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ORIGINAL ARTICLE • HIP - ARTRHOPLASTY

A new radiographic acetabular cup anteversion measurement method in total hip arthroplasty: a clinical study

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Abstract
Background The acetabular cup positioning is one of the most crucial steps affecting stability and wear rates in total hip arthroplasty. Different methods have been described for determining the anteversion of the acetabular cup in the literature. But there is still not a widely accepted method to assess the acetabular anteversion radiography. The aim of this study is to measure the acetabular anteversion angle on a single pelvis AP radiography with our method which was proven with an experimental study before.
Materials and methods A total of 15 patients (8 males, 7 females) who underwent total hip arthroplasty and have had a pelvis computed tomography scans in our outpatient clinic were evaluated retrospectively. The anteversion angle was calculated in all of pelvis CT scans. For radiological measurement, the formula defined by the authors in an experimental model previously was used.
Results Statistically significant difference was not determined between radiographic and CT-based measurements ($p = 0.207$; $p > 0.05$). A statistically significant agreement was observed at a level of 98.8% between radiographic and CT-based measurements (ICC = 0.988; 95% CI 0.966–0.996; $p < 0.01$).
Conclusion Assessment of the acetabular cup anteversion is very important to predict the possible complications after total hip arthroplasty. Although many methods have been defined for this purpose, each of these has advantages and disadvantages. In particular, with computed tomography method, the patient is exposed to excessive radiation, whereas we think that our method is a preferred method due to features not requiring additional equipment, low radiation exposure, being simple, cost-effectiveness, easily applicable and almost 100% accurate.

Keywords Acetabulum · Anteversion · Radiography · Total hip arthroplasty

Introduction

Total hip arthroplasty (THA) is an orthopedic surgical procedure which is commonly and successfully used for the treatment of diseases such as avascular necrosis, collum femoris fracture or degenerative arthritis involving the femoral head and acetabulum cup The acetabular component positioning is crucial step affecting stability and wear rates in THA. A recognized angle of anteversion ranges from 15 to 20°, and as malposition of the acetabular cup, anteversion increases the risk of early dislocation, and it causes rapid polyethylene wear and limitation in range of motion of the hip as a result of impingement [1, 2]. First of all, apart from anteversion angle, the cup must be placed in anteversion position and beware of placing in retroversion.

Fortunately, acetabular inclination can be measured on anteroposterior (AP) hip radiographs but still there is not an acetabular anteversion measuring method radiographically widely accepted yet. Many methods have been described for determining the anteversion of the acetabular cup as computed tomography (CT) or plain radiography imaging in the literature [3–6]. Each of these methods has advantages and disadvantages. By Sir Charnley, to determine the position

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of the acetabular component, the cerclage wire was placed near the edge of the cup and it was ensured to put forward an idea about the anteversion based on the ellipse formed by the cerclage wire on the plain radiography. In radiological studies performed later, the measurements were taken by using various formulas with the help of reference point taken on the acetabular cup. Determination of this reference point to calculate the anteversion of the acetabular cup is quite relevant particularly in radiological methods. This point may vary from person to person and can cause errors in the measurements. It has been suggested by some authors that only CT scans enable accurate assessment of cup orientation [7, 8]. But some factors such as high radiation dose, the unavailability of scanning time and high cost of CT are the handicaps for routine usage of CT scan measuring. Therefore, in recent years, different techniques have been defined to measure the anteversion of the acetabular cup safely through plain radiography [9–11]. But most of these are non-clinical experimental studies [12].

The aim of this study is to determine the acetabular anteversion angle through plain pelvis AP radiography by applying our previously software-based proved efficiently and nearly totally reliable measurement method in clinical use (13).

