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Anatomic Anteversion of the Acetabular Component Correlates with Polyethylene Linear Wear in Total Hip Arthroplasty: The Three-Dimensional Numerical Analysis

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Abstract

Background: Although abduction of the acetabular component is considered to predict factors for polyethylene wear attributable to osteolysis, other radiographic factors have yet to be elucidated. The purpose of the present study was to evaluate whether anteversion or change in implantation angle of the acetabular component influences polyethylene linear wear by using standing and supine radiographs of the hip joint. Methods: Standing and supine plain anteroposterior radiographs of 62 hip joints in which cementless total hip arthroplasty was performed were examined for polyethylene linear wear rate (mm/year), pelvic inclination, and radiological inclination and anatomic anteversion of the acetabular component. Results: All correlation coefficients of measurements of polyethylene linear wear, pelvic inclination angle, anatomical anteversion angle and radiological inclination angle were calculated highly. And by the three-dimensional numerical analysis, anatomic anteversion of the acetabular component had at least some effect on the degree of polyethylene wear. Conclusion: This study suggests that increased anteversion of the acetabular component reduces polyethylene linear wear in metal-on-polyethylene total hiparthroplasty.

Keywords

Total Hiparthroplasty, Polyethylene Linear Wear, Standing Position, Settingangle of Acetabular Component

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1. Introduction

Implant loosening is a clinical and radiographic complication after metal-on-polyethylene total hip arthroplasty (THA); presence of a large number of worn polyethylene particles is considered a key factor in the onset of periprostheticosteolysis. Younger age, thinner polyethylene, and larger implant head size have been acknowledged for their adverse effects on polyethylene wear [1] [2]. The position and implantation angle of the acetabular component is also related to polyethylene wear, with increased abduction shown to be a particularly important postoperative factor, as evaluated on anteroposterior radio graphs of the hip joint. However, the effects of other factors of implantation angle on osteolysis have not been explored.

Several factors are yet to be investigated, such as anteversion of the acetabular component and change in implantation angle upon pelvic inclination. Lewinnek reported that adequate anteversion of the acetabular component should be 15˚ ± 10˚ from a standpoint of dislocation [3]. Widmer also recommended adequate anteversion of the acetabular component to prevent postoperative dislocation, but they did not evaluate polyethylene wear [4]. Another point to be investigated is the effect of pelvic inclination on the acetabular component. Pelvic inclination might change according to the degree of lumbar lordosis in the supine or standing position. We consider that implantation angle of the acetabular component, previously regarded as appropriate in the supine position, might display beyond-normal range of adequate angles based on unexpected change in pelvic inclination. Although weight bearing might induce creep deformity of polyethylene [5] [6], change in implantation angle of the acetabular component has not been evaluated. Therefore, the purpose of the present study was to evaluate whether anteversion or change in implantation angle of the acetabular component influences polyethylene linear wear by using standing and supine radiographs of the hip joint.

2. Materials and Methods

2.1. Patients and Methods

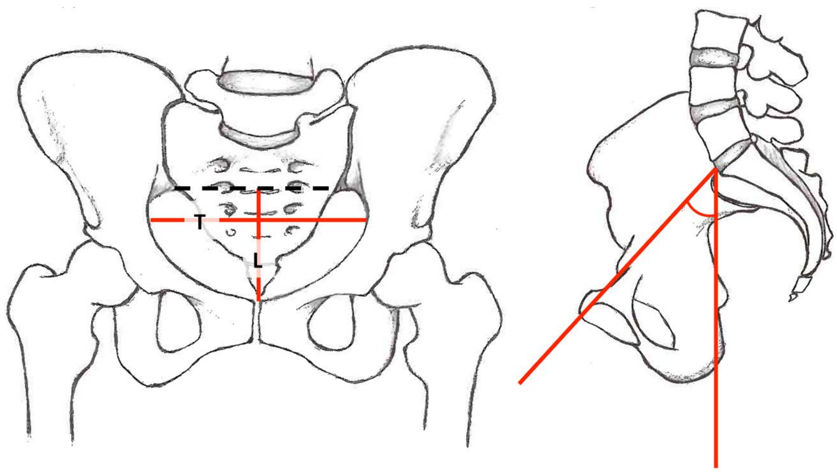
We retrospectively studied 56 patients (4 men and 52 women) who underwent 62 primary or revision THA between 1991 and 2006. The patients comprised 4 men and 58 women with a mean age of 52 years (range, 35 - 70 years) at the time of surgery. The mean weight was 53 kg (range, 35 - 72 kg), 6 patients underwent bilateral hip arthroplasty. The mean follow-up was 122 months (range, 42 - 228 months). The preoperative diagnosis was osteoartgritis in 10 hips, degenerative arthritis of developmental hip dysplasia in 44 hips, rheumatoid arthritis in 4 hips, aseptic loosening in 1 hip, failed bipolar hemiarthroplasty in 2 hips, tuberculous arthritis in 1 hip.

