■ HIP

The influence of acetabular inclination angle on the penetration of polyethylene and migration of the acetabular component

A PROSPECTIVE, RADIOSTEREOMETRIC STUDY ON CEMENTED ACETABULAR COMPONENTS

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In this prospective study we studied the effect of the inclination angle of the acetabular component on polyethylene wear and component migration in cemented acetabular sockets using radiostereometric analysis.

A total of 120 patients received either a cemented Reflection All-Poly ultra-high-molecular-weight polyethylene or a cemented Reflection All-Poly highly cross-linked polyethylene acetabular component, combined with either cobalt–chrome or Oxinium femoral heads. Femoral head penetration and migration of the acetabular component were assessed with repeated radiostereometric analysis for two years. The inclination angle was measured on a standard post-operative anteroposterior pelvic radiograph. Linear regression analysis was used to determine the relationship between the inclination angle and femoral head penetration and migration of the acetabular component.

We found no relationship between the inclination angle and penetration of the femoral head at two years' follow-up (p = 0.9). Similarly, our data failed to reveal any statistically significant correlation between inclination angle and migration of these cemented acetabular components (p = 0.07 to p = 0.9).

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The wear of articulating surfaces and its adverse effects remain an important cause of failure after total hip replacement (THR).[1] Several alternative bearing materials have been introduced in an attempt to address the problem of wear-induced osteolysis, but polyethylene remains the most frequently used bearing material for the acetabular component.

Polyethylene wear depends on several factors. Contact stress has an association with wear,[2-4] and *in vitro* studies have demonstrated that a high angle of inclination increases this stress.[5,6] However, previous literature on cemented THR has been inconclusive on the effect of the acetabular inclination angle *in vivo*.[7-11] Increased migration with higher inclination angles in a cementless metal-backed component has been reported.[12] On the other hand, a study on cemented acetabular components found an increased frequency of migration with low angles of inclination.[13] Another study on cemented and uncemented components showed that the inclination angle had no effect on the incidence of migration.[14]

The degree of migration during the first years after surgery has been shown to correlate with the long-term performance of some prostheses. Radiostereometric analysis (RSA) offers a highly precise method of measuring polyethylene penetration and migration.[15]

The aim of this prospective RSA study was to assess the effect of acetabular inclination on penetration of the femoral head and migration of a cemented acetabular component.

Patients and Methods

Patients were originally recruited for a study on wear of five different articulations.[16] During a period of 2.5 years from 2004 to 2007, 150 patients were randomised into five groups of 30. Four groups received the Spectron EF femoral stem (Smith & Nephew, Memphis, Tennessee), used with either cemented Reflection All-Poly ultra-high-molecular-weight polyethylene (UHMWPE) acetabular components (n = 60) or cemented Reflection All-Poly highly cross-linked polyethylene (XLPE) acetabular components (n = 60), combined with either cobalt–chrome or Oxinium 28 mm diameter modular femoral heads (all Smith & Nephew). The minimum follow-up was 24 months.

The manufacturer supplied the acetabular components with six spherical tantalum markers (diameter 1 mm) in the dome and periphery of the implants. The operations were either performed or supervised by eight consultant

Table I. The precision of radiostereometric analysis obtained by 50 double examinations at one year

	Acetabular component		
Type of movement	Migration (mm)	Rotation (°)	Femoral head penetration (mm)
x-axis	0.16	0.48	
y-axis	0.09	0.48	0.11
z-axis	0.21	0.35	

orthopaedic surgeons (including the authors GH, LIH, OF, KI) and one resident surgeon (TK). The surgical technique was standardised and the implants investigated were the standard implants used in our department at the time, and all the surgeons were familiar with their use. Patients were operated on with the direct lateral (Hardinge) approach in the lateral decubitus position. Spinal anaesthesia was used and the patients received prophylactic antibiotics (Cefotaxim 2 g × 4 intravenously on the day of surgery) and low-molecular-weight heparin (Dalteparin) for three weeks. Tantalum beads (diameter, 0.8 mm) were inserted into the peri-prosthetic acetabular and femoral bone and in the femoral bone cement. A standardised third-generation cementing technique was used. Patients were allowed weight-bearing as tolerated from day one. Details of the surgical procedure have been described previously.[16]

Each patient gave informed consent for participation in the study. Inclusion criteria were age between 59 and 80 years, and primary or secondary osteoarthritis. Exclusion criteria were a body mass index (BMI) > 35 kg/m^2, in alignment with the policy of one of the contributing institutions, uncompensated cardiopulmonary disease, malignant disease, dementia, rheumatoid arthritis or other serious systemic diseases.

