Measurement of Acetabular Cup Anteversion with the Circle Theorem

Arkaphat Kosiyatrakul MD*,
Suriya Luenam MD*, Thanainit Chotanaphuti MD*

** Department of Orthopaedics, Phramongkutklao Hospital and College of Medicine, Bangkok, Thailand*

Objective: *Malposition of the acetabular cup is the major risk factor of dislocation after total hip arthroplasty. Postoperatively, measuring of acetabular cup anteversion is very difficult. The new method for measuring acetabular cup anteversion on the plain radiograph of the hip with one of the circle theorems in the basic geometry was created.*

Material and Method: *An all-polyethylene acetabular cup with known angle of radiographic anteversion was mouthed to the pelvic bone. Antero-posterior hip and pelvis radiographs were taken with the cup in randomly 15 different angles of anteversion. These were reviewed by 3 orthopedic residents. All data from 3 observers were collected and examined for the accuracy, inter-observers reliability and intra-observer reliability of this method. Two films (AP radiograph of the hip and the pelvis) method was used for distinguish between anteversion and retroversion.*

Results: *The measurements of radiographic anteversion have the accuracy of plus or minus 2 degrees. The reliability coefficients of inter-observer variation in the first and second measurements for all definitions of anteversion are high. Pair t-test showed no significant different between value of the first and the second measurements for all definitions in all observers. The intra- and inter-observer variations were 3 degrees or less for all definitions.*

Conclusion: *The Acetabular cup anteversion measurement using the circle theorem iseasily to perform with high accuracy and consistency for all definitions of cup anteversion.*

Keywords: *Measurement, Acetabular cup, Anteversion, Total hip arthroplasty*

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It is generally accepted that the position of the acetabular cup which includes inclination and anteversion affect the stability[1-6] and range of motion of total hip arthroplasty[7-9]. Murray[10] suggested there are radiographic, anatomical and operative definitions of inclination and anteversion. Radiographic definition is commonly used to describe the inclination which is the angle between long axis of the cup and the transverse line of the pelvis (Fig. 1A) while the proper anteversion had been described with the different definitions[1-3,5,6,8]. For the anteversion of the acetabular cup, the authors used a cup face plane which is perpendicular to the acetabular axis as a reference[10]. The anatomical (true) anteversion is equal to the angle between the cup face plane and the sagittal plane that is presented on the transverse plane (Fig. 1B), whereas operative anteversion is equal to the angle between the cup face plane and the transverse plane that is presented on the sagittal plane (Fig. 1C). The radiographic (planar) anteversion, the most commonly used one, is equal to the angle between the cup face plane and the imaginary plane that runs along the axis of rotation of the cup and perpendicular to the coronal plane (Fig. 1D).

Various methods of measurement for the acetabular cup anteversion have been proposed with variable results[2,11-26]. As the plain radiographs are available in every orthopedic center with low cost, it is the most commonly used modality for postoperative

Correspondence to: Kosiyatrakul A, Department of Orthopaedics, Phramongkutklao Hospital and College of Medicine, Bangkok 315 Ratchawithi Road, Bangkok 10400 Thailand, Phone: 0-2246-0066 Ext 93459, Fax:0-2644-4940, E-mail: arkaphat@yahoo.com

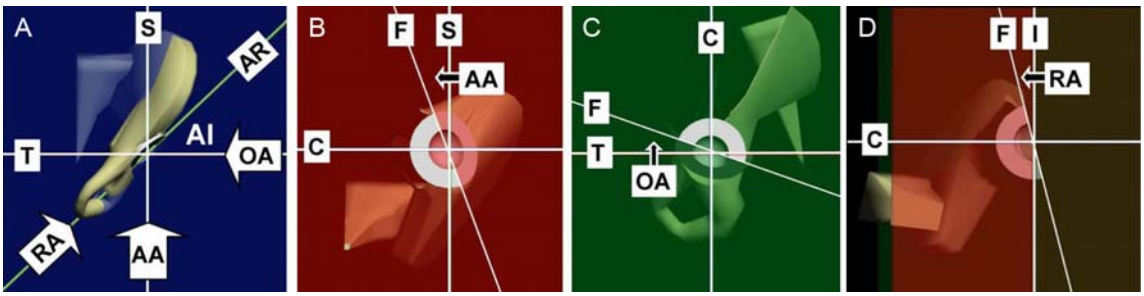

Fig. 1 A: Demonstate acetabular inclination (AI); direction for observation of anatomical anteversion (arrow AA), operative anteversion (arrow OA), and radiographic anteverion (arrow RA); axis of rotation of acetabular cup (AR)
B: Anatomical anteversion (AA)
C: Operative anteversion (OA)
D: Radiographic anteversion (RA); imaginary plane perpendicular to coronal plane (I)
S = sagittal plane, T = transverse plane, C = coronal plane, F = cup face plane

follow-up to detect the evidence of acetabular position change after total hip arthroplasty. The authors have introduced a new simple method to measure the anteversion of acetabular cup using the anteroposterior (AP) hip radiograph. This method is base on one of the circle theorems in basic geometry. The purpose of this study is to determine the accuracy and consistency of this technique.