We examined standing and supine plain anteroposterior radiographs of the hip joint centered on the pubic symphysis, which were obtained at the final follow-up. This study was approved by the hospital science ethics committee of Sapporo Medical University (No 24 - 131) and informed consent was obtained from patients.

This study included that acetabular component used was either a 300 series Duraloc spiked titanium cementless cup or a 1200 series Duraloc titanium cementless cup (DePuy International, Leeds, United Kingdom) with screw fixation. Cobalt-chromium metal-on-conventional polyethylene Enduron (DePuy International) bearings were used throughout. The diameter of the metal head was 22.225 mm. An AML Plus cementless cylindrical stem or an AML Replica cementless stem (DePuy International) was implanted.

We exclude patients, 1) radiographs in which the line between the sacrum and the coccyx did not lie on the pubic symphysis, 2) patients who had undergone bilateral THA with a long interval between the 2 operations so as to avoid measurement bias involving the influence of change in right and left pelvic inclinations. However, 6 patients (12 hips) who underwent bilateral THA within a one-year interval were enrolled in this study. We examined standing and supine radiographs for polyethylene linear wear rate (mm/year), pelvic inclination, and radiological inclination and anatomical anteversion of the acetabular component, defined by Murray [7].

All measurements were performed using OP-1 radiographic measurement software (Fuji Film Co. Ltd. Tokyo. Japan). Polyethylene linear wear was expressed as the distance between the center of the acetabular component and the femoral head, according to the method of Sugano *et al.* [8]. Real wear values were compensated by calculating the difference between the measured diameter of the metal head on radiography and the actual diameter of the inserted femoral head. Pelvic inclination was measured according to the method of Doiguchi *et al.* [9]. Horizontal diameter (T) and vertical diameter (L) of the pelvic cavity on radiography were measured, and pelvic inclination was calculated using the following formulae: $-67 \times L/T + 55.7$ for male hips and $-69 \times L/T + 61.6$ for female hips (**Figure 1**). A larger pelvic inclination indicates posterior tilt of the pelvis. radiologicalinc lination of the acetabular component was defined as the angle between the line across the acetabular teardrops and



(a) (b)

Figure 1. The method of radiographic measurement. T: The parallel line to reference line between the bottom of sacroiliac joints and maximal diameter of the pelvic cavity on radiography. L: The vertical line to the reference line and through top of the pubic symphysis (a). Pelvic inclination: The angle of the line between the sacral promontory and top of the pubic symphysis and the X-ray film plane (b).

the line through the maximum diameter of the acetabular component. Anatomic anteversion of the acetabular component was measured according to the method of Visser *et al.* [10] (**Figure 2**).

2.2. Statistic Analysis

2.2.1. Comparison the Measurement Result Supine and Standing Position

Regression line Y = aX + b was found assigned a measurement stnding to variable Y, as supine to variable X.

2.2.2. Three-Dimensional Numerical Analysis

We calculated operative anteversion and operative inclination in the following expression based on the anatomical anteversion and radiological inclination in the standing position.

$$\mathrm{Tan}(\mathrm{OA}) = \mathrm{Tan}(\mathrm{AA}) \times \mathrm{Tan}(\mathrm{RI})$$

$$\mathrm{Sin}(\mathrm{OI}) = \frac{1}{\sqrt{\sin^{-2}(\mathrm{RI}) + \tan^{2}(\mathrm{AA})}}$$

A normal vector directs to the plane.