Fig. 1 AP radiograph of the pelvis while the anterior pelvic plane parallel to the ground plane in both knees flexed in 90° to prevent pelvic flexion

Materials and methods

We retrospectively reviewed the patient demographic information and radiology images of 96 patients who underwent THA between January 2016 and July 2017. The inclusion criteria were having, pelvis CT images and proper AP hip roentgenography. Reasons for having CT images were postoperative aseptic hip pain, doubt about acetabular anteversion angle and to inspect the contralateral hip preoperatively for THA. The exclusion criteria were having revision of the hip surgery, any pelvic congenital deformities or pelvic fracture history. Finally, a total of 15 patients (8 males, 7 females) were found having both postoperative CT scan and proper digital pelvic X-rays. The mean age was 57.1 (range 38–78) years. All of the radiographs were taken by using the same digital radiography device (Siemens Axiom Aristos VX, Germany). Again all of the CT images were obtained by using Siemens SOMATOM Sensation 16 or 64 scanners at a slice thickness of 4 mm and an average in-plane (x–y) resolution of 0.72 pixels. During plain radiography, the patient was lay in the supine position on the radiographic table, X-ray source fixed 100 cm away from patient and focused femoral head, both knees at 90° of flexion to prevent pelvic flexion (Fig. 1). In this way, anterior pelvic plane was brought parallel to the ground plane. The anteversion angle was calculated in all of pelvic CT axial scans. Also, the formula defined by the authors in an experimental model previously was determined to have almost 100% accuracy both mathematically and in the software environment which was used in plain pelvic radiographs for all patients [13].

The formula designed by the authors was as follows: anteversion angle (α) = arc sin $|PK|\sqrt{|AK| \times |BK|}$ "Appendix." The ABCD ellipse in Figs. 2, 3 represents the ellipse formed by the cerclage wire around the acetabular cup. Using this formula defined by us, the anteversion angles were calculated through hip AP graphs of the patients and the results were compared with the values measured with the axial CT sections. Extreme picture archiving and communication system (Ankara, Turkey) were used in all plain radiographic and CT assessments measurements *by a senior orthopedist*, AB: 7.35 cm = 73.5 mm, AK: 1.46 cm = 14.6 mm, PK : 0.693 cm = 6.93 mm, α = arc sin PK/$\sqrt{\text{AK}}$. BK, α = arc sin 0.693/$\sqrt{5.89 \times 1.46}$, α = arc sin 0.693/$\sqrt{8.5994}$, α = arc sin 0.693/2.9324, α = 0.2363 radyan, α = 13.66° (Fig. 4).

Statistical analysis

NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) program was used for the statistical analysis. During the evaluation of the study data, descriptive statistical methods (mean, standard deviation, median, minimum and maximum) were used. Wilcoxon signed-ranks test was used for the in-group comparisons of the variables without normal distribution. Intraclass correlation coefficient (ICC) was used for evaluation of pairwise agreement between radiography and CT scan. Significance was evaluated at the lowest level of $p < 0.05$.

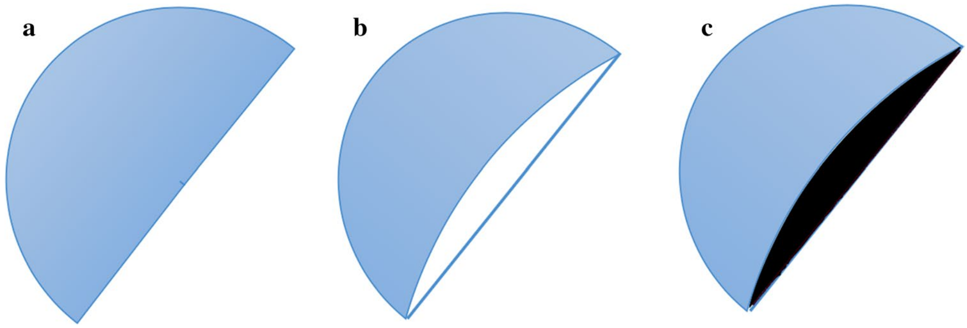

Fig. 2 Differerent acetabular positions from the AP view; **a**: if acetabular anteversion is "0" degree, the anterior and posterior acetabular edges will be overlapped, **b** if acetabular anteversion is a value except "0," an ellipse will be observed. **c** And the shaded elliptical area can be used to measure the acetabular anteversion angle