Material and Method

The authors' principle is to evaluate the cup in the area which the femoral component does not obscure the shadow of the wire marker (Fig. 2). The method for measuring radiographic, anatomical, and operative anteversion were shown in Fig. 3 and 4. Two films (AP radiograph of the hip and the pelvis) method was used to distinguish between anteversion and retroversion[15,27].

To evaluate the accuracy and reliability of the method, the model with a known angle of radiographic anteversion was made. This model includes the polyethelene cup and a protector with their centers in the same axis. Then the model was mouthed to the pelvic bone for the radiographic studies. AP radiographs of the hip and pelvis were taken with the cup in 15 different random angles from 45 degree of radiographic anteversion to 45 degree of radiographic retroversion. Each angle was performed 6 AP radiographs of the hip and pelvis. Each set of the films were measured for all definitions of anteversion by 3 orthopedics residents. Only AP radiographs of the hip measured all of the definitions of cup anteversion. Each pair of AP radiographs of the hip and the pelvis were used to determine weather the cup was in anteversion or retroversion. The second measurement was performed 3 months apart. The inter-observer and intra-observer reliability were analyzed with paired t-test and intraclass correlation coefficient.

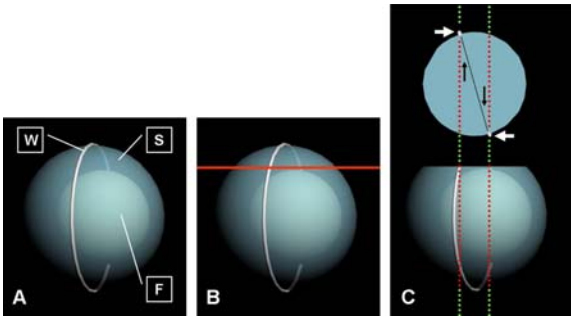

Fig. 2 Radiographic anteversion. Principle of the circle theorem method is to evaluate the cup in the area which the femoral component dose not obscure the shadow of the wire marker (Fig. 2A-C are correlated to Fig. 3A-C respectively)
A: The shadow of a wire marker (W) in the plain radiograph is the equator of the imaginary sphere (S). The smaller sphere (F) is the femoral head component
B: The sphere is cut perpendicularly to the long axis of the ellipse in the area which the femoral component dose not obscure the shadow of the wire marker
C: The cut surface of the sphere is opened up. The angle between line connecting two cut wire markers (white arrows) and the dash lines which parallel to the long axis of the ellipse are equal to radiographic anteversion (black arrows)

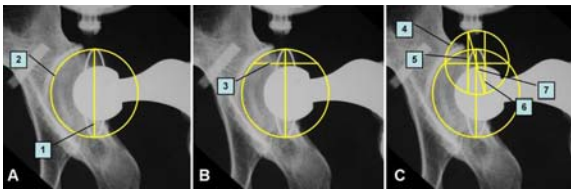

Fig. 3 Measuring of radiographic anteversion
A: Creating the sphere (correlated with Fig. 2A)
Step 1: draw a long axis of the ellipse
Step 2: draw a circle around the ellipse. The center of the circle and the center of the ellipse are the same point. The radius of the circle is equal to a half of the length of the long axis
B: Cutting the sphere (as a Fig. 2B)
Step 3: draw line 3 perpendicular to the long axis and pass the ellipse at two points which are not obscured by the femoral head component
C: Looking at the cut surface of the sphere (correlated with Fig. 2C)
Step 4: draw the circle 4 around line 3 with the radius equal to a half of line 3, the center of the circle 4 and the center of the line 3 are the same point (Note: the circle 4 represents the upper part of the cut sphere in Fig. 2C)
Step 5: draw line 5 and line 6 parallel to the long axis of the ellipse
Step 6: draw line 7 connect each side of line 5 and line 6
Step 7: the angles between line 5 and 7, and line 6 and 7 are equal to radiographic anteversion because the size of the circle 4 and the cut surface of the sphere Fig. 2C) are equal (according to the circle theorem, in the same circle or different circles but same size, the angles in the same segment of a circle are equal[28])

