Could We Expect Postoperative Cup Anteversion after Total Hip Arthroplasty Using Postoperative Plain Anteroposterior and Lateral Radiograph? A Three-Dimensional Experimental Operation Study

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ABSTRACT

Could We Expect Postoperative Cup Anteversion after Total Hip Arthroplasty Using Postoperative Plain Anteroposterior and Lateral Radiograph? A Three-Dimensional Experimental Operation Study

Introduction: A postoperative radiograph in total hip arthroplasty (THA) is usually obtained to evaluate the inclination and anteversion of the acetabular components. However, there is no gold standard method for calculating the exact inclination and anteversion of the acetabular components on post-THA radiographs. We aimed to measure the actual anteversion of the acetabular component on postoperative radiographs by obtaining correlation data between the virtual and actual acetabular component positioning using virtual three-dimensional (3D) surgery.

Materials and Methods: A total of 64 hip scans of 32 patients who underwent lower-extremity computed tomography (CT) were retrospectively reviewed. We reconstructed 3D models of the 64 hips using customized computer software (Mimics). Furthermore, to identify the safe zone of acetabular component position in THA, we performed virtual 3D surgery simulations for five anteversion (-10, 0, 10, 20, and 30) and five inclination (20, 30, 40, 50, and 60) types. We analyzed the acetabular anatomy using 3D models to measure the radiographic, anatomical, and operative anteversion (RA, AA, OA) and inclination (RI, AI, OI) angles. Additionally, we used the Woo–Morrey (WM) method to calculate the anteversion angle in the reconstructed cross-table lateral (CL) radiographs and determined the correlation between these measurements.

Results: The safe zone of the acetabular component was visualized on post-THA CL radiographs using the WM method of anteversion measurement based on the different anteversions and inclinations of the acetabular component. The AA, RA, OA, OI, and WM differed significantly between males and females (p value < 0.05). As the anatomical inclination or anteversion increased, the WM anteversion measurements also increased. The radiographic anteversion measurement best matched the WM method of measurement, followed by anatomical and operative methods.

Conclusions: The actual anteversion of the acetabular component after THA can be measured on

CL radiographs with the WM method using a 3D virtual program, with good reproducibility.

Key words : total hip arthroplasty; dislocation; anteversion; inclination

I. INTRODUCTION

According to Statistics Korea, 31,301 cases of hip reconstruction surgery, including total hip arthroplasty (THA), were performed in 2020. [1] Since John Charnley pioneered hip replacement surgery in 1960 [2], the demand for THA in the treatment of arthritis, femoral head osteonecrosis, and hip developmental dysplasia has been increasing annually. However, dislocation after THA is a devastating complication, [3-6] with an incidence of 1.9%−2.3%. [7,8] Although the incidence rate is low, once it is occurred, it can lead to revision surgery.[9,10] The risk factors of dislocation after THA are divided into patient-related and surgical risk factors. [4] Patient-related risk factors include neuromuscular and cognitive disorders, cerebral palsy, muscular dystrophy, psychosis, dementia, and alcohol consumption. [11] Additionally, surgical risk factors include the surgical approach, soft-tissue tension, component positioning (cup anteversion and inclination), impingement, cup size, head size, liner profile, and surgeon experience. [4] These factors, particularly the positioning of the acetabular component, can be adjusted to reduce the number of dislocations.[12] If in case of posterior approach of THA, if anteversion of acetabular component is not enough, there could be tendency to dislocate posteriorly.

During the planning and execution of surgery, several intraoperative factors are carefully considered by surgeons, including adequate positioning and orientation of the components. [5,13] Lewinnek et al. described a “safe-zone” of cup positioning: 5−25° of anteversion and 30−50° of inclination. [14] Inappropriate anteversion and inclination can cause impingement and levering out which can lead to dislocation. [15,16] Therefore, a post-THA radiograph is usually obtained for assessing the anteversion and inclination of the acetabular component. Although the inclination of the acetabular component can be easily measured on plain anteroposterior (AP) radiographs, anteversion is difficult to measure. Several studies have focused on evaluating anteversion of the acetabular component on plain AP radiographs. [14,17-20] However, no gold standard method has been established till date, making it difficult to determine the exact anteversion on plain AP radiographs. [21,22] Several studies have also focused on plain cross-table lateral (CL) radiographs (Figure 1) for evaluating the anteversion; [23-26] they provide an acceptable assessment of the general component position. [23,24,27,28] In a previous study, the anteversion of the acetabular component was measured using the method described by Woo and Morrey (WM) [5] and the

