

In Vivo Measurement of Polyethylene Wear in Cementless Total Hip Arthroplasty

Měření polyetylenového otěru u necementované endoprotézy kyčle *in vivo*

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ABSTRACT

PURPOSE OF THE STUDY

Recent years have seen an increase in cementless total hip endoprosthesis (THP) implantations. Easy radiological measurement of wear in cups coated with X-ray dense material, such as metal or ceramics, is not applicable. An alternative technique has thus been developed to radiographically measure wear on cementless spherical implants.

MATERIAL AND METHODS

The authors present a method in which the center of the head of the prosthesis relative to the center of the cup was defined by graphical extrapolation. Changes between the two centers on subsequent images allowed the estimation of wear. Data from 148 randomly selected patients with cemented THP were compared with that from 50 with cementless THP (head diameter always 32 mm).

RESULTS

Within the cemented group metal heads showed significant more wear than ceramic heads (1.244 mm vs. 0.504 mm). However, calculating the wear rate per year showed no significant difference. No significant differences were observed comparing cemented and cementless group. A comparison of the own results with those of the literature revealed analogous values.

DISCUSSION

Data of the cementless group were comparable with those obtained from conventional wear measurements on cemented hip cups thus validating the technique.

CONCLUSION

The method offers the potential to define wear of metal cups with a polyethylene inlay or with X-ray dense components such as ceramic or metal inlays.

Key words: wear measurement; hip endoprosthesis; cementless cup; ceramic-on-polyethylene; metal-on-polyethylene; ceramic-on-ceramic.

INTRODUCTION

Limiting parameters for the survival of a total hip endoprosthesis include particles of debris caused by wear (10, 19, 25) between the femoral head (metal or ceramic) and cup or cup insert (polyethylene). The relationship between linear prosthetic wear, penetration and loosening after total hip replacement is well known (11, 18, 20). As a result of implant loosening caused by wear debris, the measurement of polyethylene wear is an ongoing objective of orthopedic research (3, 13, 21).

In the past, polyethylene wear in cemented cups has been quantified for metal-polyethylene as well as for ceramic-polyethylene combinations (1, 2, 29, 30). In order to achieve this, models were generated which determined the penetration of the head of the prosthesis

within the polyethylene inlay (liner) using radiographs taken over a number of years (1, 2, 30). The key to these measurements was the presence of a semicircular radiographic marker which had been attached to the outer surface of all polyethylene cups. As the polyethylene inlay of a cementless cup is fixed in a metal groove, it is not possible to use markers such as those used in the cemented system. That is why, until now, measurements of polyethylene wear in cementless metal-backed cups have been made mainly on retrieved cups or using simulator tests (6, 9, 12, 27).

The ability to measure wear *in vivo* becomes more relevant with the advent of new materials (4) such as cross-linked thermally-stabilized polyethylenes (14) and metal-on-metal and ceramic-on-ceramic bearings (3, 23, 26). These are all intended to have the advantage of very

low wear (4). Due to the increased use of these materials in combination with cementless metal-backed acetabular components, this study aims to adapt radiological wear measurements to these new requirements.

In vivo, wear measurements rely on the comparison of recent radiographs with those taken soon after an operation. Wear is measured as the change in distance between the femoral head and the outline border of the cement-polyethylene interface along this vector. Another way to measure wear is to calculate the center of the femoral head and the acetabular component and to gauge changes in the distance between the two (15). A further technique uses only a single radiograph (8). Computerized techniques have also been developed to improve edge-detection (24) and generate a three-dimensional technique (16). Radiologic calculation of wear is not affected from joint loading (17).

This study presents a new method based on those described by Afifi and Jacob (1981), Ziller et al. (1985) and Babisch et al. (1993). In this approach, the center of the head relative to the center of the cup is defined by graphical extrapolation; changes in the distance between the two centers allow the estimation of wear. In order to validate these measurements they are compared with conventional data from cemented, polyethylene hip cups.

MATERIAL AND METHODS

Data from 148 randomly selected patients, fitted with a cemented total hip endoprosthesis between 1989 and 1990, were analyzed as a reference group. All of these patients had primary osteoarthritis of the hip and received a cemented polyethylene cup. Within this group, the X-rays of 62 patients (33 female, 29 male) were used; for exclusion criteria, see below. Forty-four of these had received a Müller-Charnley prosthesis (formerly Protek[®], now Zimmer Germany[®]) with a metal head; 18 had a ceramic compound prosthesis (formerly Keramed[®], now Mathys AG[®], Germany) with a ceramic head. Polyethylene cups had outer diameters of between 44 and 58 mm. The diameter of the head in all cases was 32 mm.