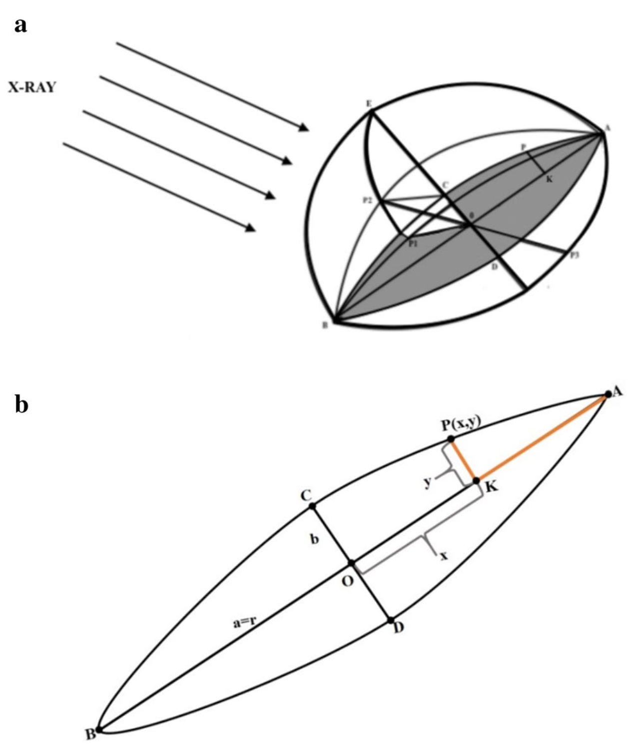

Fig. 3 **a** Creation of the acetabular anteversion model for mathematical explanation of the formula according to the X-ray beam direction the shaded elliptical area, **b** for the formulation of acetabular anteversion measurement

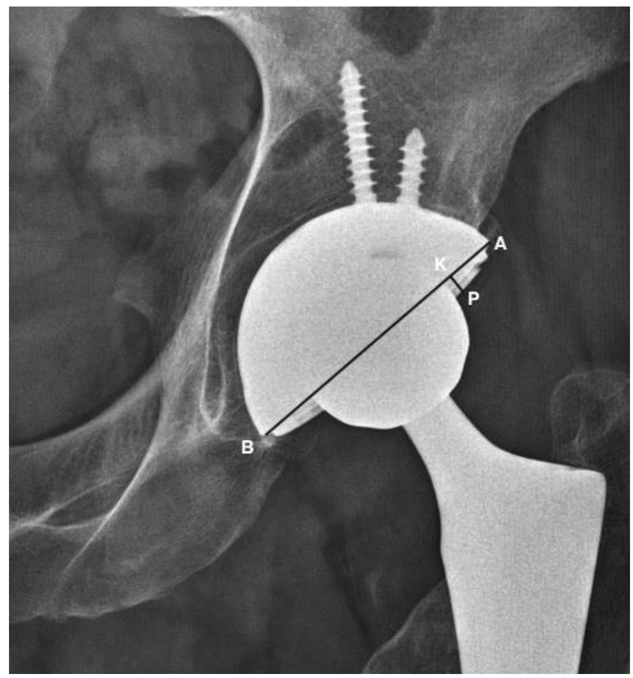

Fig. 4 Acetabular anteversion measurement sample on AP hip X-ray of patient number three on Table 2

Results

Radiographic measurements ranged between 6.3 and 25.6, mean value was 13.76 ± 4.70; CT-based measurements ranged between 6.9 and 26.9, mean value was 13.52 ± 4.95. No statistically significant difference was determined between radiographic and CT-based measurements ($p = 0.207$; $p > 0.05$). A statistically significant agreement was observed at a level of 98.8% between radiographic and CT-based measurements (ICC = 0.988; 95% CI 0.966–0.996; $p < 0.01$) (Table 1).

