to determine the accuracy, we made a Widmer's[11] protractor through his linear regression equation (y = 48.05x - 0.3) and our protractor (Fig. 3B). We simulated 336 total hip arthroplasty radiographs with 48 different anteversions ranging from 5°–52° and seven different inclinations (30°, 35°, 40°, 45°, 50°, 55°, 60°) using our simulation program. We removed the femoral heads and necks in our simulated radiographs to eliminate the occluding effects. We used these two protractors to measure anteversions on these simulated radiographs. We found first the perpendicular bisector of the long axis of the acetacular cup. Then we found three intersection points between the perpendicular bisector and the ellipse by the rim of the acetabular cup or the hemispehere curve by outer shell. Then we applied the protractors to read the anteversion angle (Fig. 3C & 3D). Widmer's[11] protractor had a built-in correction of the projection obliquity. For comparison, we corrected the anteversion centered at hip to anteversion centered at symphis pubis by following procedure. First we converted the real anteversion to anatomic anteversion, subtracting 5.46°, and then converting back to radiographic anteversion. The anteversion angles on the simulated radiographs were measured by one author in a random order using either method. The precision error was calculated from the difference between the measured angles and the assumed angles of these simulated radiographs. These results were compared by Student’s t-test.

To justify our improvement, we did an inter-observer difference study by randomly selecting 10 hip arthroplasty radiograms and measured the radiographic anteversion with our method and Widmer’s[11] method each twice by two of the authors. Then we calculated absolute difference of two measurements. Our improvement made little sense if the difference was larger than the error of Widmer’s[11] error.

Results

The angles measured with Widmer’s[11] method ranged from 7° to 41° (mean ± SD =28.0° ± 9.8°), and for our methods, 5° to 51° (27.7 ±13.2°). After oblique projection correction, the real radiographic anteversion (centered at symphysis pubis) used for Widmer’s[11] method ranged from 0.3° to 49.0°. The error of Widmer’s[11] protractor ranged from 0° to 8.7°, and the mean ± SD is 5.2 ± 2.5°(Fig. 4A); the range with our protractor, 0° to 3°, and mean ± SD, 0.8° ± 0.8°(Fig. 4B)(Student’s t-test, $p<0.0001$).

For the inter-observer study, the radiographic anteversion measured by Widmer’s[11] method twice ranged from 3° to 21° (mean ± SD =12.3° ± 5.9°), and by ours twice, 2° to 16° (8.7° ± 4.7°). The absolute difference between two measurements of Widmer’s[11] method ranged from 0° to 2° (mean ± SD =0.5° ± 0.7°), and of ours, 0° to 1° (0.5° ± 0.7°).

Discussion

Measuring anteversion is a cumbersome work for a medical doctor. In our experience, Widmer[11] designed a rather convenient method as compared with others whereas his method incorporated a potential imprecision. Therefore, to improve the imprecision of his method may refine the measurement.

With application of perpendicular bisector for the measurement and mathematical equations, our modified protractor has significantly reduced the error by using our own protractor for the measurement of the anteversion of the acetabular cups. The improvement was statistically significant. The error of Widmer's[11] method was mainly related to inclination angle and anteversion angle. The correlation between error and inclination was caused by that Widmer ignored the influence of inclination when correcting oblique projection. The correlation between error and anteversion was because that Widmer used linear regression to approximate the curve. This finding in this study correlated well with his previous report. Our method improved the precision in both types of error. However, our method has larger error when anteversion increased. The reason was we underestimated the short axis (S). When anteversion increased, the outer edge became blurred. If we measured with the inner edge, thus we underestimated the short axis (S). Fortunately this error was small in our study, only 3° when anteversion larger than 45°. The intra-observer difference of Widmer's[11] method was between 0° to 2°, and of ours 0° to 2°, which was smaller than the error of Widmer's[11] method. Our improvement did make difference in this situation.

The range of the simulated radiographs' anteversion is between 5° to 51° for our method and 0.3° to 49.0° for Widmer's[11] method. In study of Olivecrona et al[2], the range of anteversion is between 0° to 52° and inclination is between 30° to 65°.[2] Therefore we chose the aforementioned range of anteversion for measurement in this study.

Our method is a plain-radiograpic method, thus share the disadvantages. Position problems, including patient and X-ray source positions, are the major disadvantage. Currently there is no published solution for this problem. We suggest measuring the qualified radiographs and excluding unqualified radiographs. Qualified radiographs mean acceptable position, which indicated a perfect controlled rotation (0^o rotation) and tilt. In radiographs, zero-degree rotation means alignment of vertical line from the symphysis pubis to the interteardrop line and the vertical line from the middle of the coccyx to the interteardrop line. A controlled tilt means the same vertical distance between the upper border of the symphysis and the center of the sacrococcygeal joint on an antero-posterior radiograph of the same patient.[12]

Since we had to face the possible error caused by the projection, the limitation of this study was that we need a basic assumption of the perfect hemi-ball shape for the acetabulum. If not, our method was not suitable. In that situation, Liaw's[10] and Fabeck's[9] protractors were preferred. Otherwise, our improvement had significantly reduced the error, thus can be used in precise measurement of the anteversion.

Our improvement did improve the error from 0° - 8.7° to 0° to 3°. The clinical significance is that we make this measurement more comparable with other established methods. Furthermore, we suggest that all reports about anteversion should clearly mention which anteversion is measured (radiographic, anatomic, operative)[13], and which method is used for the measurements. Thus the readers can understand the range of error and limitations of the measurements.

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