The effects of polyethylene cup thickness on wear of total hip prostheses

H. OONISHI*, H. IWAKI, N. KIN, S. KUSHITANI, N. MURATA, S. WAKITANI, K. IMOTO
Department of Orthopaedic Surgery, Artificial Joint Section and Biomaterial Research Laboratory, Osaka-Minami National Hospital, 677-2, Kido-Cho, Kawachinagano-Shi, Osaka, 586, Japan

The wear rate of the ultrahigh molecular weight polyethylene cups in combination with a 28 mm alumina femoral head was measured on the radiographs of patients without any complications, and on cups retrieved due to slight loosening of the prosthesis or due to late infection between bone and components. The wear rate on the radiographs did not include the initial wear, but the wear rate on the retrieved cups did include the initial wear. The wear rate on the retrieved cups was higher, by 50%, than that measured on the radiographs. In both cases, the thicker the polyethylene cups, the lower was the wear rate measured. The average wear rate of the 7 and 8 mm thick cups was about twice that of cups 10 and 11 mm thick. From these results, we conclude that polyethylene cups more than 11 mm thick should be used.

1. Introduction

The potential for polyethylene-debris-activated osteolysis has now been well documented worldwide.

The causes of wear in polyethylene cups in total hip prostheses, include polyethylene cup thickness, femoral head size, prosthesis design, material combinations, fixation condition of the components, as well as patient-related factors such as activity, sex, age, occupation, body weight, and so on.

The objective of our study was to evaluate the relationship between wear and polyethylene cup thickness in the total hip prostheses, using measurement of the wear on patient radiographs and on retrieved cups.

We reported, previously, the effect of the polyethylene cup thicknesses ranging from 7–9 mm on wear measured on radiographs [1]. In this study the polyethylene cup thicknesses of 7–11 mm were compared on radiographs and with retrieved cups.

2. Experimental procedure

2.1. Measurement of cup wear on the radiographs

2.1.1. Materials

The clinical wear rates of different thicknesses of standard cemented polyethylene cups, mated to 28 mm alumina femoral ball (Bioceram, Kyocera Inc.), whose clinical case was begun in 1977, were analysed.

Radiographs of Bioceram (Kyocera total hip prostheses; 28 mm alumina ceramic ball; cemented ultra-high molecular weight polyethylene (UHMW PE) cup (Kyocera Co. Japan) were all measured by the same investigator (Mr Li, medical student, Osaka City University, Medical School) using the same technique. Excluded from this study were cases which had less than 6 years follow up, or lacked standing, weight-bearing radiographs, cases with metal-backed acetabular cups, cases with loosening of either stem or cup, and cases where the radiographic detail was insufficient were also excluded from this study. 111 joints in 102 cases were considered suitable for inclusion in this study. 14 joints in 13 cases were in males and 97 joints in 89 cases were in females. All cases were diagnosed as having secondary osteoarthritis due to dysplasic acetabulum. 93 cases were unilateral and 9 cases were bilateral.

2.1.2. Methods

Anterior–posterior (A–P) roentgenograms were taken of both hips in a standing position (weight-bearing). The decrease in thickness of the UHMW PE cup (due to migration of the femoral ball) was used as an estimate of wear. It was assumed that most of the initial settling in of the total hip replacement (THR) components, plus UHMW PE creep, had occurred in the first year and that from the second year onwards, ball migration basically represented wear.

Observation periods were from 1 month after surgery and the last follow-up after surgery. For measurement on the radiographs, backlit-type digitizers with

* Corresponding author.

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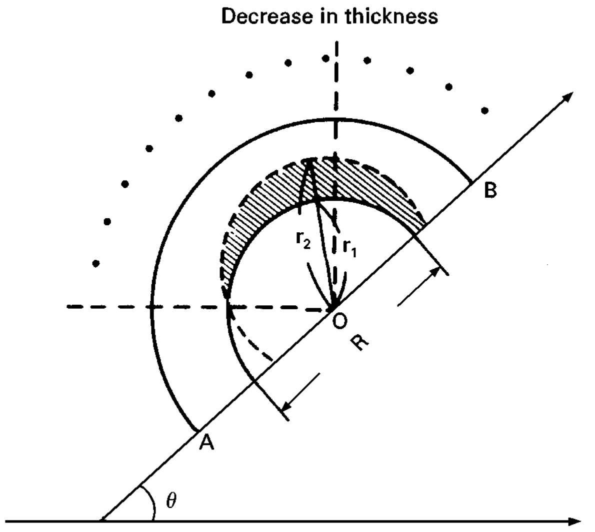


$$W = \left(r_2 \times \frac{R_1}{R_2} - r_1 \right) \times \frac{28}{R_1} \text{ where } R_1/R_2,\ 28/R_1 \text{ are magnification ratios}$$

Figure 1 Schematic illustration showing the main features of the wear-measurement technique on clinical radiographs. O, Centre of the wire; *R*, diameter of the head; A, B, outer edge of the socket; θ, socket angle.

