

## Measurement of the Acetabular Cup Anteversion on Simulated Radiographs

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**Abstract:** Widmer (J Arthroplasty 2004;19:387) reported a protractor for measuring the anteversion of acetabular cups on radiographs but with limited precision. We intended to improve its precision by trigonometric mathematics. We measured the anteversion of the acetabular cups on 336 simulated radiographs using aforementioned 2 methods. The anteversion measured by Widmer's protractor ranged from 7° to 41° (mean  $\pm$  SD = 28.0°  $\pm$  9.8°), and our methods, 5° to 51° (27.7°  $\pm$  13.2°). The mean  $\pm$  SD of error by Widmer's protractor was 5.2  $\pm$  2.5°, and our protractor, 0.8°  $\pm$  0.8° (Student *t* test, *P* < .0001). The interobserver study showed the difference between measurements less than 2° for each method. Therefore, the smaller error of our method than that of Widmer implicated a potentially precise measurement of the anteversion (level of evidence: diagnostic study, level II). **Key words:** hip arthroplasty, acetabulum, anteversion, protractor.

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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 extraarticular impingement and their respective effects on wear, impingement, and instability. Previously reported methods can be classified into 3 groups, the computed tomographic methods [1,2], the trigonometric methods [3-8,13], and the protractor methods [9-11]. Olivecrona et al

[2] measured the orientation of the acetabular cups on the computed tomographic 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 ranged 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  $\pm$  SD of error with 1.2°  $\pm$  0.57°. In addition, Liaw et al used his own protractor method to get the mean  $\pm$  SD of the error of 0.96°  $\pm$  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. Practically, the most common disadvantages are to find the ends of long axis and short axis (*S*). 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

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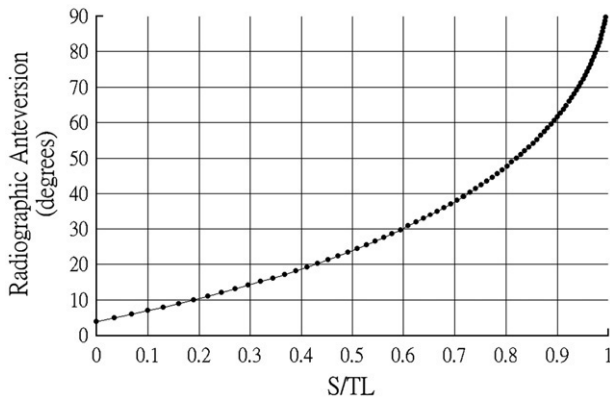
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**Fig. 1.** The relationship between  $S/TL$  ratio and radiographic anteversion. This figure is derived from Eqs. (1) and (2), and the inclination angle is  $45^\circ$ .

protractor through his linear regression equation. The user can apply for direct 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 results of Widmer [11].

## 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 and the total length (TL) of the projected cross-section of the cup along the short axis by linear regression [anteversion =  $48.5 \times (S/TL) - 0.3$ ].

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

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

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

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

Through Eq. 2, we reproduced the results of Widmer [11], which are shown in Fig. 1 and Table 1. The results were quite the same as the data shown by Widmer.

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

Second, we improved the precision by a mathematic model. The method of Widmer [11] 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