Discussion

Acetabular cup orientation is crucial for postoperative evaluation of the patients following THA. Acetabular cup orientation is usually described in terms of inclination and anteversion, and malorientation causes an increased risk of postoperative pain, prosthetic instability, early wear, loosening and dislocation [1, 2]. Recently, many methods have been described for determining acetabular cup anteversion as CT, plain radiography imaging, navigation-assisted method or intraoperative fluoroscopy [4, 9, 10, 14–16]. CT provides an accurate measurement of acetabular cup orientation, but the patient is exposed to a higher dose of radiation also this may result in time consumption and high cost. Despite this measurements through plain

Table 1 Statistical results of radiography and CT-based measurements

	Min–Max° (Median)	Mean ± SD°	Test value; p	ICC (95% CI); p
Radiography	6.3–25.6 (13.8)	13.76 ± 4.70	Z: − 1.262???	0.988 (0.966–0.996)
CT	6.9–26.9 (13.1)	13.52 ± 4.95	$^{a}p = 0.207$	$p = 0.001$**

ICC intraclass correlation coefficient; *CI* confidence interval

[a]Wilcoxon signed-ranks test **$p < 0.01$

radiographs have limited use due to some disadvantages such as dependency on patient position, affection by the distance from the X-ray source, prone to user error and magnification problem.

In the study performed by Nunley et al. and comparing CT and cross-table lateral radiography for measurement of acetabular anteversion, the authors found a strong correlation between two methods [17]. But in the study performed by Ghelman et al., it was reported that acetabular anteversion measured on cross-table radiographs was highly dependent on radiographic technique and patient positioning [7]. The method defined by us previously and used also in this study is not affected by the distance from X-ray source or magnification [13]. The most important step in our method is focusing the X-rays just at the center of the acetabulum.

In postoperative radiographs, as part of the ellipse is covered by the femoral head and neck in cemented prostheses and half of the ellipse cannot be well determined in uncemented ones, there are problems related to the clinical application of all of the formula. Therefore, it was preferred by the authors to complete the invisible part of the ellipse using relative lines. However, it is important to draw the lines correctly while completing this part. At this stage, even minor mistakes can cause major angular changes. For this purpose, Lewinnek et al. used Draughtsman's French curves to complete the invisible part of the cup in radiography [18]. However, this method is quite prone to user errors, whereas our method, the selected point is not significant, and there is no need to complete the ellipse. Widmer et al. defined for acetabular cup anteversion on plain X-rays and assessed to have a good inter- and intraobserver agreement. But in another study performed by Kalteis et al. evaluating the correlation between this method and CT-based measurement method, the authors considered that the result as unreliable [8, 11]. However, in our study, the values measured and calculated through plain radiographs are compared with the CT-based measurements (Table 2).

One of the popular methods for the assessment of acetabular anteversion is navigation-assisted method (NAM). The results obtained from studies performed using NAM were compared with the results of CT-based measurement methods that are almost similar [19–21]. However, imaging difficulties during determination of the symphysis pubis and the iliac spines in obese patients and especially operations performed in the lateral decubitus position may cause measurement errors. Additionally, obligatory and expensive equipment are needed for this method that not routinely available in every hospital. In our method, the measurements were taken through a single pelvic AP radiographs and can measure the anteversion angle of the acetabular cup with almost 100% accuracy without a need for additional equipment.