20 μm resolution, × 5 magnification viewing loupes, and especially designed angle scales (0.2 mm graduation). Data collation and analysis were via computer. When multiple, replicate prestudy wear assessments were made 8–20 times, the standard deviation of the measurements was less than ± 50 μm. However, this level of resolution was impossible in the clinical study, due to uncertainties of various clinical and radiographic phenomena.

With our method, the centre of the hip joint (Fig. 1, point O) was first identified (where O was the midpoint of the major axis of the elliptical image of the X-ray wire marker). Then, the superior–medial migration of the ball centre was measured with respect to time. At 10° intervals from plane A–B, the distance *r* from point O to the ball–cup interface was routinely measured. Wear was taken as the difference between the r_1 value at 1 month follow-up, and the r_2 value at a subsequent follow-up time. This measurement, *W*, was then corrected for the X-ray magnification. The direction of the maximum *W* value indicated the orientation of the wear track relative to plane A–B. The lateral opening of each cup was assessed with reference to the plane linking the ischial tuberosities on the bilateral standing X-rays. We found that the tear-drop reference was frequently unreliable, because of the THR installation.

In previous studies of the measurement of wear of polyethylene cups on radiographs, a tendency for the thicker cups to have lower wear was found. Similar results were reported in hip simulator tests by Saikko [2]. Therefore, in this study, the relationship between cup thickness and wear was investigated. The thickness of the cups and the case number are shown in Table I.

Volumetric wear rate was calculated from the linear wear rate using a system developed by Cabo [3].

TABLE I Polyethylene cup wear measurement on the radiographs of 28 mm alumina head total hip prostheses (Bioceram)

Cup thickness (mm)	Outer diameter of the cup (mm)	Number of cases
7	42	22
8	44	21
9	46	21
10	48	20
11	50	22

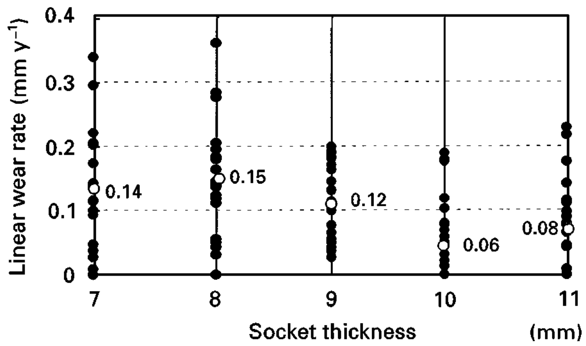


Figure 2 Linear wear rate of polyethylene cups on the radiographs. Relationships between linear wear rate and cup thickness.

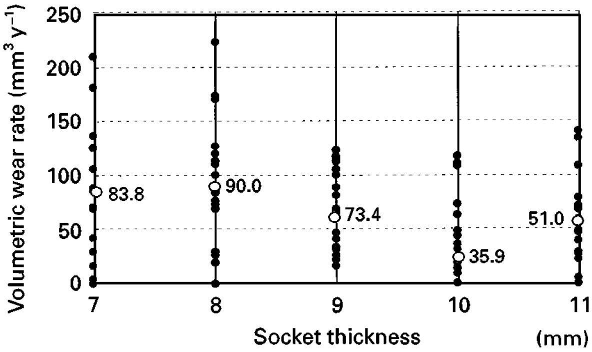


Figure 3 Volumetric wear rate of polyethylene cups on the radiographs.

2.1.3. Results

The linear wear rate and the volumetric wear rate of each case and an average wear rate are shown in Figs 2 and 3. Figs 4 and 5 show the average wear rates which were calculated by computer. The wear rates of individual cases are widely scattered. The average wear rate of cups 7 and 8 mm thick, was about twice of that of cups 10 and 11 mm thick. On the whole, the thicker the cup, the lower was the wear rate measured.

2.2. Measurement of cup wear on retrieved cups

2.2.1. Materials

The change in cup thickness, including wear and creep deformity, of Bioceram prostheses, consisting of a combination of a 28 mm alumina femoral head with an UHMW PE cup, was measured on retrieved prostheses.

