MEASUREMENT OF POLYETHYLENE WEAR IN CEMENTLESS TOTAL HIP ARTHROPLASTY

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We made a clinical study of polyethylene wear in 240 hips of 187 patients having primary total hip arthroplasties from 1989 to 1990, using uncemented Osteonics components, with a head size of 26 mm. We excluded cups with anteversion of over 20° and measured linear wear by a new method using a digitiser and special software of our design. Follow-up was from two to five years (mean 4.3).

The mean age at operation was 50.3 years, with more men than women (1.4:1). The mean linear wear per year was 0.15 mm; this did not increase with the longevity of the prosthesis ($p = 0.54$). In 59 hips showing evidence of osteolysis, the mean linear wear rate was significantly higher at 0.23 mm/year ($p < 0.001$). The mean linear wear rate also correlated significantly with age at the time of operation ($p = 0.008$), but we found no significant correlations with body-weight, gender, aetiology of the disease, thickness of polyethylene, or cup position.

Our new method of measurement is time-saving and reproducible. The results confirm the greater rate of linear wear of polyethylene in patients showing osteolysis and in those who are younger.

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Polyethylene wear is a growing concern¹⁻⁴ since the biological response to particulate debris is thought to be an important contributor to osteolysis and to affect the longevity of total hip arthroplasty.⁵⁻⁷ Retrieval studies^{8,9} and measurement of wear at the bearing surface by imaging have been widely used to quantitate this in large series.¹⁰⁻¹² The measuring techniques have been criticised,¹³⁻¹⁵ and a new method has been developed by Devane et al⁴ for the three-dimensional assessment of polyethylene wear from plain radiographs. Using a digitising tablet and custom-written software, it has an accuracy of ± 0.15 mm, and was validated by use of a precise acrylic phantom with a milled metal-backed acetabular component. We have used a computer-based technique designed to measure two-dimensional linear wear in the frontal plane from clinical anteroposterior (AP) radiographs, and evaluated the method for its reproducibility.

The diameter of the femoral head is known to be a factor in polyethylene wear.^{4,11,12,16} A 32 mm head produces greater volumetric wear than a 28 mm or 22 mm head, but the latter gives greater head penetration and a higher incidence of hip dislocation. The middle range is considered to have the best wear characteristics, and in our study, the femoral head had a diameter of 26 mm.

Metal-backed acetabular components are widely used^{17,18} and provide the necessary metal surface for biological fixation. Metal backing has been shown by finite-element analysis to stiffen the polyethylene and produce a more even distribution of stress,¹⁹ but after early success, later results failed to confirm this biomechanical prediction; higher wear rates have been reported for uncemented arthroplasties.^{2,20,21}

We have examined changes at the bearing surface in uncemented total hip arthroplasties during a two- to five-year follow-up period in a single surgeon's practice (C-HS), to estimate the wear of the polyethylene liner and to identify its related risk factors.

PATIENTS AND METHODS

We studied 240 total hip arthroplasties in 187 patients from 1989 to 1990, all performed by the senior author (C-HS). The mean follow-up period was 4.3 years (2 to 5). All the prostheses were of the Osteonics pattern (Allendale, New

Fig. 1a

Fig. 1b

Fig. 1c

Radiographs of a 24-year-old woman before total hip arthroplasty (a), three months after (b) and at four years showing marked polyethylene wear and two areas of osteolysis (arrows) (c).

Fig. 2a

Fig. 2b

From the standard AP radiograph, points are selected at the front and back of the opening of the cup, the head, and the margin of the cup using a digitiser (a). The computer system and software convert the data points after correction for magnification into two circles and one ellipse, before calculating the required measurements (b).