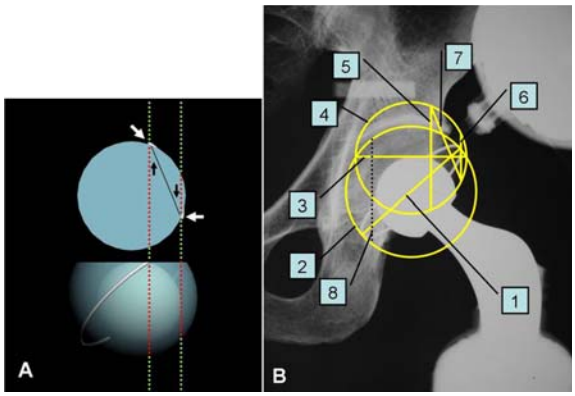

Fig. 4 Demonstrating anatomical anteversion and measuring method
A: Demonstrating a sphere as in the Fig. 2A
This time the sphere was cut parallel to the transverse axis. The cut surface of the sphere is opened up. The angle between line connecting two cut wire markers (white arrows) and the dash lines which parallel to the longitudinal axis of the body are equal to anatomical anteversion (black arrows)
B: Measuring method of anatomical anteversion
Step 1 and 2 are same as steps 1 and 2 in Fig. 3
Step 3: draw line 3 parallel to transverse axis of the body and pass the ellipse at two points which are not obscured by the femoral head component
Step 4 is same as step 4 in Fig. 3
Step 5: draw line 5 and line 6 parallel to the vertical axis of the body and end at the curve of the circle 4
Step 6: draw line 7 connect each side of line 5 and line 6
Step 7: the angles between line 5 and 7, and line 6 and 7 are equal to anatomical anteversion because the size of the circle 4 and the cut surface of the sphere in Fig. 4A are equal (according to the circle theorem[28])
Step 8: Because the operative anteversion and anatomical anteversion are observe perpendicular to each other (Fig. 1), the measuring of operative antevesion can perform in the perpendicular manner to the measuring of anatomical anteversion, draw line 8 (dash line) instead of line 3 and the following steps are same

Results

The measurement of radiographic anteversion has an accuracy of plus or minus 2 degrees. The intra-class correlation coefficients of inter-observer variation in the first and the second measurement were 0.9987 and 0.9982 for radiographic anteversion, 0.9983 and 0.9989 for anatomical anteversion and 0.9982 and 0.9984 for operative anteversion. Paired t-test showed no significant different between value of the first and the second measurement for all definitions of anteversion in all observers.

The inter-observer variation between the first and the second measurement were 3 degrees or less for all definitions of anteversion. The intra-observer variation between the first and the second measurement were 2 degrees or less for radiographic anteversion and 3 degrees or less for anatomical and operative anteversion.

Discussion

Anteversion of the acetabular cup can be measured by 3 sources of radiographic modality, the computer tomography (CT)[17,24,25], the fluoroscopy[12] and plain radiography[2,10,11,13-16,18-23,26].

Table 1. P-value of the first and the second measurement in three observer (paired t-test)

Observer	p-value		
	RA	AA	OA
1	0.233	0.774	0.760
2	0.806	0.822	0.685
3	0.364	0.430	0.452

RA = radiographic anteversion, AA = anatomical anteversion, OA = operative anteversion

The CT method demonstrated the good reproducibility and high level of precision for determining acetabular cup anteversion regardless of the position of the patient[17,24,25]. However, this method is impractical because of the high costs and the increase risk of radiation exposure.The fluoroscopic method can measure all definitions of anteversion[12]. However, this method takes a longer time and is improper to be used as a follow-up means in the clinical practice.

Plain radiograph is the most commonly used modality for follow-up postoperative total hip arthroplasty because it is inexpensive and available in every orthopedic center. Measurement on the plain radiograph can be further classified into trigonometric methods, law of ellipse methods, and descriptive geometric methods.

Trigonometric methods can be performed in AP hip radiograph[10,11,13-15,18,21,26], AP pelvis[2,23] or lateral cross-table hip radiograph[19]. Some methods use trigonometry to create conversion table[11,14,20,23]. The ratio of the shortest to the longest diameter of the cup on radiograph is used to determine the angle of anteversion. Others create normogram[10,19] or protector[23,26]. However, these methods have to draw the remaining parts of ellipse which is obscured by the femoral component and contribute to the inaccurate measurement[16,20,22,26]. Pradhan[21] used the theorem of Pythagoras to solve this problem. However, the trigonometric calculator is needed. Yao et al[19] used a lateral cross-table of the hip to stay away from drawing the obscured part, but normograms are needed to determine all of the definition for the anteversion.