**Table 1.** The Relationship Between  $S/TL$  and Anteversion in Different Inclinations

Radiographic cup anteversion				
Cup inclination				
$S/TL$	$40^\circ$	$45^\circ$	$50^\circ$	$55^\circ$
0	3.51587	3.866659	4.187843	4.477031
0.04	4.693584	5.04297	5.362842	5.650818
0.07	5.612107	5.959745	6.278064	6.56466
0.11	6.887252	7.231518	7.546915	7.830973
0.14	7.884051	8.224921	8.53742	8.818993
0.17	8.917967	9.254613	9.563543	9.842082
0.2	9.991429	10.32294	10.62757	10.90247
0.23	11.1071	11.43248	11.73199	12.0026
0.26	12.26792	12.58607	12.87957	13.14515
0.29	13.47711	13.78681	14.07333	14.33309
0.31	14.31186	14.61519	14.89646	15.15187
0.34	15.6098	15.90238	16.17482	16.4229
0.36	16.50749	16.79204	17.05789	17.30053
0.39	17.90606	18.17715	18.43199	18.66555
0.41	18.87536	19.13645	19.38314	19.60998
0.43	19.87613	20.12635	20.36418	20.58374
0.46	21.44033	21.67245	21.89557	22.10306
0.48	22.5281	22.74687	22.95917	23.15779
0.5	23.65447	23.85878	24.05936	24.2484
0.52	24.8219	25.01055	25.19848	25.37717
0.54	26.0331	26.20483	26.37909	26.54662
0.56	27.29106	27.44451	27.60403	27.75954
0.58	28.5991	28.73282	28.87644	29.01901
0.6	29.9609	30.07333	30.19982	30.32845
0.62	31.38057	31.47005	31.57809	31.69174
0.63	32.11352	32.19087	32.28916	32.3949
0.65	33.6288	33.6805	33.75821	33.84723
0.67	35.21463	35.23872	35.29429	35.36536
0.68	36.03593	36.04545	36.08934	36.15094
0.7	37.73971	37.71844	37.73767	37.77929
0.71	38.62412	38.58662	38.59284	38.62393
0.73	40.4635	40.39172	40.37051	40.37939
0.74	41.42091	41.33107	41.2954	41.29258

By Eqs. (1) and (2), the relationship between  $S/TL$  ratio and anteversion is shown. These results are similar to the report of Widmer [11].

mathematic model fully approximated the curve, thus improving the precision.

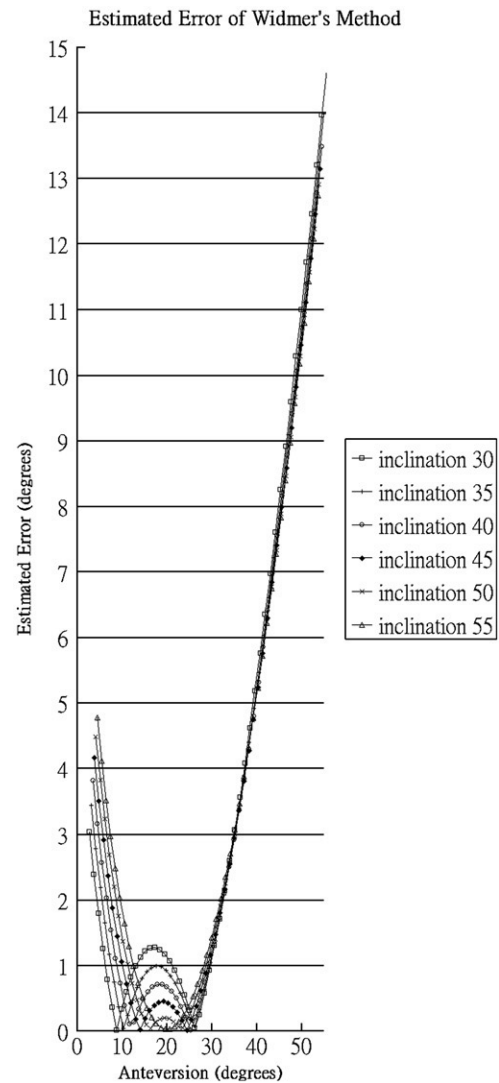
Based on these 2 points, we developed our protractor through Eq. (1) (Fig. 3A).

To determine the accuracy, we made a Widmer [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 7 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 2 protractors to measure anteversions on these simulated radiographs. We found first the perpendicular bisector of the long axis of the acetabular cup. Then we found 3 intersection points between the perpendicular bisector and the ellipse by the rim of the acetabular cup or the hemisphere curve by outer shell. Then, we applied the protractors to read the anteversion angle (Fig. 3C and D). The Widmer [11] protractor had a built-in correction of the projection obliquity. For comparison, we corrected the anteversion centered at hip to anteversion centered at symphysis pubis by the 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 1 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 *t* test.