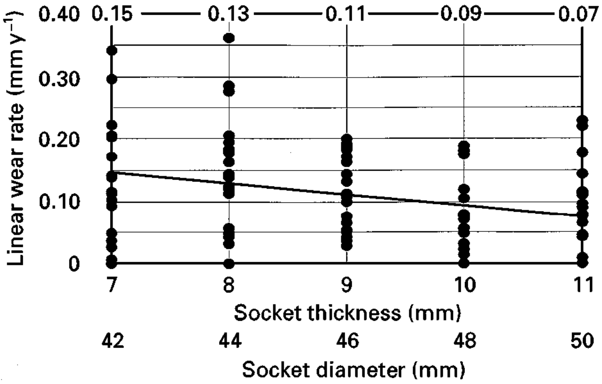


Figure 4 Linear wear rate of polyethylene cups on the radiographs. The average wear rates were calculated from the straight line by computer.

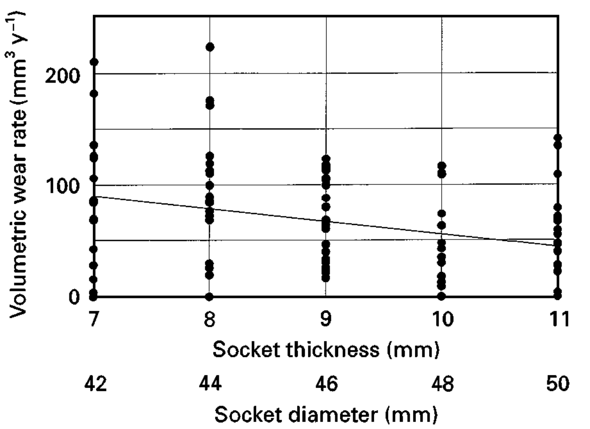


Figure 5 Volumetric wear rate of polyethylene cups on the radiographs. The average wear rates were calculated from the straight line by computer.

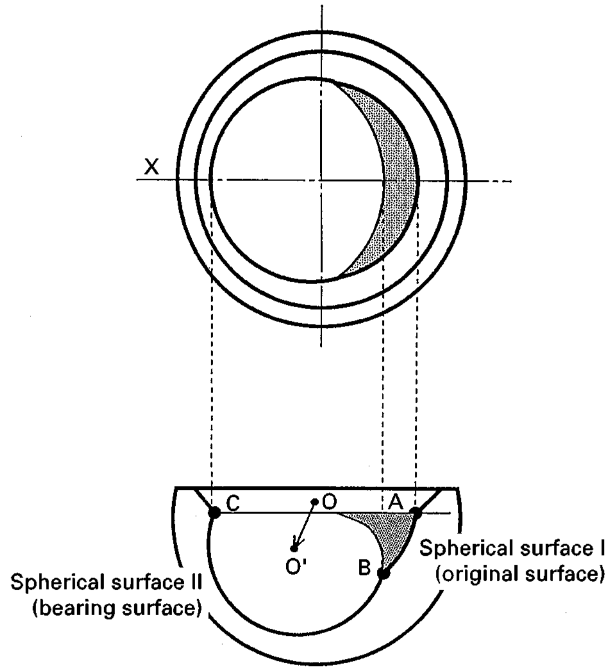
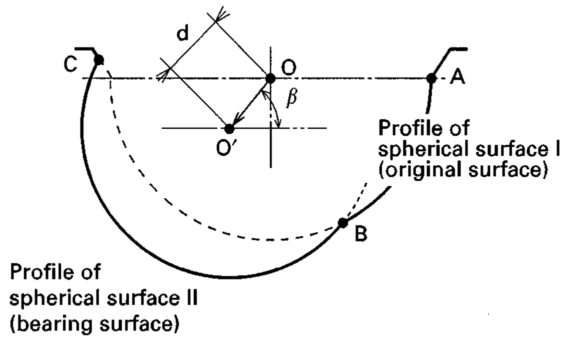


Figure 6 Schematic illustration showing the main features of the wear-measurement technique on retrieved cups.



Equation of the volumetric wear:

$$V = \pi r^2 d - r^2\left[\pi d \cos^{-1}\left(\frac{d\tan\beta}{r}\right) - \tan^2\beta\left(\frac{r}{\tan^2\beta} - d^2\right)^{1/2}\right] - \frac{r^3\tan\beta}{3}\left[\left(1 - \frac{d^2\tan^3\beta}{r}\right)^{3/2} + 2\right]$$

Figure 7 Diagram of the wear profile corresponding to Fig. 6 and the equation for volumetric wear. O, Centre of spherical surface I; O′, centre of spherical surface II; *d*, distance O–O′ (linear wear); β, wear angle (measured from the plane of the mouth of the socket).

The prostheses were retrieved because of slight loosening of the stem, cup or both, or due to late infection between bone and components. Prostheses damaged by means other than wear by the femoral head were excluded from this study.

Cup thicknesses and the number of cases of retrieved prostheses, in which the inner surface could be measured, are shown in Fig. 8, below.