ischiolateral method described by Pulos et al. [23]. The anteversion of the acetabular component measured using these plain radiographic methods was consistently valid with good interobserver reproducibility. [29] However, these methods do not show the actual anteversion, which can be precisely measured using computed tomography (CT). Murray defined and measured the acetabular orientation using three methods (radiographic, anatomical, and operative measurements of inclination and anteversion). [28] Thus, the terms “inclination and anteversion” are frequently confused with these three methods. Inclination is usually defined as radiologic inclination which can be measured in coronal plane on CT scan. And Anteversion is usually defined as anatomical anteversion which can be measured in axial plane on CT scan. However, according to Murray et al[28], there are three inclinations and anteversions.

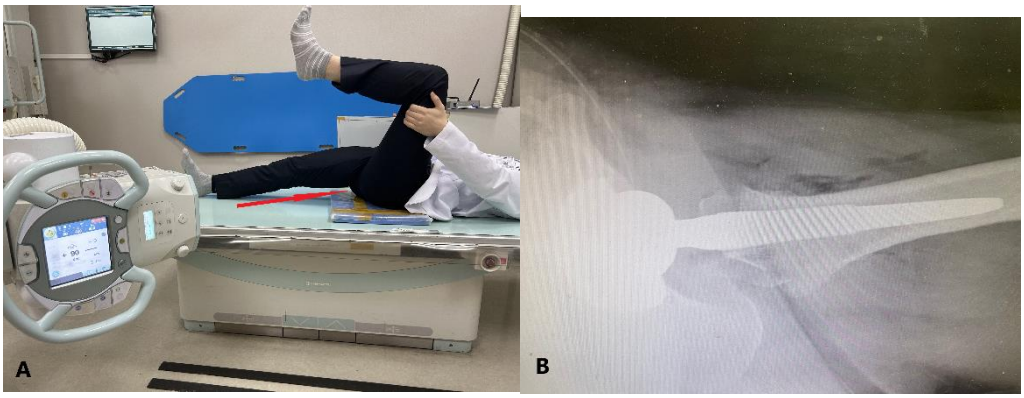


Figure 1. Photograph of the positioning of patients when taking a CL plain radiograph (A) and an actual CL plain radiograph (B).

Currently, there is no gold-standard method for calculating the exact inclination and anteversion of the acetabular components in post-THA radiographs. Surgeons often obtain only a postoperative radiograph, and not a CT, due to the effects of radiation and to ensure cost-effectiveness. Furthermore, only a few studies have focused on the measurement of acetabular orientation. Therefore, in this study, we aimed to determine the actual anteversion of the acetabular component on postoperative radiographs by obtaining correlation data between virtual and actual acetabular component positioning using three-dimensional (3D) virtual surgery. We also aimed to analyze the acetabular anatomy to calculate the radiographic, anatomical, and operative anteversion and inclination to determine the correlation between them.

II. MATERIALS AND METHODS

1. Data collection

This study was approved by the Institutional Review Board. A total of 32 patients (16 males and 16 females) who underwent THA between January 2011 and May 2022 were included in this study, and their data were retrospectively reviewed. Patients who had been diagnosed with osteoarthritis or osteonecrosis of femoral head and underwent primary THA were included. Patients who had been diagnosed with septic arthritis, had undergone previous surgery on the hip and spine, had a dysplastic hip, or had sequelae of childhood hip diseases were excluded. Preoperative CT data were saved in the digital image communication in medicine (DICOM) format.