To justify our improvement, we did an interobserver difference study by randomly selecting 10 hip arthroplasty radiograms and measured the radiographic anteversion with our method and that of Widmer [11], each twice by one 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.

## Results

The angles measured with the Widmer [11] method ranged from 7° to 41° (mean  $\pm$  SD =  $28.0^\circ \pm 9.8^\circ$ ), and for our methods, 5° to 51° ( $27.7^\circ \pm 13.2^\circ$ ). After oblique projection correction, the real radiographic anteversion (centered at symphysis



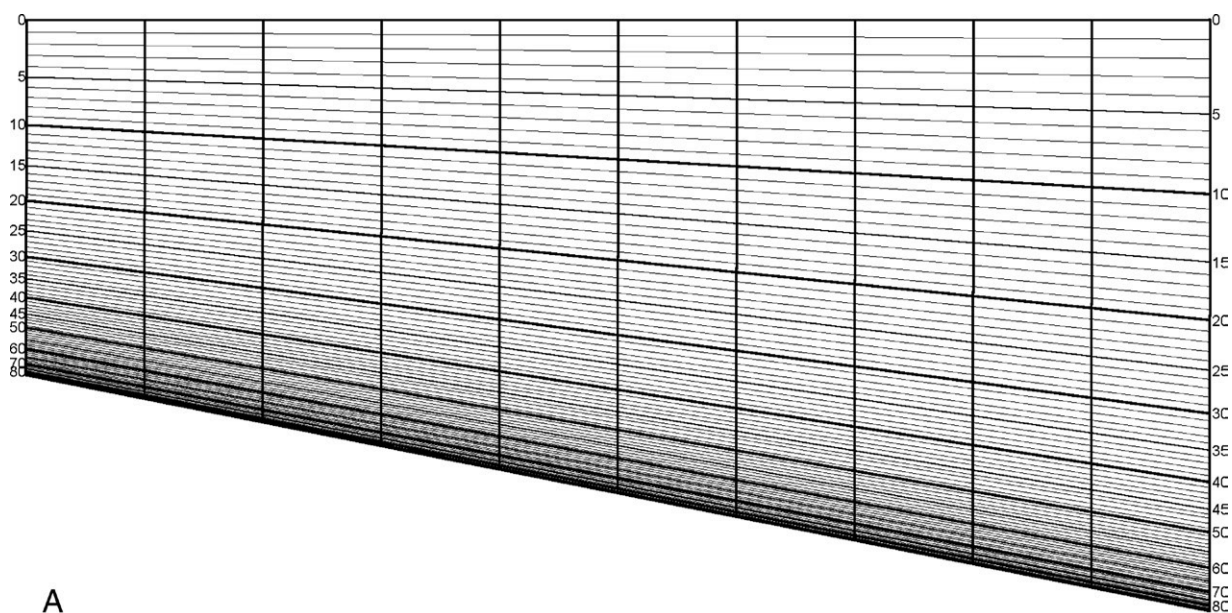
**Fig. 2.** Estimated error of the Widmer [11] linear regression equation. With our mathematic model, we calculate the ideal anteversion from S/TL ratio. The error is the difference between the ideal anteversion and the Widmer linear regression anteversion.

pubis) used for the Widmer [11] method ranged from 0.3° to 49.0°. The error of the Widmer [11] protractor ranged from 0° to 8.7°, and the mean  $\pm$  SD is  $5.2^\circ \pm 2.5^\circ$  (Fig. 4A); the range with our protractor, 0° to 3°, and mean  $\pm$  SD,  $0.8^\circ \pm 0.8^\circ$  (Fig. 4B) (Student *t* test,  $P < .0001$ ).