With the law of ellipse, the problem of drawing the obscured part can be avoided[16,20], but conversion tables are necessary otherwise a computer is needed to calculate the complex mathematical formulas.

The descriptive geometric method described by Fabeck et al[22] is simple on this basis. This method uses a special goniometer with a protactor inside to measure anteversion of acetacular cup. However, drawing the obscured part of the ellipse is needed and sometimes the circles inside the goniometer does not match the side of the acetabular cup.

Conclusion

The authors proposed the circle theorem method based on a simple descriptive geometry. With this method, drawing of the obscured part can be avoided with high accuracy and consistency for all definitions of the acetabular cup anteversion. This method can also be used for measuring the cementless cup version as the obscured side of the ellipse can be drawn symmetrically to the visible part[22]. To reduce the errors, standard AP radiograph of the hip without any rotation in any axis of the pelvis is compulsory[2,15,18,23,26,28]. Another error may occur if the apex of the ellipse is difficult to identify when the ellipse is broaden[21]. The circle theorem method also has some limitations of numerous steps and a compass is required. Nevertheless, after a few times of measurement, all of the observers can be performed in a few minutes.

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การวัดมุม anteversion ของเบ้าสะโพกเทียมด้วยทฤษฎีบทวงกลม

อรรคพัฐ โกสิยตระกูล, สุริยา ลือนาม, ธไนนิธย์ โชตนภูติ

วัตถุประสงค์: *การวางเบ้าสะโพกเทียมที่ผิดตำแหน่งนั้นเป็นหนึ่งในสาเหตุหลักของการเกิดข้อสะโพกหลุดเคลื่อนภายหลังการผ่าตัดเปลี่ยนข้อสะโพกเทียมแบบ total hip arthroplasty ในปัจจุบันการวัดมุม anteversion ของเบ้าสะโพกเทียมนั้นทำได้ยาก และยังไม่มีวิธีใดที่ดีที่สุดสำหรับการวัดค่ามุมดังกล่าว ทฤษฎีบทวงกลม ซึ่งเป็นทฤษฎีบทพื้นฐานในวิชาเรขาคณิตได้ถูกนำมาประยุกต์ใช้เพื่อเป็นวิธีการในการหาค่ามุม anteversion ของเบ้าสะโพกเทียม*

วัสดุและวิธีการ: *เพื่อที่จะศึกษาว่าวิธีการดังกล่าวมีความถูกต้อง แม่นยำ และเที่ยงตรงเพียงใด ทางผู้รายงานได้นำเบ้าสะโพกเทียมชนิด all-polyethylene ซึ่งทราบค่าของมุม radiographic anteversion ไปประกอบกับกระดูกเชิงกรานจริงเพื่อใช้ในการถ่ายภาพรังสี โดยทำการถ่ายภาพรังสีในแนวหน้าหลังของข้อสะโพกและอุ้งเชิงกรานในมุมที่แตกต่างกัน 15 มุมซึ่งได้จากการสุ่ม นำแผ่นภาพรังสีที่ได้มอบให้แก่แพทย์ประจำบ้าน 3 ท่าน เพื่อใช้ในการวัดมุมตามนิยามต่าง ๆ 2 ครั้งห่างกัน 3 เดือน ข้อมูลที่ได้จะนำมาวิเคราะห์เพื่อหา accuracy, inter-observer reliability และ intra-observer reliability การศึกษานี้ใช้การเปรียบเทียบแผ่นภาพรังสี ในแนวหน้าหลังของอุ้งเชิงกรานและข้อสะโพกในการแยกระหว่าง anteversion กับ retroversion*

ผลการศึกษา: *การวัดมุม radiographic anteversion มีความคลาดเคลื่อน 2 องศาจากค่าจริง ค่า reliability co-efficient ของการวัดมุม anteversion ตามนิยามต่างๆอยู่ในเกณฑ์ที่สูง ไม่พบว่ามีความแตกต่างกันอย่างมีนัยสำคัญระหว่างการวัดครั้งแรกและครั้งที่สองในทุกนิยามของมุม anteversion ค่า interobserver variation และค่า intraobserver variation ของการวัดครั้งแรกและครั้งที่สองในทุกนิยามมีค่าน้อยกว่าหรือเท่ากับ 3 องศา*

สรุป: *การวัดมุม anteversion ของเบ้าสะโพกเทียมโดยใช้ทฤษฎีบทวงกลม สามารถทำได้ง่ายมีความถูกต้องอยู่ในเกณฑ์ที่ยอมรับ และมี inter-observer และ intra-observer reliability ที่สูงสำหรับการวัดมุม anteversion ของเบ้าสะโพกเทียมในทุกนิยาม*