Penetration of the femoral head and migration of the acetabular component were evaluated by RSA[16] using the UmRSA Digital measure, version 5.0, for computation (RSA Biomedical, Umeå, Sweden). The initial RSA examination was performed between nine and 15 days post-operatively and examinations were repeated at three, six, 12 and 24 months after surgery. All were done with the patients supine and non-weight-bearing and measurements were only done if three or more markers could be identified on repeated examinations. Femoral head penetration was calculated along the longitudinal (y) axis. Migration and rotation was calculated along and around the horizontal (x), longitudinal (y) and sagittal (z) axes on the basis of signed values. In order to ensure appropriate stability and distribution of the tantalum markers the upper limit for the mean error of body fitting was set at 0.35, and for the condition number at 150.[17] The precision of the RSA measurements was assessed from 50 double examinations by methods previously described[16] (Table I).

The angle of inclination of the acetabular component was measured on standard post-operative anteroposterior (AP) pelvic radiographs. It was measured as the angle between a line drawn along the opening of the acetabular

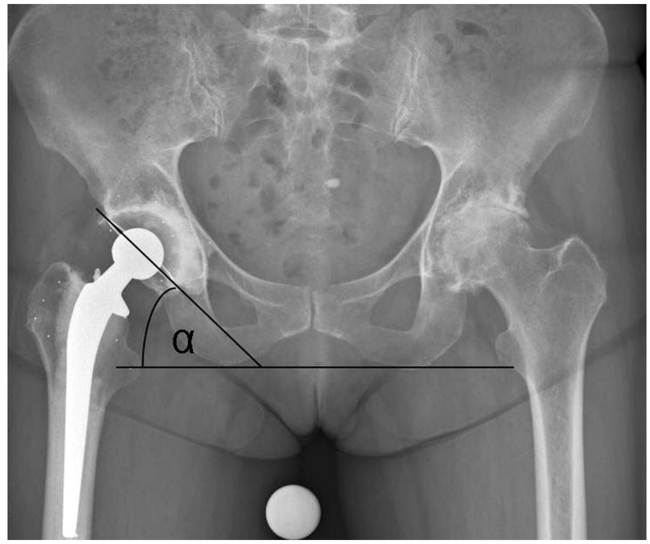

Fig. 1

Anteroposterior pelvic radiograph showing the method of determining the inclination angle of the acetabular component.

component and one joining the ischial tuberosities (Fig. 1).[18] The first author (TK) measured it on all radiographs. Another author (GH) measured the inclination angle on 20 radiographs in order to assess interobserver agreement. The intraclass correlation between the two observers was strong (correlation quotient r = 0.9). The mean difference between the observers in this measurement was 0.56°. In order to assess intra-observer agreement, 20 measurements were repeated by the author with an interval of at least two weeks between them. The intraclass correlation was again very strong (r = 0.99). The mean difference between these observations was 0.14°.

The study was approved by the Regional Ethical Committee and conducted according to the Helsinki Declaration.

Statistical analysis. Linear regression analysis was used to determine the relationship between the angle of inclination of the acetabular component and penetration of the femoral head and migration of the acetabular component. A sample size of 95 achieved 87% power to detect a difference in slope between the null hypothesis value 0 and the alternative hypothesis value 0.01 when the standard deviation (SD) of the inclination angle was 5.5; the SD of the penetration was 0.18 and the two-sided significance level was 0.05. Analysis was also performed with adjustment for gender and BMI. We further investi-

Table II. Patient demographics

	Spectron EF	
	Reflection All-Poly (n = 60)	**Reflection All-Poly XLPE* (n = 60)**
Male:Female	17:43	18:42
Mean age (years) (range)	69 (59 to 80)	70 (60 to 78)
Primary:Secondary osteoarthritis	52:8	49:11
Mean weight (kg) (range)	74 (46 to 98)	78 (50 to 106)
Mean height (cm) (range)	168 (152 to 187)	169 (154 to 183)
Mean BMI† (kg/m^2) (range)	26 (18 to 34)	27 (18 to 35)