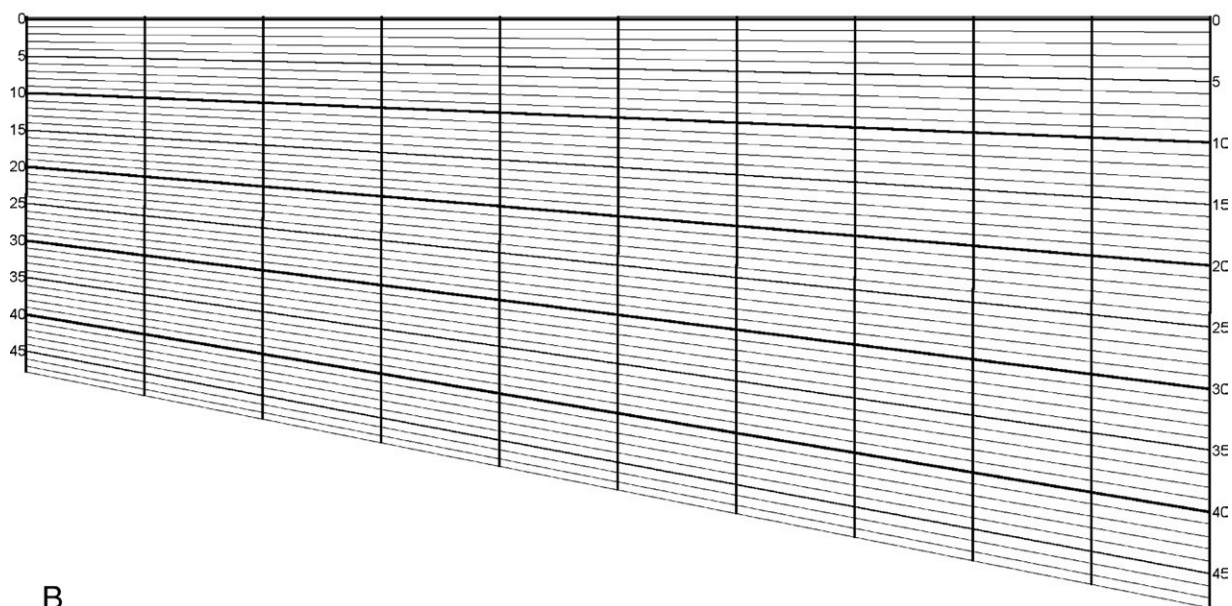
For the interobserver study, the radiographic anteversion measured by the method of Widmer [11] twice ranged from 3° to 21° (mean  $\pm$  SD =  $12.3^\circ \pm 5.9^\circ$ ), and by ours, twice, from 2° to 16° ( $8.7^\circ \pm 4.7^\circ$ ).

**Fig. 3.** (A) Our protractor developed through Eq. (1). (B) The Widmer [11] protractor made according to his linear regression equation ( $y = 48.05x - 0.3$ ). (C) The simulated radiographs are printed on papers; then, we use our protractor to measure the radiographic anteversion. (D) The simulated radiographs are printed on papers; then we use the Widmer [11] protractor to measure the radiographic anteversion.