Jersey), with porous-coated titanium shells, modular polyethylene liners, and a cobalt-chromium alloy femoral head and stem (Omnifit). The femoral components had a plasma-sprayed porous coating in their proximal third and a modular femoral head of 26 mm in diameter. The mean age at operation was 50.3 years (19 to 82) and the male to female ratio was 1.4:1. Sockets showing more than 20° of anteversion were excluded, because in our previous study calculation of the polyethylene wear has been shown to be

influenced by anteversion.²²

Standard AP and lateral radiographs were taken on non-portable equipment using the same technique for all patients.²³ Poor control of the relationship between the AP and lateral radiographs and the poor quality of some lateral views led us to use only the consecutive annual AP films to measure head displacement (Fig. 1). The data points which we digitised were from the acetabular cup-bone interface, the surface contour of the head and the opening of the cup

Table I. Reproducibility of the digitising technique

Observation	Number of observations	Standard deviation	95% confidence limits
Linear wear (mm)			
Intraobserver	10	0.0047	± 0.0034
Interobserver	10	0.0080	± 0.0057
Version (degrees)			
Intraobserver	10	0.37	± 0.26
Interobserver	10	0.52	± 0.37
Inclination (degrees)			
Intraobserver	10	0.17	± 0.12
Interobserver	10	0.38	± 0.27

(AccuGrid, Model, Light Box 012581; Numonics Corporation, Montgomeryville, Pennsylvania), using our own formula and software program to measure linear wear.²² This uses custom-written CAD software with 64 bit-precision, corrects for magnification, and converts the data points into two circles and one ellipse correlatively. One circle represents the outer surface of the acetabular component and the other the prosthetic femoral head. The ellipse represents the opening of the cup (Fig. 2). The computer then calculates the linear wear, the angle of version of the cup, its inclination and the direction of socket wear.

The annual wear rate for each hip was the difference in wear calculated from two consecutive radiographs, divided by the time interval. The metal-backed acetabulum partly obscured full visualisation of the femoral head, but this did not prevent accurate determination of its centre because of the relative transparency of the titanium shell on plain radiographs, regardless of version and inclination. For greater accuracy, all data used in the operating processes of the software program were of a double-precision type which allocated eight bytes of memory.

We defined osteolysis as any discrete area of endosteal scalloping greater than 3 mm in any direction which was adjacent to the femoral or acetabular component on serial radiographs, but not on the immediate postoperative film.

Reproducibility and statistics. The same AP radiograph was digitised by ten observers independently to assess interobserver variance. Intraobserver variance was assessed by having one observer digitising the same radiograph ten

Table II. Comparison of osteolysis *versus* mean polyethylene linear wear (mm/year) ($p < 0.001$, *t*-test)

	Number	Mean polyethylene wear rate
Osteolysis	59	0.23 ± 0.15
No osteolysis	181	0.13 ± 0.088

times. Statistical analysis determined the intraobserver and interobserver variances of this new method and validated its reproducibility. The relationship between polyethylene wear rate and various clinical and radiological factors was evaluated either by linear regression analysis or by the *t*-test.

RESULTS

The intraobserver and interobserver variability for the digitising technique used to evaluate linear wear was insignificant (Table I).

The mean linear wear rate in the whole series was 0.154 mm per year, and did not increase significantly with time ($p = 0.54$). It correlated significantly in hips showing osteolysis (Table II), in which the rate was 0.23 mm/per year. It was also significantly correlated with the age of the patient at the time of operation ($p = 0.008$, Fig. 3). We found no significant correlations with body-weight, gender, aetiology of the disease, thickness of the polyethylene or cup position.

DISCUSSION

Excessive polyethylene wear and particle production are thought to be important contributors to osteolysis and aseptic loosening.^{9,24,25} The earliest wear measurements of acetabular components were performed by Charnley and Cupic²⁶ on early Teflon sockets, and osteolysis around cemented femoral components was first reported by Charnley and Cupic²⁶ and Harris et al.²⁷ Osteolysis also occurs around stable uncemented prostheses.^{28,29}

The main cause of osteolysis in cementless total hip arthroplasty is believed to be secondary to wear of the

Fig. 3

Regression analysis of patient age related to linear wear of polyethylene.

acetabular liner²⁸⁻³⁰ and the longevity of the implant may well be limited by bone destruction initiated by minute wear particles. Reduction of the number of these is therefore important, and some recent investigations have focused on better understanding of the performance of an acetabular liner, in terms of wear rate and related risk factors.^{1,2,31,32} Series of postmortem retrievals would be an optimal method of study, but are impractical on a large scale. Radiological measurement of linear wear has limitations, but serial radiographs from one institution, of a single surgeon's practice for long periods of use of similar techniques, are probably the next best available source of long-term data.