Using Mimics (version 19.0; Materialize, Leuven, Belgium), 3D reconstruction of the pelvic bone was performed. Furthermore, by setting the hip center in the acetabulum, half of the acetabular component hemisphere was fixed. Thereafter, to identify the safe zone of acetabular component position in THA, we performed virtual 3D surgery simulations for five anteversion types (-10°, 0°, 10°, 20°, and 30°) and five inclination types (20°, 30°, 40°, 50°, and 60°).

We obtained plain CL radiographs using the method commonly used in practice. The radiation beam was directed through the groin, with the opposite lower extremity excluded from the imaging field. A cassette was positioned on the side of the hip at a right angle relative to the incidence angle; thus, it was projected toward the groin region at an angle of 45°, parallel to the longitudinal axis of the pelvis. [30] A 3D reconstruction image was rotated 45° internally and then projected onto a 2D plane to generate a plain CL radiograph (Figure 2). Acetabular anteversion was calculated using the WM method, which is computed using the angle between a line perpendicular to the horizontal plane of the film and a line along the opening of the acetabular component [29] (Figure 2).

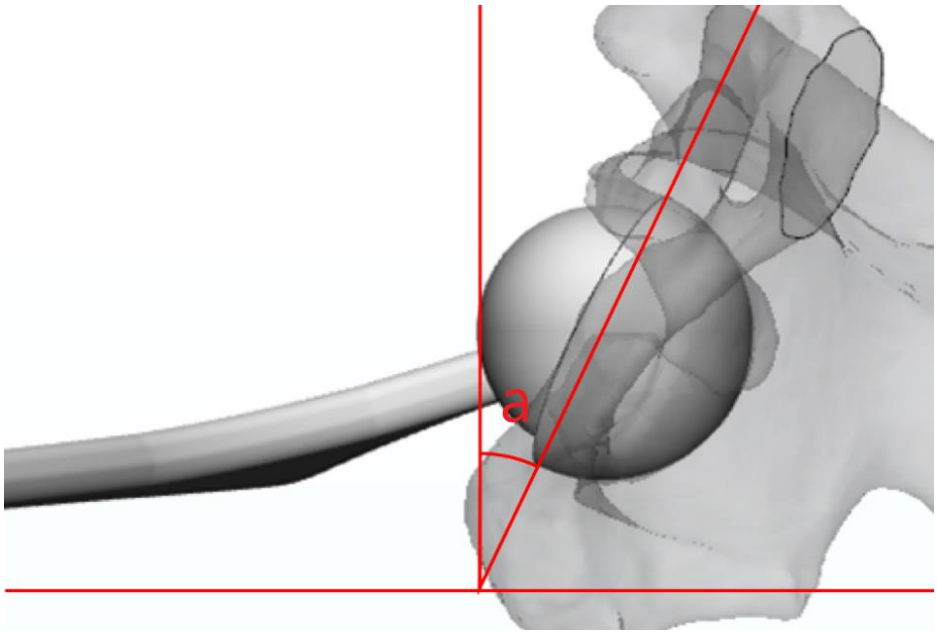


Figure 2. Represented CL plain radiograph on Mimics / Calculating acetabular anteversion (a) by the WM method of anteversion on the represented CL plain radiograph on Mimics (Red line). CL Cross lateral.

The coronal plane was defined as the plane connecting three points: bilateral anterior superior iliac spine (ASIS) and the center of the symphysis pubis. The sagittal plane was defined as the plane connecting the center of the symphysis pubis and sacral crest. The transverse plane was automatically defined by the two other planes (coronal and sagittal).

Furthermore, the orientation of inclination and anteversion was calculated using three methods (radiographic, anatomical, and operative measurements). Anatomical anteversion (AA) was defined as the angle between the transverse and acetabular axes when it is projected onto the transverse plane. The anatomical inclination (AI) was defined as the angle between the acetabular and longitudinal axes. Operative anteversion (OA) was defined as the angle between the longitudinal axis of the patient and the acetabular axis projected onto the sagittal plane. Operative inclination (OI) was defined as the angle between the acetabular and sagittal planes. Radiographic anteversion (RA) was defined as the angle between the acetabular and coronal planes. Radiographic inclination (RI) was defined as the angle between the longitudinal and acetabular axes when projected onto the coronal

plane (Figure 3). [28]