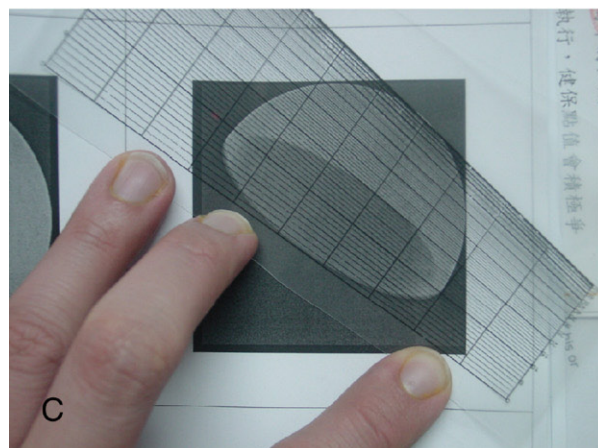




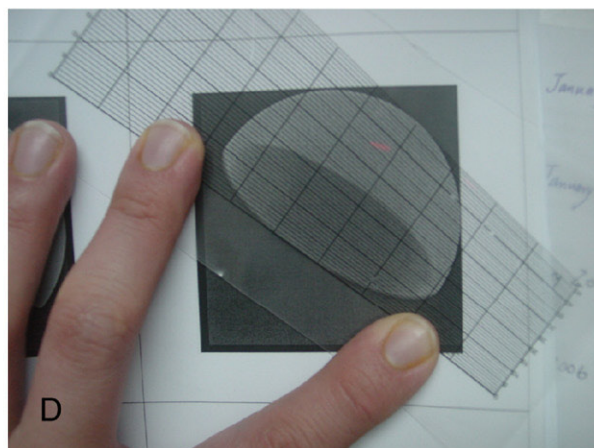
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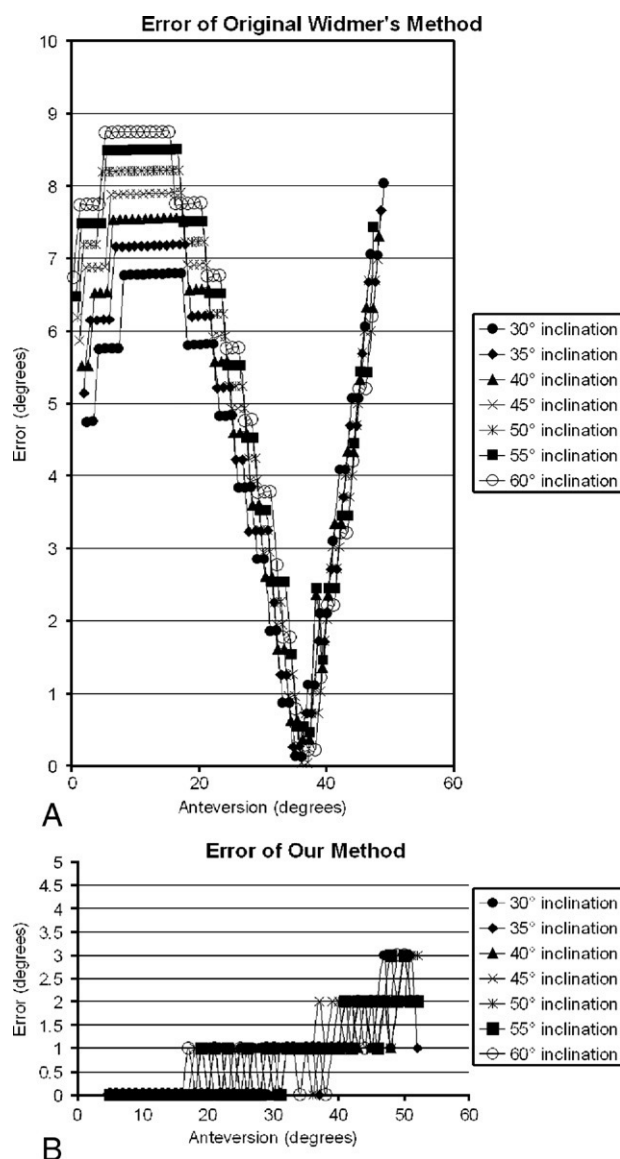
B



C



D



**Fig. 4.** (A) The error of the Widmer [11] method. Clearly, the error is related to inclination angle and anteversion angle. (B) The error of our method. The error is slightly related to anteversion angle.

The absolute difference between 2 measurements of Widmer's method ranged from 0° to 2° (mean  $\pm$  SD =  $0.5^\circ \pm 0.7^\circ$ ), and of ours, 0° to 1° ( $0.5^\circ \pm 0.7^\circ$ ).

## 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, improving 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 the method of Widmer [11] was mainly related to inclination angle and anteversion angle. The correlation between error and inclination due to Widmer's ignoring the influence of inclination when correcting oblique projection. The correlation between error and anteversion was due to Widmer's use of 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. When anteversion increased, the outer edge became blurred. If we measured with the inner edge, we underestimated the short axis. Fortunately this error was small in our study—only 3° when anteversion was larger than 45°. The intraobserver difference in Widmer's method was between 0° to 2°, and of ours, 0° to 2°, which was smaller than the error of Widmer's 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 the method of Widmer [11]. In the 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-radiograph method; thus, we have to take into account the disadvantages of unknown positions of patients if such information was not mentioned in the report. Position problems, including patient and x-ray source positions, are all other major disadvantages. We suggest measuring the qualified radiographs and excluding unqualified radiographs. Qualified radiographs mean acceptable position, which indicates a perfect controlled rotation (0° rotation) and tilt. In radiographs, 0° 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 anteroposterior radiograph of the same patient [12]. If we hardly get enough qualified radiographs, one possible solution is to estimate pelvis tilt and rotation

by method of Tannast et al [12] and then transfer to neutral-position anteversion by the formula of Murray [13].