Data from 50 randomly selected patients who received a cementless total hip endoprosthesis (AML/Duraloc, DePuy[®]) between 1991 and 1992 formed the basis of the experimental group. All of these patients had primary osteoarthritis of the hip. Within this group the X-rays of 27 patients (16 female, two with dual replacements, and nine male) could be evaluated; for exclusion criteria, see below. The following types of Duraloc cups were implanted: 10 of series 500 and 17 of series 1200; these ranged in size from 44 to 68 mm. Nineteen of these cups were fixed additionally with screws. Only ceramic heads with a 32 mm diameter were used.

Exclusion criteria for patient X-rays were as follows:

1. Images not in anterior/posterior orientation.
2. Images taken immediately after surgery.
3. Images taken in the first three months after surgery.
4. Images with poor contrast.

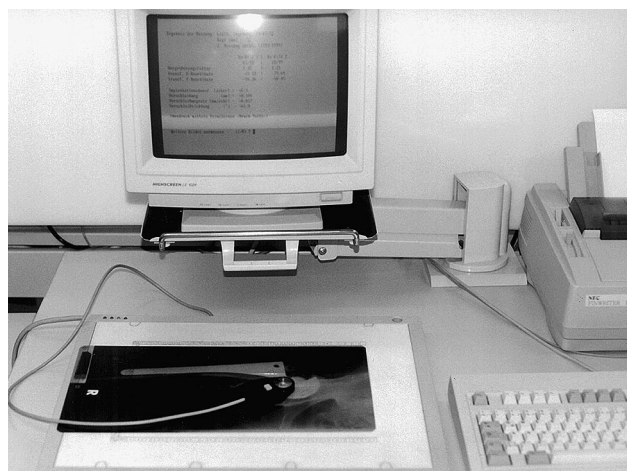


Fig. 1. Digitizer tablet used to define the measuring points

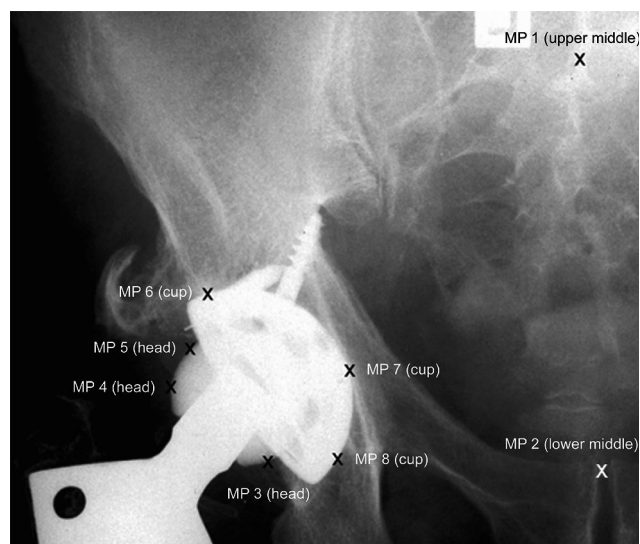


Fig. 2. X-ray of a total hip arthroplasty with marked measuring points

5. No comparable progress radiographs.
6. Non-identical positioning of the implant.
7. Less than two years between the first and last image.

The method used here centers around the evaluation of standardized X-ray images over an extended time course (1, 2, 30). A computerized digitizer tablet (Fig. 1) was used to define the coordinates. In the case of the cemented cups these coordinates were used to define the center of the head and the position of the marker wire. The extent of wear was determined by comparing the position of the head in relation to the marker wire in two subsequent images. This included a correction of scale.

In contrast, for cementless cups, the distance from the estimated center of the circular head to the outer contour of the cup was compared on two subsequent images. Calculations were based on measurements of the right hip and left hips were mirrored. Three measurement points (MPs) with a distance of more than 5 mm between them were marked on the X-ray image of both the head (MP3-MP5) and the cup (MP6-MP8) (Fig. 2).

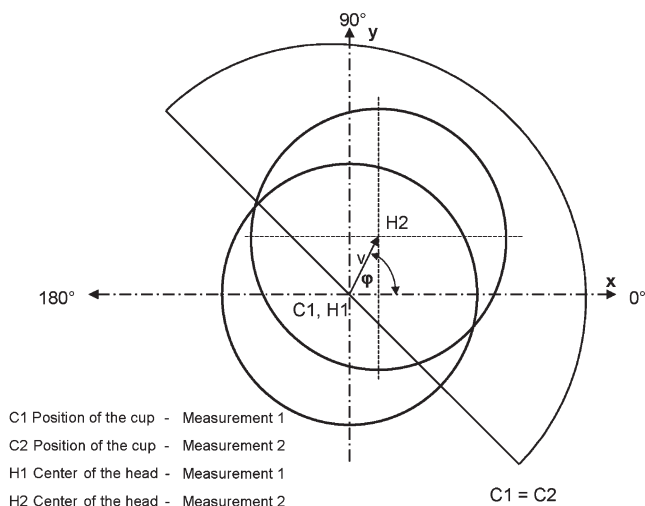


Fig. 3. Graphical explanation of the principle of the measurements

To define the vertical body axis, a line was drawn between the *Processus spinosus* from L5 (MP1) and the symphysis (MP2). MP1 also marked the origin of a rectangular coordinate system. Using the x- and y-coordinates of the points of measurements around the cup and the head, the radius (R) of both circles was calculated. Using the circle-equation, the parameters c and d were defined (equation 1).