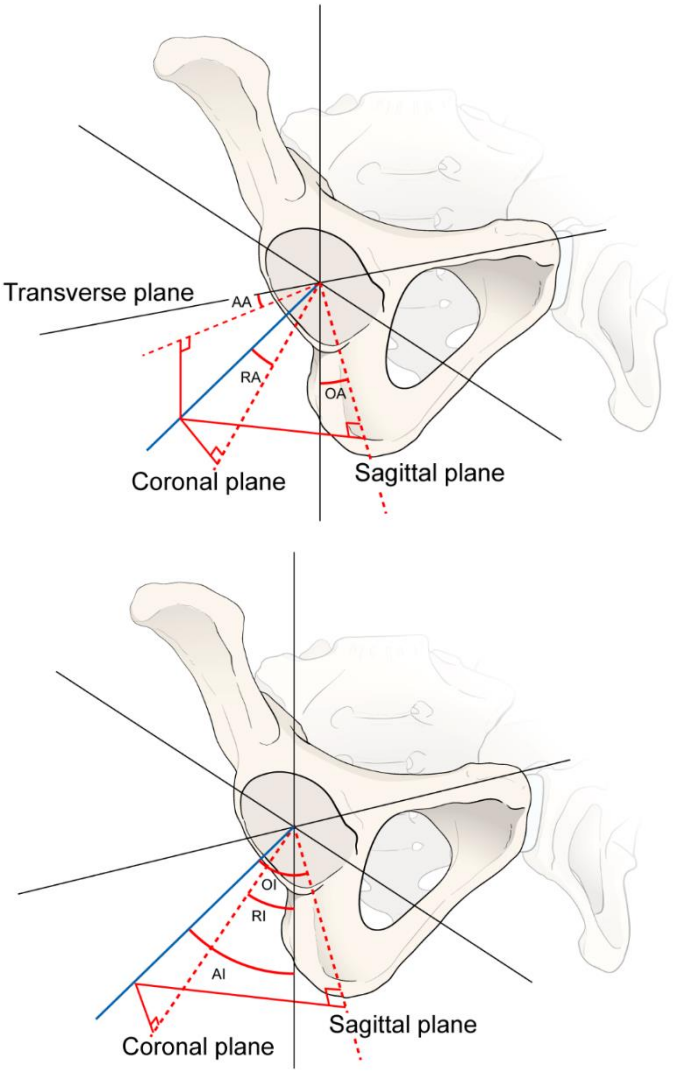


Figure 3. Orientation of the three methods of anteversion and inclination. AA anatomical anteversion RA radiological anteversion OA operational anteversion AI anatomical inclination RI radiological inclination OI operational inclination.

Thereafter, to identify the safe zone of acetabular component position in THA, we performed virtual 3D surgery simulations for five anteversion types (-10°, 0°, 10°, 20°, and 30°) and five

inclination types (20°, 30°, 40°, 50°, and 60°). Second, 64 hip CT scans of 32 patients were analyzed. The acetabular component was set in a normal position based on the positioning of their own acetabulum. Subsequently, we analyzed the hip acetabular anatomy to calculate the radiographic, anatomical, and operative anteversion and inclination angles to determine the correlation between them.

2. Statistical analysis

To obtain a power of 0.95 (1-β) with an α of 0.05, the calculated sample size was 27 cases per group.[31,32] Considering a dropout rate of 20%, the target sample size was 32 cases per group. The Shapiro–Wilk test was performed to determine the normal distributions for anteversion and inclination angles. Pearson correlation and regression tests were performed to evaluate the correlation between the three methods and the WM method of anteversion measurement. When correlation coefficient is closer to 1, there is a strong correlation. When correlation coefficient is closer to 0, there is a weak correlation. Statistical analyses were performed using IBM SPSS Statistics for Windows (Version 25.0; IBM Corp., Armonk, NY, USA), and p-values < 0.05 were considered significant.