Because 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, the protractors of Liaw et al [10] and Fabeck et al [9] were preferred. Otherwise, our improvement had significantly reduced the error and, thus, can be used in precise measurement of the anteversion.

Our improvement did improve the error from 0° to 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, or operative) [13], and which method is used for the measurements. Thus, the readers can understand the range of error and limitations of the measurements. For example, the error of Lewinnek et al [5] is 0° to 2.61°; the error of Liaw et al [10] is 0° to 3°; the error of Widmer [11] is 0° to 8.7°; and the error of our improvement is 0° to 3°.

## Appendix A

Mathematical relationship between version and S/TL ratio

Lewinnek et al [5] described an equation to measure radiographic (planar) anteversion  $\beta$ .

$$\beta = \sin^{-1}(s/l) \quad (\text{A} - 1)$$

where  $s$  is the length of the short axis; and  $l$  is the length of long axis of the ellipse. The ellipse is formed by the outer ring of the acetabulum component.

When we measure the anatomic (true) anteversion  $\alpha$ . The length of short axis in this equation is changed.

$$\alpha = \sin^{-1}(s_d/l) \quad (\text{A} - 2)$$

where  $s_d$  is the length of the ellipse intercept by horizontal line passing through center of the ellipse; and  $l$  is the length of long axis of the ellipse [10]. The  $s_d$  can be derived from  $s$ ,  $l$ , and abduction angle of acetabulum mathematically.

Eqs. (A-3) and (A-4) show the relationship between anatomic and radiographic anteversion.

$$\alpha = \tan^{-1}(\tan\beta \csc\gamma) \quad (\text{A} - 3)$$

$$\beta = \tan^{-1}(\tan\alpha \sin\gamma) \quad (\text{A} - 4)$$

where  $\gamma$  is the abduction angle. This equation is shown in Murray's report [13].

In the Widmer [11] method, he showed the relationship between S/TL ratio and true anteversion in Fig. 3 and Table 1 of his paper.

$$\text{TL} = (l + S)/2 \quad (\text{A} - 5)$$

$$\text{TL} = S / (S/\text{TL ratio})$$

$$l = 2\text{TL} - S = 2S / (S/\text{TL ratio}) - S$$

$$S/l = S / [2S / (S/\text{TL ratio}) - S] = (S/\text{TL ratio}) / [2 - (S/\text{TL ratio})]$$

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

## Appendix B

Correction of radiographic oblique projection

After we calculate  $\beta$  by Eq. (A-5), we can calculate  $\alpha$  by Eq. (A-3).

$$\alpha = \tan^{-1}[\tan(\sin^{-1}(S/\text{TL ratio}) / [2 - (S/\text{TL ratio})]) \csc\gamma] \quad (\text{A} - 6)$$

The anatomic anteversion must be corrected due to oblique projection.

$$\alpha = \tan^{-1}[\tan(\sin^{-1}\{(S/\text{TL ratio}) / [2 - (S/\text{TL ratio})]\}) \csc\gamma] + 5.46^\circ \quad (\text{A} - 7)$$

Then we can calculate radiographic anteversion from anatomic anteversion from Eq. (A-4).

$$\beta = \tan^{-1}(\tan\{\tan^{-1}[\tan(\sin^{-1}\{(S/\text{TL ratio}) / [2 - (S/\text{TL ratio})]\}) \csc\gamma] + 5.46^\circ \sin\gamma\}) \quad (\text{A} - 8)$$



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