In order to reduce statistical errors, the procedure was performed three times, without ever repeating the position of the MPs around the cup. The coordinates of the centers and the diameters of the circles were calculated. The standard deviation (SD) and the mean value (MV) of these measurements were the foundations for the calculation of the coefficient of variation (V) for each X-ray, given as a percentage (equation 2). For $V \leq 0.15\%$ the measurement was accepted, otherwise the measurements were repeated.

After the correction of scale, the center of the cup from both the first and second image, were brought into congruency. Wear (v) and wear direction (φ) (equations 3 and 4) were calculated from the relative penetration of the position of the center of the head compared to the center of the cup (Fig. 3).

$$(x-c)^2 + (y-d)^2 - R^2 = 0 \quad (1)$$

$$V = \frac{SD}{MV} * 100\% \quad (2)$$

$$v = \sqrt{(xK2 - xK1)^2 + (yK2 - yK1)^2} \quad (3)$$

$$\varphi = 90^\circ - \arctan \frac{(xK2 - xK1)}{(yK2 - yK1)} \quad (4)$$

The cemented cups were subdivided into the following groups:

- Cups combined with metal head,
- Cups combined with ceramic head.
- Cups fixed with screws,
- Cups without screw fixation.

The following parameters were then calculated and compared:

- time (period between the first and the last date of the measured radiographs)
- wear “v” (mm)
- wear rate (mm/year)
- wear direction “φ” (angle to the horizontal line)
- cup inclination (°)
- body mass index (BMI).

The polyethylene used in the prostheses investigated here was ultra high molecular weight polyethylene. Cups made from cross-linked polyethylene were not investigated. In this text the term „ceramic“ is used for alumina ceramics, unless noted otherwise.

All data were analyzed statistically using SPSS software (SPSS Inc., Chicago, IL). Student’s t-test was used to compare data. P-values of less than 0.05 were considered to be significant.

RESULTS

Results for the cemented cups are shown in table 1 and those for cementless cups in table 2. The Kolmogorov Smirnow test showed that all parameters were normally distributed except wear and wear direction (for both groups).

Within the cemented group, there was a significant difference between the wear (v) of the metal versus the wear of the ceramic heads (1.244 mm vs. 0.504 mm) and the time taken for the two materials to wear (6.4 years vs. 4.2 years respectively). However, calculating the wear rate per year showed no significant differences between metal and ceramic heads.

Comparing the cemented group with the cementless group showed significant differences in the time the materials took to wear (4.4 years vs. 5.8 years respectively) and the inclination (50.4° vs. 45.1°). No other significant differences were observed. In both groups there was no correlation between inclination and wear or wear direction. Similarly, no connection was observed between body mass index and wear or wear direction. Whether the cementless cups were fixed with screws or not also had no bearing on wear measurements.

DISCUSSION

The mean rate of wear in both cemented and cementless prostheses was the same independent of the type of prosthesis; these results (from either group) are in agreement with data from the literature (1, 2, 26, 30). Although the rate of wear was higher for prostheses with metal heads than those with ceramic heads, it was not statistically significant. Zichner and Willert (1992) have reported a lower rate of wear in ceramic heads than in metal heads. It is likely that the number of patients in this study was insufficient for this result to be significant.

Table 1. Measured parameters and calculated values for the wear measurement of cemented cups

Whole group (n=62)				
Parameter	Mean	Max.	Min.	Standard deviation
Age (years)	63.6	79.2	37.1	9.0
Time (years)	5.8	13.0	0.6	3.3
Total linear wear (mm)	1.029	3.60	0.15	0.802
Wear rate (mm/year)	0.219	1.200	0.030	0.211
Wear direction (degrees)	81.6	170.0	0.0	41.0
Body height (cm)	165	183	144	8.75
Body weight (kg)	72.4	102.0	36.0	11.9
Body mass index (BMI)	26.5	36.4	15.8	3.8
Inclination (degrees)	45.1	66	12	9.5
Group metal heads (n=44)				
Time (years)	6.4	13.0	1.3	3.4
Total linear wear (mm)	1.244	3.560	0.150	0.846
Wear rate (mm/year)	0.237	1.200	0.030	0.231
Wear direction (degrees)	87.2	170.0	8.0	38.7
Group ceramic heads (n=18)				
Time (years)	4.2	8.8	0.6	2.6
Total linear wear (mm)	0.504	1.240	0.140	0.294
Wear rate (mm/year)	0.173	0.490	0.050	0.145
Wear direction (degrees)	67.7	143.0	1.0	44.4