* XLPE, cross-linked polyethylene
† BMI, body mass index

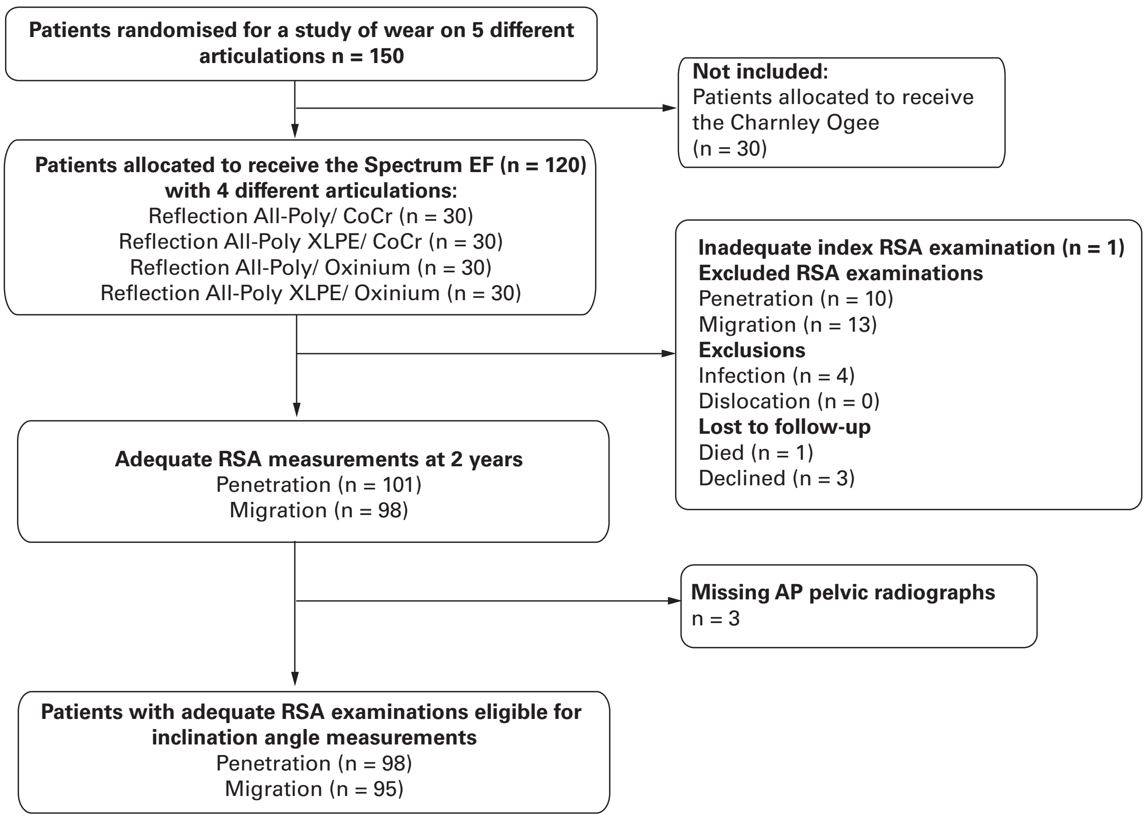

Fig. 2

Flowchart of patients in the study (RSA, radiostereometric analysis; AP, anteroposterior).

gated a possible interaction (effect modification) by the different types of acetabular component and femoral head. Assumptions for the use of linear regression were evaluated and regarded as satisfactory. We compared the mean femoral head penetration at two years between the two different acetabular components using Student's *t*-test for independent samples. Statistical analysis was performed using SPSS v17.0 (SPSS Inc., Chicago, Illinois). Differences were regarded as statistically significant if the p-value < 0.05.

Results

The patient demographics are summarised in Table II.

At two years we were able to analyse wear and inclination angle in 98 patients (82%). The measurements of migration and the inclination angle were possible in 95 cases (79%). The follow-up of patients is presented in Figure 2. The reasons for excluding RSA examinations at two years included missing examinations, an insufficient number of visible markers or a transient problem with the reading of the digital plates.