The three dimensional implantation angle was calculated back from this operative anteversion and operative inclination, and direction of acetabular component opening was showed by a plane parallel to the acetabular component opening with using three-dimensional normal vector. This normal vector ${}^{t}(x, y, z)$ was calculated by using the following rotation matrix when the Y axis represents anteroposteroir direction of pelvis, the X axis represents the bilateral direction and the Z axis represents the upper and lower direction (**Figure 3**, **Supplemental Table 1**).

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\mathrm{OA}) & -\sin(\mathrm{OA}) \\ 0 & \sin(\mathrm{OA}) & \cos(\mathrm{OA}) \end{pmatrix} \begin{pmatrix} \cos(\mathrm{OI}) & 0 & \sin(\mathrm{OI}) \\ 0 & 1 & 0 \\ -\sin(\mathrm{OI}) & 0 & \cos(\mathrm{OI}) \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

Normal vectors calculated were projected on the YZ plane and each the side Y and Z divided into three equal parts, consequently, this plane was divided into 9 areas A-I (**Figure 4(a)**, **Figure 4(b)**). We compared mean values of polyethylene linear wear in each area. This analysis was performed with using 3D graph soft ware (RINEARN Graph 3D, Kyoto, Japan).

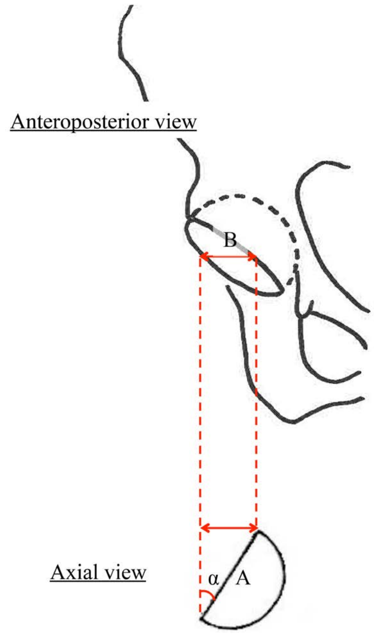


Figure 2. Calculation of anatomic anteversion of the implanted acetabular component using the fomula sin α = B/A. A: acetabular component diameter. B: the distance measured from anteroposterior radiographs. α = anatomic antevertion.