III. RESULTS

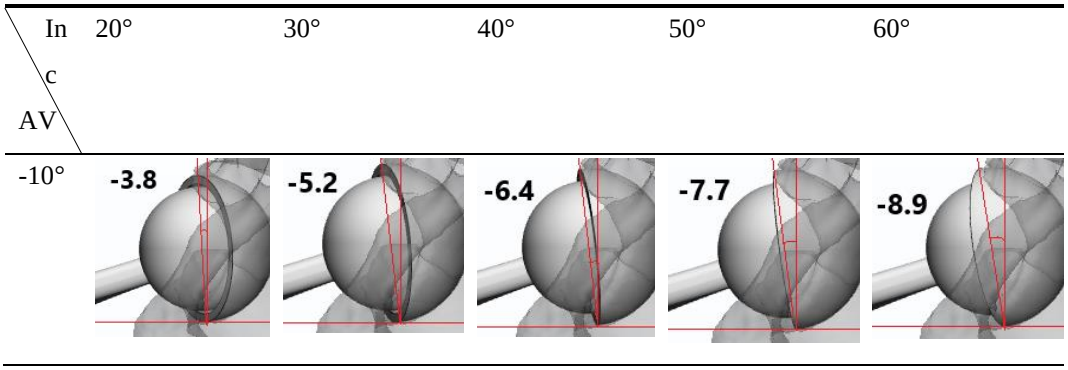
Inclinations and anteversions in each of the three methods of measurement, including sex distribution, were measured. The AA, RA, OA, OI, and WM anteversion differed significantly between males and females (Table 1). The mean values of AA, RA, OA, and WM anteversion were 20.1 ± 6.1, 15.5 ± 4.8, 23.3 ± 7.3, and 15.6 ± 4.8, respectively. Furthermore, the mean values of AI, RI, and OI were 51.5 ± 6.1, 49.5 ± 4.9, and 46.9 ± 4.5, respectively.

Table 1. Anteversions and inclinations with different measurements and gender distribution.

		Gender		
	Total	**Male**	**Female**	**p value**
AA	20.1 ± 6.1	18.0 ± 5.7	22.6 ± 5.8	0.004
RA	15.5 ± 4.8	14.0 ± 4.6	17.1 ± 4.6	0.008
OA	23.3 ± 7.3	21.4 ± 6.9	25.2 ± 7.2	0.04
AI	51.5 ± 4.7	51.8 ± 5.0	51.1 ± 4.6	0.57
RI	49.5 ± 4.9	50.3 ± 5.0	48.8 ± 4.7	0.23
OI	46.9 ± 4.5	48.0 ± 4.7	45.7 ± 4.1	0.04
WM	15.6 ± 4.8	14.1 ± 4.6	17.2 ± 4.6	0.009

AA anatomical anteversion RA radiological anteversion OA operational anteversion AI anatomical inclination RI radiological inclination OI operational inclination WM Woo and Morrey method of anteversion.

Figure 4 shows a plain post-THA CL radiograph and the WM anteversion measurement according to different anteversions and inclinations. of the acetabular component. For example, if the inclination of the acetabular component was 30° and the WM method of anteversion was 10.3°, the actual anteversion of the acetabular component was 20°. If the inclination of the acetabular component was 0°, then the WM method of anteversion was also 0°. In the final schematic, the inclination was measured using the WM method. As the anatomical inclination or anteversion increased, the WM anteversion measurements also increased.