Table III. Correlation between the inclination angle of the acetabular component and proximal penetration, and with the various measurements of migration of the acetabular component (CI, confidence interval)

	Regression coefficient, r (95% CI)	p-value
Proximal penetration	0.000 (-0.006 to 0.007)	0.9
Translation		
x-axis	0.003 (-0.004 to 0.009)	0.4
y-axis	0.000 (-0.006 to 0.006)	0.9
z-axis	0.008 (0.00 to 0.017)	0.07
Rotation		
x-axis	-0.15 (-0.036 to 0.007)	0.2
y-axis	0.09 (-0.12 to 0.031)	0.4
x-axis	-0.11 (-0.03 to 0.008)	0.3

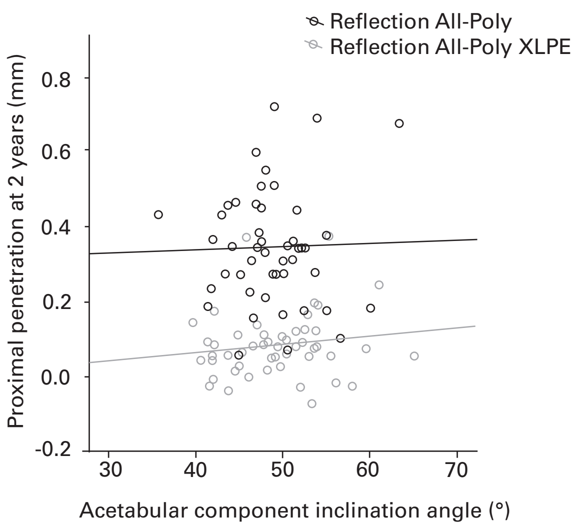

Fig. 3

Scattergraph showing the correlation between proximal penetration at two years and the inclination angle of the acetabular component, for conventional and highly cross-linked polyethylene (XLPE). The lines represent the mean regression line for Reflection All-Poly and Reflection All-Poly XLPE components, respectively.

The mean inclination of the acetabular component was 48.7° (35.0° to 65.0°). The overall mean penetration of the femoral head at two years was 0.21 mm (SD 0.18). The Reflection All-Poly and the Reflection All-Poly XLPE acetabular components had a mean penetration of 0.35 mm (SD 0.15) and 0.08 mm (SD 0.09), respectively ($p < 0.001$).

The inclination angle of the acetabular component did not influence penetration ($r = 0.00$, $p = 0.9$) (Table III and Fig. 3). Migration of the acetabular component was not influenced by the inclination angle (Table III). Similar findings were made for the two different acetabular components ($p = 0.8$) and femoral heads ($p = 0.8$). Adjustment for gender and BMI did not influence the results.

Discussion

We found no relationship between the inclination angle of the acetabular component and penetration of the femoral head or migration of the acetabular component. This study used a high-precision tool (RSA) to evaluate the influence of inclination of the acetabular component on femoral head penetration and acetabular component migration. Another study also used RSA and found no influence of the inclination angle on wear.[11] Other previous studies that have reported on this topic have used less precise methods.[8,9,12,19]

Our study confirms the results of some studies in which no association between the inclination angle of the acetabular component and femoral head penetration was found,[8,10] but is in contrast to other reports, which showed more wear with higher inclination angles.[7,9] We cannot resolve the controversy, but our results imply that *in vivo* results do not necessarily agree with *in vitro* findings, as experimental tests have shown an increasing rate of penetration as a function of the inclination angle of the acetabular component.[5] We found no effect of the inclination angle on migration of the acetabular component, which contrasts with the results with cementless metal-backed components from another study.[12] Our findings suggest that the stability of cemented components is less sensitive to the angle of inclination than that of cementless metal-backed components. This might be explained by the different distribution of stresses on the surrounding bone and differences in the polyethylene thickness.[20]

Other studies[21,22] have shown less wear with cemented acetabular components than with cementless metal-backed components. The effect of inclination on femoral head penetration of cementless metal-backed polyethylene components cannot be deduced from our study. Most studies on the influence of the angle of inclination on femoral head penetration have been done on cementless metal-backed acetabular components.[6,12,19,23-29] In the majority of these studies higher rates of wear were found with higher inclination angles. Our results suggest that cemented all-polyethylene acetabular components have a higher tolerance to high inclination angles with respect to femoral head penetration.