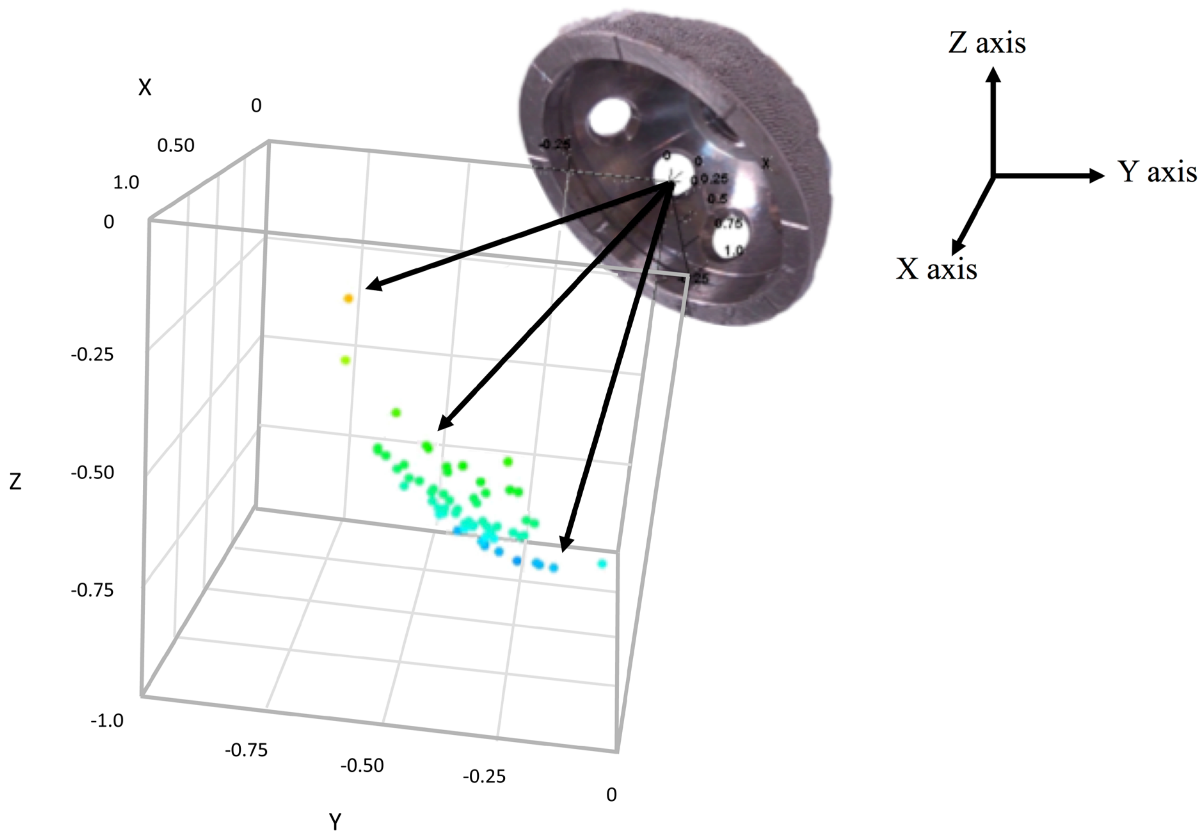
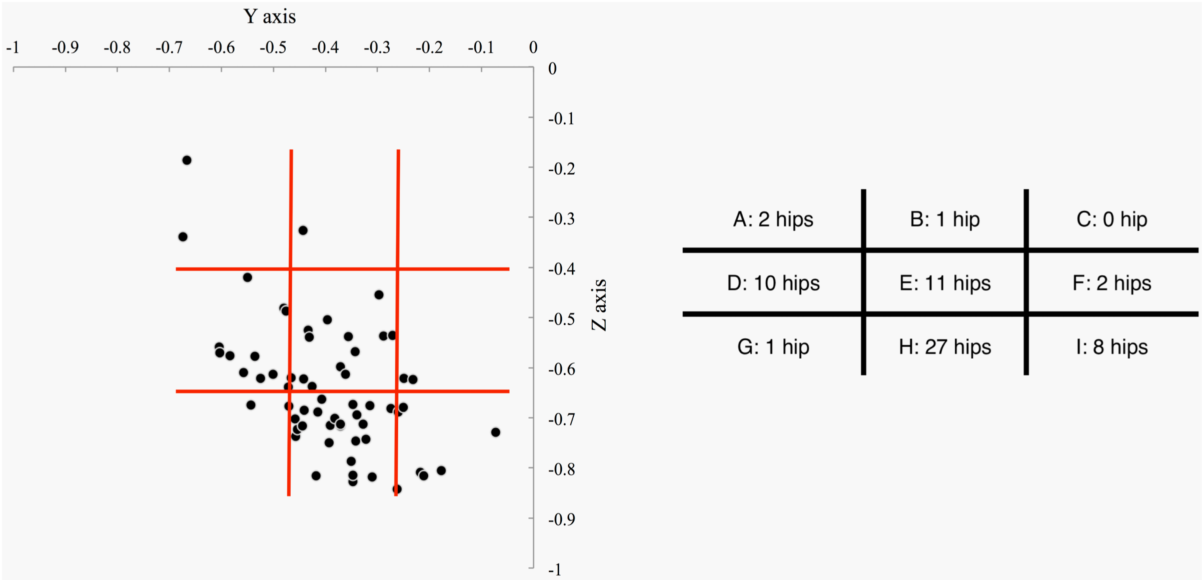


Figure 3. The relation between the acetabular component direction and the coordinate. When the left acetabular component is viewed from lateral side, a normal vector directs to the plane parallel to the acetabular compnent opening. All cases were replaced with left side in this figure. The acetabular component directs lateral when X is plus, similary, directs anterior when Y is minus, inferior when Z is minus. All normal vectors directied lateral and anterior, inferior.