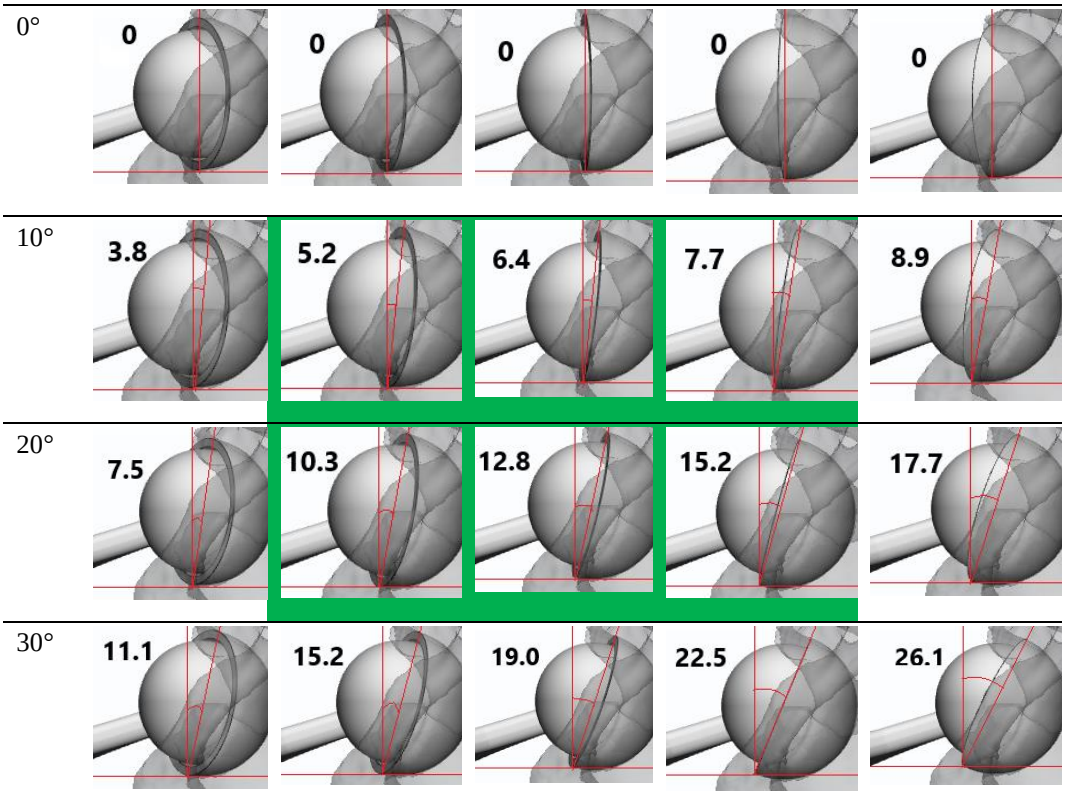
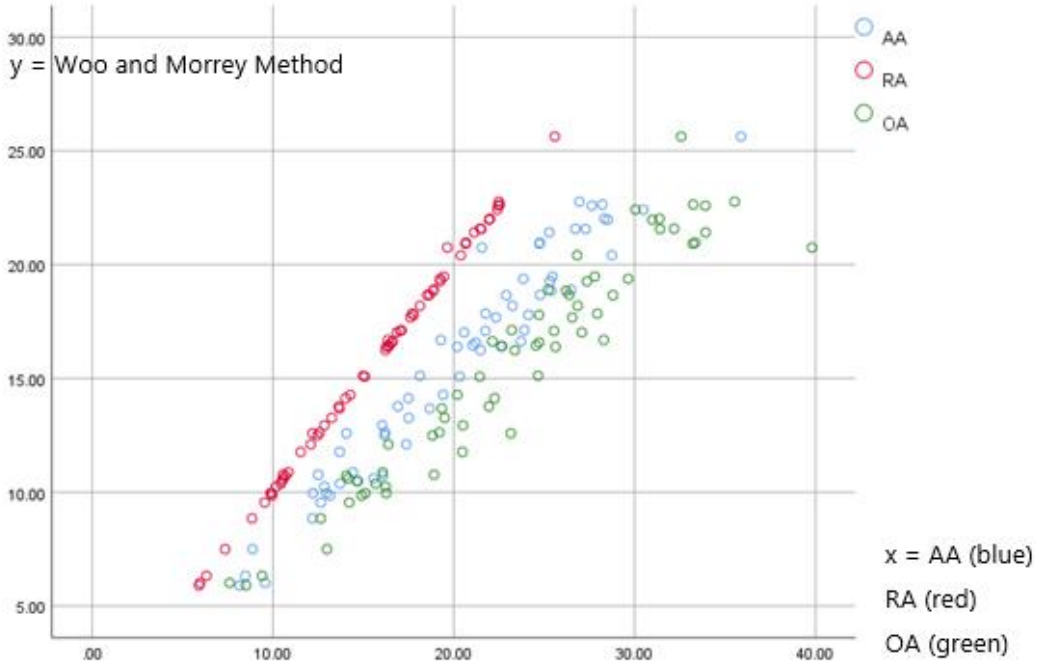