Highly cross-linked polyethylenes (HXLPE) are associated with a considerable reduction of wear compared with conventional polyethylene[16] as shown in our study. However, edge-wearing of the more brittle HXLPE could possibly lead to mechanical failure and fracture of the HXLPE implant.[30] So far we have not seen this.

There are some limitations to this study. We only measured femoral head penetration at two years. The non-elastic deformation of the polyethylene (creep) explains part of the penetration at two years,[31,32] although it probably becomes negligible after the first year. Longer follow-up is needed to evaluate the steady-state penetration rate, which represents the actual removal of substance. There might be a relationship between steady-state penetration rate and inclination, and our results may therefore be considered preliminary.

There has been some debate as to whether the RSA examinations should be undertaken with the patient supine or standing (weight-bearing) due to a possible underestimation of penetration in supine radiographs. An RSA study that compared supine and weight-bearing radiographs in 111 patients found that there were no clinically relevant differences in the measurement of penetration (0.02 mm) between the two groups, and concluded that supine radiographs were adequate.[33] We therefore chose to undertake the RSA examination with the patient supine and non-weight-bearing.

In the present study the patients were operated at two geographically separate units, but all the RSA radiographs were taken in one unit. For practical reasons we undertook the index RSA examination between nine and 15 days post-operatively. At this point some patients will be well-mobilised and able to put some weight on the operated hip, whereas others remain immobile. This can affect the penetration of the femoral head due to a higher degree of bedding in (creep) in the well-mobilised patients before the first examination is done. Hence the starting point for wear measurements can differ from one patient to another according to the degree of mobilisation and weight-bearing. This problem would be minimised if the index RSA examination was undertaken within the first one or two days post-operatively. Furthermore, our RSA measurements of penetration are given as proximal migration of the femoral head into the polyethylene acetabular component. RSA is a three-dimensional (3D) method, and the mean total point motion represents the magnitude and direction of maximal penetration. We chose, however, to present the proximal penetration instead of the mean total point motion because most of the penetration occurs in the frontal plane and because other studies to which we compare our results report the two-dimensional penetration. The 3D wear rates from the present study have been previously published.[16]

The effect of anteversion of the acetabular component was not accounted for in this study. Among other methods,[34] Einzel-Bild-Roentgen-Analysis (EBRA)[35] provides a valid method of measuring anteversion of the acetabular component from plain radiographs. However, it requires software that is not available at our institution. A study using finite-element analysis reported on reduced peak contact stresses with an increased anteversion angle (0° to 30° of anteversion)[6] and implied less wear with more anteversion of the component. The literature on this issue is sparse and the effect of anteversion on the rate of wear has still to be resolved. The proposed effect of anteversion on wear could possibly bias our results since anteversion was not accounted for in our study. However, there is no reason to believe that there was an association between anteversion and inclination of the acetabular component. The possible effect of anteversion would probably be evenly distributed over the range of inclination angles of the components in our study.

Furthermore, we did not analyse the effect of femoral offset. A previous study reported increased polyethylene wear with under-restoration of femoral offset.[36] However, in our study only patients suitable to receive the Spectron EF stem size 2-5 with a standard offset were included,[16] and the groups were randomised. Factors such as BMI and gender that could influence offset were equally distributed between the groups. Thus a systematic difference in femoral offset between the groups is unlikely in this study.

One earlier study reported that completely contained acetabular components had a lower incidence of complete cement–bone radiolucency and wear, and that vertically oriented components had a lower incidence of continuous radiolucency.[37] The authors of that study therefore suggested that it might be better to accept vertical orientation and obtain full bony coverage of the component, rather than to have a more horizontal orientation with partial containment of cemented acetabular components.

On the other hand, higher inclination angles have been linked to dislocation.[38] However, horizontal positions, with small acetabular components and anteversion of the femoral component may result in limited movement of the hip.[39] Thus, several concerns other than polyethylene wear and migration must be considered in conjunction with the inclination angle of cemented all-polyethylene acetabular components.

An optimal angle of inclination for the acetabular component is notably of greater importance in prostheses with metal-on-metal articulations, such as hip resurfacing prostheses.[40,41]

In this RSA study of cemented all-polyethylene acetabular components with two years of follow-up, we found no correlation between the angle of inclination of the acetabular component and either penetration of the femoral head or migration of the acetabular component.

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