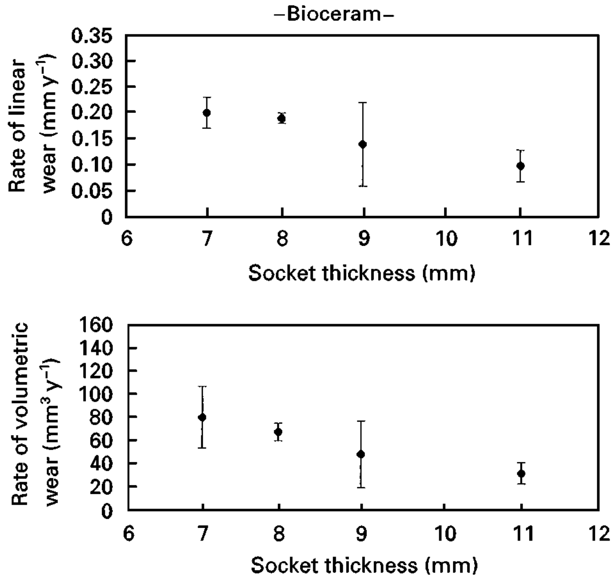
2.2.2. Methods

Generally, the inner surface of the retrieved cup has two spherical surfaces (Fig. 6). Consequently, the distance between the centre O of spherical surface I and the centre O′ of spherical surface II was regarded to be the length of the femoral head movement during use, that is, wear including creep deformity of the polyethylene cup. This is termed linear wear. The distance between O and O′ was defined as the length of the femoral head movement, *d*. The direction of the movement was defined as the angle from the datum plane, β. The volumetric change (volumetric wear), *V*, occurring following contact with the ball head was calculated using *d*, β and radius γ, using a system developed by Cabo [3] (Fig. 7). In this case, the initial wear, which was much higher than the steady state wear, could not be excluded; thus, the wear rates recorded included the initial wear in the final steady state wear rate calculated. The retrieved cups in which the inner surface could be measured are shown in Fig. 8.

2.2.3. Results

Relationships between linear and volumetric wear rates and cup thickness are shown in Fig. 8.

The wear rates of the cups, 7 mm and 8 mm thick, were almost the same. The wear rates of the 7 and 8 mm thick cups was twice of that of the 11 mm thick cups. The thicker the cup, the lower was the wear rate measured.



Socket thickness (mm)	Rate of linear wear ($mm\,y^{-1}$)	Rate of volumetric wear ($mm^3\,y^{-1}$)	N
7	0.20 ± 0.03	79.8 ± 26.7	4
8	0.19 ± 0.01	67.2 ± 7.7	3
9	0.14 ± 0.08	47.9 ± 28.7	5
11	0.10 ± 0.03	31.7 ± 9.0	2

Figure 8 Linear and volumetric wear rate of polyethylene cups on the retrieved prostheses. Relationships between wear rates and cup thickness are shown in the table.

In this case, where the number of cases was higher, the scatter of the wear rates was wider.

3. Discussion

In this study the number of the cases was insufficient to draw a final conclusion. Scatter of the wear rate was very wide, especially in the case of radiographs, where the thickness of the cup was thinner.

In the case of radiographs, the wear rate of 8 mm cups was somewhat higher than that of 7 mm cups. In addition, the wear rate of 11 mm cups was higher than that of 10 mm cups. If many more cups had been available, the average wear rate line on the graphs might have become a slowly sloping curve or approached a straight line. If one case of a 44 mm cup and two cases of the 50 mm cups, which showed extreme wear rates, are excluded from the population, the average line on the graph approaches the slowly sloping or the straight line.

In the case of retrieved cups, the average line on the graphs shows a slowly sloping curve. In every case, as there were many other contributing factors (for example, activity, sex, age, occupation, body weight, the settling condition of the component and so on), the scatter of the data can be expected to be wide. However, in both studies on wear measurement, using both radiographs and retrieved prostheses, similar tendencies were obtained in the relationship between cup thickness and wear rate of the cups.

As a result, on the whole, we conclude that the thicker the polyethylene cups, the lower is the wear rate.

The average wear rate of the cups 7 and 8 mm thick, was about twice of that of cups 10 and 11 mm thick. The same tendency was reported in hip simulator tests, using a water lubricant, by Saikko [2].

The wear rate on the retrieved cups was higher by 50% than that measured on the radiographs. In the retrieved cases, as the prostheses were removed from the patients suffering from loosening of the components or late infections, higher wear rate might be expected. Moreover, in the case on the radiograph study, the initial wear, which was much higher than the steady state wear, was excluded. However, in the case of the retrieved cups, because initial wear was included, wear rates would be expected to be higher than with the case using radiographs.

From these results, we recommend that cups with a thickness of more than 11 mm be used.

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