Figure 4. Schematic figure of the five types of anteversion (-10° : retroversion 10°) and the five types of inclination in a CL plain radiograph (Number : WM method of anteversion, Green zone : safe zone of acetabular component by Lewinnek et al, If the anteversion is retroverted, the WM method of anteversion is also retroverted. (1st row, AV -10°) If anteversion is 0°, the WM method of anteversion measurement is 0°. (2nd row, AV 0°) The WM method of anteversion measurement increases as the anteversion and inclination increases. (3^{rd}–5^{th} row, AV 10°, 20°, 30°).

All three anteversion measurement methods (AA, RA, and OA) showed strong significant positive correlations with the WM method of measurement. Radiographic measurement best matched the WM method (correlation coefficient: 0.999), followed by anatomical and operative measurement methods (0.972 and 0.957, respectively). Using a regression analysis, all three anteversion methods could be calculated using the WM method (Figure 5).



	Correlation coefficient
AA	0.972
RA	0.999
OA	0.957

Figure 5. Correlation between the WM method of anteversion and the three methods of anteversion / Correlation coefficient of AA, RA, OA with the WM method of anteversion. The WM method of anteversion shows the most correlation with RA with a correlation coefficient of 0.999, followed by AA with a correlation coefficient of 0.972, and OA with a correlation coefficient of 0.957.

IV. DISCUSSION

In this study, we developed 3D models of plain CL radiographs to measure the WM anteversion

angle, which can evaluate the actual anteversion of the acetabular component after THA. The schematic figure (Figure 4) provides an idea for readers to understand the optimal position of the acetabular component on a plain CL radiograph. Although virtually reconstructed, it exhibits the reproducibility of an actual plain CL radiograph. The coronal, sagittal, and transverse planes were consistently set by the anatomical structure of the pelvis and could produce the actual orientation of the acetabular component. The "safe-zone" of cup positioning at 5−25° anteversion and 30−50° inclination was defined by Lewinnek et al. [14]. Harris et al. stated that the acetabular component should be inserted during surgery with a 20° anteversion and 30° inclination. [34] Therefore, in the final schematic figure (Figure 4), the light green zone of the six figures (including the dark green zone) presented a tolerable and acceptable position of the acetabular component. The dark green zone of 20° anteversion/30° inclination area was the optimal position.

Assessment of the anteversion of the acetabular component is possible on both AP and CL plain radiographs. [18,19,28,35] However, because of the metallic density of the acetabular component, which was white in plain radiographs, anteversion assessment using plain AP radiographs has its limitations. Thus, plain CL radiographs can provide an anteversion assessment of general component positions. [23,24,27,28]

The WM method of anteversion can be easily measured and shows good interobserver reproducibility. Therefore, this study developed an intuitive figure to help surgeons determine the optimal acetabular cup position after THA. In addition, this study showed a strong significant positive correlation between the three anteversion measurement methods and the WM anteversion method. By analyzing the WM method of anteversion in a CL plain radiograph, we can calculate the angle of the three original anteversions, which can act as an indicator for the "safe zone" of cup positioning.

The WM method measurement of anteversion in a plain CL radiograph increased as the inclination increased (Figure 5). Therefore, surgeons should understand the correlation between anteversion and inclination. If in an AP plain radiograph, the inclination of the acetabular cup position is larger than that on a CL plain radiograph, the anteversion of the acetabular cup position should be greater than the estimated value. All three unique anteversion (AA, RA, OA) have high correlation with Woo and Morrey method. So we can conclude that with Woo and Morrey method, we can evaluate the actual anteversion of hip component after THA whether it is positioned in "safe zone".

Acetabular protrusion is rare, and THA is difficult surgery for better surgical outcome than other

osteoarthritis or osteonecrosis of femoral head patients who underwent THA. And evaluation of anteversion is also difficult. During THA, bone grafting on medial acetabular wall showed good midterm clinical and radiological results.[36] If bone grafting on medial acetabular wall which can restore the acetabular component position not much medially, the cross-lateral plain radiograph can evaluate more actual anteversion easily.