(a) (b)

Figure 4. Grouping by directions of normal vectors (a). Each number of hips in 9 areas (b). Normal vectors in the group A, B, C are tend to face to the lateral direction, and normal vectors in the group A, D, G are tend to face to the anterior direction.

3. Results

3.1. Comparison the Measurement Result Supine and Standing Position

Table 1 showed regression lines of polyethylene linear wear, pelvic inclination angle, anatomical anteversion angle, radiological inclination angle. All correlation coefficients were calculated highly, 0.84 - 0.89.

3.2. Three-Dimensional Numerical Analysis

Figure 4(b) showed each number of hips in 9 areas. Mean value of polyethylene linear wear, pelvic inclination angle, anatomical anteversion angle, radiological inclination angle and operative anteversion angle were compared in each groups D, E, H, I which included three or more hip joints (**Table 2**).

Polyethylene linear wear of the group D was tend to be smaller and which of group I larger ($p = 0.052$).

4. Discussion

As factors related to increased polyethylene wear, patient characteristics as well as abduction of the acetabular component and femoral offset have been reported in several studies [11]-[15]. Some clinical reports have revealed that increased abduction of the acetabular component resulted in increased polyethylene linear wear [12] [16]. On the other hand, few reports suggest that the implantation angle of the acetabular component does not influence polyethylene wear [17] [18]. Despite many reports focusing on abduction, few have referred to anteversion of the acetabular component.

In terms of anteversion, appropriate implantation angle of the acetabular component recommended by Lewinnek [3] and Widmer [4] was aimed to prevent of postoperative dislocation of THA, however it was unclear whether polyethylene wear volume was decreased. We evaluated implantation angle of the acetabular component to define the effect for polyethylene wear.

We compared measurements of polyethylene linear wear, pelvic inclination, anatomical anteversion, radiological inclination in the supine and standing position. As a result, calculated regression lines showed all measurement supine were highly correlated with each measurement standing. Polyethylene linear wear was verified with higher precision in the standing position than supine position. However, we did not find increased polyethylene wear on the basis of change in posture.

The results of three-dimensional numerical analysis, we investigated that polyethylene linear wear of the group D was tend to be smaller and which of group I larger ($p = 0.052$). In the present study, when the absolute

Table 1. A regression coefficient and a correlation coefficient calculated with measurements in the supine and standing position.

	slope	Y intercept	correlation coefficient R
WY (mm)	0.95	0.019	0.86
PIA (˚)	1.28	0.46	0.84
AA (˚)	0.78	10.62	0.89
RI (˚)	1.06	0.43	0.86

WY: polyethylene linear wear, PIA: pelvic inclination angle; AA: anatomical anteversion angle, RI: radiological inclination angle.

Table 2. The mean value of polyethylene linear wear, pelvic inclination, anatomical anteversion, radiological inclination and operative anteversion of each groups.

	WY (mm/year)	PIA (˚)	AA (˚)	RI (˚)	OA (˚)
Total	0.118	30.2	33.1	43.6	32.1
Group D	0.095	32.8	43.0	46.5	44.6
Group E	0.128	32.0	28.2	52.0	34.3
Group H	0.116	26.5	34.9	37.6	28.1
Group I	0.141	26.8	19.3	39.3	15.8

value on a Y axis is larger, anteversion is larger. Similarly, when the absolute value on a Z axis is larger, abduction is larger. Therefore normal vectors in the group A, B, C are tend to face to the lateral direction, and normal vectors in the group A, D, G are tend to face to the anterior direction. This result suggested a relevance between polyethylene linear wear and anatomical anteversion, operative anteversion, because larger data of anatomical anteversion and operative anteversion was distributed into group D, also smaller data of anatomical anteversion and operative anteversion was distributed into group I. Although Wan *et al.* measured anteversion of the acetabular component clinically, they did not refer to polyethylene wear [13]. Patil *et al.* reported that increased abduction of the acetabular component led to elevated contact stress on the articulation surface, whereas increased anteversion led to decreased contact stress in a finite element model [16]. D'Lima *et al.* reported similar experimental results [19].

Our study revealed that increased anatomic anteversion of the acetabular component resulted in decreased polyethylene wear and confirmed the experimental results of the finite element analysis performed to determine contact stress on the weight-bearing rim.