Table 2 Acetabular anteversion values of plain radiographic and CT-based measurements

Patients	Age	Sex	Radiography-based measurement (°)	CT-based measurement (°)
1	62	M	17.6	17.3
2	66	F	8.2	8.2
*3	39	M	13.6	12.7
4	62	M	14.7	13.1
5	42	M	25.6	26.9
6	38	F	18.7	18.1
7	45	F	9.58	8.5
8	68	F	13.9	13.2
9	52	F	10.5	10.2
10	68	M	6.3	6.9
11	78	M	10.7	10.5
12	58	F	12.9	12.2
13	62	M	15.6	15.9
14	64	M	14.7	15.0
15	53	F	13.8	14.1

*Patient radiographic acetabular measurement formulation sample in Fig. 4

Nevertheless, our study has several limitations. First, it is a retrospective study of non-consecutive patients requiring them to have postoperative CT of the pelvic which are not performed routinely for all. Second limitation of this study is not an assessment of interobserver agreement regarding the results of measurements performed using the present method. The strength of this study is to obtain the same results also clinically with our method which was proved almost 100% accuracy in an experimental model previously.

Current clinical study confirms that as previously done experimentally, our method can reliably and simply assess the acetabular cup anteversion on plain pelvic radiography without any equipment supply or additional radiation dose.

Conclusion

Assessment of the anteversion of the acetabular cup is of crucial to identify the etiology of possible complications which may develop after THA. Although many methods have been defined for this purpose until today, each of these methods has advantages and disadvantages. In particular, in CT-based methods, the patient is exposed to excessive radiation, whereas we think that our method defined by us in an experimental study previously is a preferable method due to features not requiring additional equipment, low radiation exposure, being simple, cost-effective, easily applicable and almost accurate.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Appendix: The mathematical explanation of the formula

$OA = OB = OE = r$

$OP_1 = OP_2 = r$

When the AP1B circle turns around AB as much as AP2B, the turning angle will be P1OP2 = α.

While the view of AP1B circle is AB line, the view (projection) of AP2BP3 circle is ACBD ellipse.

$OP_1P_2E \perp AB = OP_1 \perp AB,\ OP_2 \perp AB,\ OP_1 \perp OE$

$OP_{1//}P_2C$ and CP_2O angle is equal α angle.

$P_2C \perp OE$ (projection) $OC = b\ OP_2 = r$

OP_2C right triangle, $\sin \alpha = OC/OP_2 = b/r$

AB: distance between two tips of ellipse

AK: distance between P point and projection of P point on AB line.

P point: the optimum point which was not superimposed by the head and neck of the femoral component on the ellipse.

K point: projection of P point on AB line

Ellipse equation $x^2/a^2 + y^2/b^2 = 1$ here; $OA = a = r$, $OC = b$

PK and KA are measurable lengths, $PK = y$, $OK = x = OA–AK = r - 1$

$x^2/a^2 + y^2/b^2 = 1 \cdot (a^2b^2)$

$b^2x^2 + a^2y^2 = a^2b^2 \pm b^2x^2 \pm a^2b^2 = \pm a^2y^2 \cdot (-1)$

$\mathrm{b}^2\ (a^2 - \times^{2)} = a^2y^2$

$b^2 = a^2y^2/a^2–x^2\ \mathrm{b} = \mathrm{ay}/\sqrt{a^2 - x^2}\ a = r,$

$x = (r - l)$ to find b.

$x^2 = r^2 - 2\mathrm{rl} + l^2$

$\sin \alpha = b/a = y/\sqrt{r^2 - r^2 + 2\mathrm{rl} - 1^2} = y/\sqrt{2rl - l^2}$

$= \mathrm{PK}/\sqrt{2\mathrm{r} \cdot \mathrm{AK} - \mathrm{AK}^2} = \mathrm{PK}/\sqrt{\mathrm{AK}(2r - \mathrm{AK})}$

$2r - \mathrm{AK} = \mathrm{BK}\ \mathrm{Sin}\ \alpha = \mathrm{PK}/\sqrt{\mathrm{AK} \cdot \mathrm{BK}}$

$\boldsymbol{\alpha = \mathbf{arc\ sin\ PK}/\sqrt{\mathbf{AK \cdot BK}}}$

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