This study has some limitations. First, although angle measurement was automatically performed using a computer program, measurement bias remained. As shown in Figure 3, the calculation of anteversion can differ depending on the endpoint setting of the acetabular cup. Second, pelvic tilt can influence anteversion and inclination. [37] As the pelvic tilt decreases, anteversion decreases. Hence, we set all cases in the coronal plane to reflect the pelvic tilt. However, in practice, the pelvic tilt can affect the results. Third, the position of the pelvis differs in each person; therefore, it is difficult to set a standard universally applicable position in a plain CL radiograph in actual practice. Thus, standardization of the patient's position while obtaining a plain radiograph is important. And finally, this study focused mainly on the anteversion and inclination of acetabular component after THA, which can be adjustable when surgeons focus on it and evaluate after surgery. Future studies can focus on patient-related factors and other surgical risk factors.

V. CONCLUSION

The actual anteversion of the acetabular component after THA can be measured on a plain CL radiograph by the WM method of anteversion using a 3D virtual program. Plain CL radiographs showed anteversion of the acetabular cup position with good reproducibility. On plain CL radiographs, radiographic anteversion showed the best correlation with the WM anteversion method.

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Abstract in Korean

인공 고관절 전치환술 후 컵의 수술 후 전향각에 대해 수술 후 단순 방사선 사진을 통한 예측 : 3차원 실험적 수술 연구

서론

인공고관절 전치환술 수술 후 단순 방사선 사진은 절구의 경사각과 전향각을 평가하기 위해 촬영한다. 그러나 정확한 절구의 경사각과 전향각을 측정하는 것은 지금까지 최적화된 표준은 없는 실정이다. 따라서 본 연구는 3차원의 가상의 수술을 시행하여 절구에 위치하는 컵의 실제 경사각과 전향각을 측정하여 단순 방사선 사진에서의 각도와의 정확한 연관 관계를 찾고자 한다.

대상 및 방법

32명의 환자의 64개의 고관절을 하지 컴퓨터 단층 촬영한 자료를 토대로 후향적으로 고찰하였다. Mimics 프로그램을 통해 3차원 모델로 64개의 고관절을 재구성하였다. 또한, 인공고관절 전치환술 후 안전한 각도의 절구에 위치하는 컵 각도를 밝혀내기 위하여 3차원의 가상의 수술을 시행하였다. 5개의 전향각(-10, 0, 10, 20, 30도)과 5개의 경사각 (20, 30, 40, 50, 60도)를 조합하여 각각의 단순 방사선 사진을 구현하였다. 이를 통해 분석하여 3차원 모델에서 방사선학적, 해부학적, 수술적 전향각과 경사각을 측정하였다. 추가로, 3차원 모델에서 고유의 전향각과 경사각과 단순 방사선 사진의 전향각과 경사각의 연관 관계를 Woo-Morrey(WM) 방법을 이용하여 밝히고자 하였다.

결과

5가지의 전향각과 5가지의 경사각을 조합하여 설정한 25가지의 상황에서 절구에 위치하는 컵의 안전 각도에 대해 단순 방사선 cross-table lateral 사진에서 WM 방법으로 측정한 전향각을 시각화하여 표시하였다. 해부학적 전향각, 방사선학적

전향각, 수술적 전향각, 수술적 경사각 및 WM 전향각이 남성과 여성에서 통계학적으로 유의미하게 차이가 났다. 해부학적 경사각이나 전향각이 증가함에 따라, WM 전향각 또한 증가하였다. 방사선학적 전향각이 WM 전향각과 가장 연관 관계가 높았고, 그 다음으로 해부학적 그리고 수술적 전향각이 연관 관계가 있었다.

결론

인공고관절 전치환술 후 실제 절구에 위치하는 컵의 전향각은 단순 방사선 cross-table lateral 사진에서 WM 전향각으로 측정 및 계산할 수 있다.

핵심되는 말 : 인공고관절 전치환술, 탈구, 전향각, 경사각