Table 2. Values for the wear measurement of cementless cups

Ceramic heads whole group (n=27)				
Parameter	Mean	Max.	Min.	Standard deviation
Age (years)	67.4	78.0	38.7	8.4
Time (years)	4.4	7.1	1.9	1.7
Total linear wear (mm)	0.629	1.687	0.131	0.368
Wear rate (mm/year)	0.153	0.390	0.047	0.090
Wear direction (degrees)	78.6	171.6	12.2	42.1
Body height (cm)	164	178	152	7.75
Body weight (kg)	72.9	93.0	58.0	11.4
Body mass index (BMI)	26.7	33.9	21.2	3.7
Inclination (degrees)	50.4	66	33	8.4

Table 3. Published wear rates versus those from this study, both considering prostheses of various material combinations

Head/cup	Wear rate (mm/year)				
	Afifi 1981	Ziller 1985	Babisch 1993	Zichner, Willert 1992	This study
	cemented				cementless
Metal/UHMWPE	0.16	0.15	0.23	0.2	0.24
Alumina/UHMWPE	-	0.12	0.14	0.1	0.17

Although there was a significantly higher inclination in cementless implants versus cemented, greater wear was not observed overall. Yang and Shih (1998) reported that a cup inclination angle beyond the range of 35–55 degrees was required to contribute to a higher rate of wear in cementless hip endoprostheses. These values were not achieved by the majority of measured prostheses in all groups in this study. Furthermore, the use of screws did not influence wear within the cementless group. This confirms the results of Dorr et al. (1998), who reported that wear in hemispheric titanium porous coated acetabular components without screw fixation was no different to that in sockets with fixation. Last but

not least, BMI did not influence wear in either group. These findings support the results of Schmalzried et al. (2000) who reported that the extent of wear is not determined by BMI, but by use of the joint.

In the case of cementless cups, results generated with the novel technique described here were comparable with those obtained using an established method of measurement for cemented cups. Similarly, a comparison of the results presented here with those from the literature revealed analogous values (table 3). As the measurements of cementless cups using the described method revealed similar values to the cemented cups, it was concluded that the reported method is suitable to evaluate wear in metal-backed spherical implants such as cementless cups.

However, in order for the results to be consistent, stringent exclusion criteria were applied. Only anterior/posterior-directional images taken with high contrast, for maximal contour imaging, were used. Images with poor contrast could lead to errors of measurement that obscure changes caused by wear. In addition, the central axis of the lower spine (definition of vertical body axis) was required on the radiograph.

Since wear depends on the loaded surface, only implants with similar head sizes should be compared. Clarke et al. (1996) reported that head size can affect wear and confirmed data from Charnley et al. (1969), describing an increase in wear with increasing head diameters ranging from 22 to 32 mm. The present study only used 32-mm heads, thus eliminating size problems.

The procedure described here is based on known principles of radiological wear measurement for cemented prostheses. Consequently, the presented data correlates well with published data of wear in polyethylene cups. This study offers the potential to define wear of metal cups with a polyethylene inlay or with X-ray dense components such as ceramic or metal inlays.

Abbreviations

- BMI body mass index
- C1 position of the cup – measurement 1
- C2 position of the cup – measurement 2
- c, d parameters of the circle equation
- H1 center of the head – measurement 1
- H2 center of the head – measurement 2
- MV mean value
- MP measuring point
- n number of values
- R calculated radius
- SD standard deviation
- v wear (in mm)
- V coefficient of variation
- φ wear direction (angle to horizontal)
- x, y x and y coordinates
- xk1, xk2, yk1, yk2 x and y coordinates of circle 1 and 2

ZÁVĚR

Nová alternativní metoda pro měření ořezu u necementované endoprotézy kyčle in vivo je založena na grafické extrapolaci centra hlavičky a centra jamky a jejich

vzájemného vztahu v průběhu času. Změna v poloze těchto dvou center v průběhu sledování na rtg snímku umožní stanovit míru otěru. Tato metoda umožní definovat otěr kombinace kovové hlavice s polyetylenovou jamkou stejně jako u radiologicky densních komponent jako je keramika nebo kovová jamka. Validace metody proběhla porovnáním výsledků nového způsobu měření s výsledky měření konvenčním způsobem u cementovaných endoprotéz s použitím kovové hlavice a polyetylenové jamky.

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