Charnley and Cupic²⁶ reported a nine- to ten-year follow-up study on low-friction arthroplasty in 1973, measuring the position of a wire marker in the acetabular component on single radiographs, to a claimed accuracy of 0.5 mm. Clarke and Amstutz³³ evaluated the techniques of Charnley, and concluded that the use of successive radiographs was more accurate. Griffith et al³⁴ compared radiological with direct measurement and found an average error of 0.2 mm. Livermore et al¹² reported a method using a transparent template with concentric circles, compass and calliper. They compared direct and radiological measurement, and reported an average error of 0.075 mm. Kabo et al⁹ confirmed that measurement of linear wear from AP radiographs gave reasonable estimates and Bankston et al³⁵ further evaluated the Livermore method, reporting an error of less than 0.2 mm, not statistically different from direct measurement. They concluded that although wear in the sagittal plane did occur, it did not affect the accuracy of measurement in their study. Devane et al⁴ were the first to report a three-dimensional technique using a digitiser and custom-written software, validating it by measuring a precise acrylic phantom and a milled metal-backed acetabular component. Their method has an accuracy of ± 0.15 mm with good reproducibility. They found a two-dimensional displacement of the femoral head in the AP radiographs of 0.15 mm/year which was comparable with that obtained by previous studies. Their rate for three-dimensional femoral head displacement, however, measured in both AP and lateral radiographs by the same technique was significantly higher at 0.264 mm per year. This suggests that two-dimensional measurements underestimate the rate of wear, because they cannot measure displacement away from the plane of an AP radiograph. The accuracy of such measurements warrants more work on the relationship between radiological and true wear.

Instead of using a transparent overlay, compass, and calliper, we employed a computer-based system and a digitiser. The custom-written software can correct for radiological magnification, estimate the two-dimensional linear wear, the angle of version of the cup and its inclination and the direction of socket wear. In our study, we excluded sockets with more than 20° anteversion²² as did Schuller.³⁶ The major advantages of our method are the short learning

curve, the speed and accuracy of 0.0125 mm, which is much better than 0.05 mm using a manual calliper.^{1,2} Our interobserver and intraobserver variances were statistically insignificant.

There are several reports of polyethylene wear in cemented acetabular components, but few for uncemented metal-backed cups. Using the technique of Livermore et al,¹² Hernandez et al² first reported a mean linear wear rate for uncemented acetabular cups of 0.22 mm per year. Results obtained by identical methods for cemented acetabular components showed a significant increase in polyethylene wear in the uncemented metal-backed cups, with even worse results when the femoral component was also uncemented. They discuss three factors: the uncemented metal-backed cups, machined polyethylene, and titanium femoral components. In our series, all components were uncemented but the femoral components were chrome-cobalt alloy. The mean linear wear rate was 0.154 mm per year, slightly greater than the reported rate for cemented cups.

Factors affecting polyethylene wear in total hip arthroplasty include the size and material of the femoral head, the physical properties of polyethylene itself,³ the conformity of the articulation,³¹ metal backing,¹ cementing³⁷ and various host factors. Kim and Kim²⁸ reported a statistically significant relationship between patient age and excessive wear, but found no link with diagnosis, body-weight, or gender. Griffith et al³⁴ showed correlations of age and gender with increased wear, and Rimnac et al⁸ also found increased wear in younger patients. Nashed et al³⁷ found a positive correlation in younger and male patients, but not for body-weight. Devane et al⁴ reported a tendency for the younger patients to show more femoral-head displacement and a greater volume of polyethylene wear debris.

We have shown that linear wear rate correlated significantly with age and with osteolysis, but not with body-weight, gender, diagnosis, thickness of polyethylene liner, and the position of cups. Our results confirm the clinical impression that polyethylene wear correlates with the incidence of osteolysis and with younger age.

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