Thus, this study proved that anatomic anteversion of the acetabular component had at least some effect on the degree of polyethylene wear.

This study was limited by a lack of information regarding position of the acetabular component, creep deformity, and deviation of the femoral head in the anteroposterior direction. Further studies will be necessary to investigate polyethylene wear.

5. Conclusions

We investigated whether anteversion of the acetabular component has an influence on polyethylene linear wear. Standing and supine plain anteroposterior radiographs of 62 hip joints in which total hip arthroplasty was performed were evaluated for polyethylene linear wear rate (mm/year), pelvic inclination, and abduction and anatomic anteversion of the acetabular component.

Pelvic inclination as well as operative anteversion and anatomic anteversion of the acetabular component increased in the standing position compared with that in the supine position.

By the three-dimensional numerical analysis, increased anteversion of the acetabular component reduces polyethylene linear wear in metal-on-polyethylene total hip arthroplasty.

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Supplemental Table 1. The mean value of polyethylene linear wear, pelvic inclination, anatomical anteversion, radiological inclination and operative anteversion of each groups.

	X	Y	Z
patient 1	0.466	−0.347	−0.814
patient 2	0.507	−0.351	−0.787
patient 3	0.667	−0.314	−0.675
patient 4	0.565	−0.177	−0.806
patient 5	0.748	−0.342	−0.569
patient 6	0.399	−0.419	−0.816
patient 7	0.702	−0.362	−0.614
patient 8	0.620	−0.328	−0.713
patient 9	0.608	−0.471	−0.639
patient 10	0.442	−0.347	−0.827
patient 11	0.617	−0.535	−0.577
patient 12	0.793	−0.289	−0.537
patient 13	0.566	−0.470	−0.677
patient 14	0.499	−0.544	−0.674
patient 15	0.558	−0.603	−0.570
patient 16	0.591	−0.371	−0.716
patient 17	0.677	−0.260	−0.689
patient 18	0.545	−0.458	−0.703
patient 19	0.800	−0.271	−0.536
patient 20	0.539	−0.444	−0.716
patient 21	0.722	−0.667	−0.186
patient 22	0.768	−0.396	−0.504
patient 23	0.732	−0.476	−0.487
patient 24	0.595	−0.371	−0.713
patient 25	0.581	−0.441	−0.684
patient 26	0.628	−0.407	−0.663
patient 27	0.645	−0.442	−0.623
patient 28	0.579	−0.391	−0.715
patient 29	0.764	−0.356	−0.538
patient 30	0.595	−0.414	−0.689
patient 31	0.657	−0.674	−0.339
patient 32	0.835	−0.444	−0.326
patient 33	0.484	−0.310	−0.818
patient 34	0.722	−0.550	−0.420
patient 35	0.678	−0.275	−0.682
patient 36	0.571	−0.342	−0.746
patient 37	0.710	−0.371	−0.598
patient 38	0.732	−0.434	−0.526

Continued

patient 39	0.601	-0.382	-0.702
patient 40	0.572	-0.584	-0.576
patient 41	0.568	-0.604	-0.559
patient 42	0.582	−0.525	−0.621
patient 43	0.611	−0.500	−0.614
patient 44	0.547	−0.218	−0.808
patient 45	0.733	−0.481	−0.481
patient 46	0.564	−0.557	−0.609
patient 47	0.520	−0.454	−0.723
patient 48	0.840	−0.298	−0.454
patient 49	0.746	−0.231	−0.624
patient 50	0.538	−0.211	−0.816
patient 51	0.632	−0.466	−0.620
patient 52	0.653	−0.347	−0.673
patient 53	0.690	−0.250	−0.679
patient 54	0.642	−0.426	−0.637
patient 55	0.498	−0.458	−0.737
patient 56	0.743	−0.249	−0.621
patient 57	0.634	−0.339	−0.695
patient 58	0.680	−0.072	−0.729
patient 59	0.470	−0.263	−0.843
patient 60	0.723	−0.432	−0.539
patient 61	0.532	−0.393	−0.750
patient 62	0.587	−0.322	−0.743
Mean	0.6260	−0.3956	−0.6414
SD	0.0999	0.1193	0.12934