

Measurement of Polyethylene Wear in Total Hip Arthroplasty - Accuracy Versus Ease of Use -

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The aim of this study was to compare the accuracy of four different methods for measuring wear using an apparatus that simulates known amounts of three dimensional wear. Wear was measured using the manual methods reported by Charnley, Livermore, Dorr and Wan and the computerized method reported by Devane. Only the method reported by Devane measured the three-dimensional (superior and anterior) wear with a reasonable accuracy, with a mean measurement error of 0.21 mm. With superior wear alone, Charnley's method underestimated the extent of wear by 16.6%, with a mean error of 0.35 mm; Livermore's method estimated wear to within 9.5%, with a mean error of 0.16 mm; Devane's method estimated wear to within 9.5%, with a mean error of 0.15 mm; and Dorr's method underestimated wear by 25.4%, with a mean error of 0.56 mm. Dorr's method was modified as a result of the experimental tests. The clinical application of the new method showed comparable data to that using the Devane method. In conclusion, this new method can be used to estimate the average wear in groups of patients accurately.

Key Words: Hip, arthroplasty, wear, measurement

INTRODUCTION

The wear characteristics of polyethylene acetabular components is the most important factor affecting implant loosening and the development of osteolysis after a total hip arthroplasty.¹⁻³ Particulate debris are generated primarily from the

articular bearing surfaces *in vivo*. Linear wear is the amount of wear measured on an anteroposterior radiograph using the displacement of the femoral ball relative to the center of the acetabular cup.⁴ Many measurement techniques have been described by various authors, and used to quantify the extent of wear in a large clinical series.⁵⁻⁷ However, there is some controversy as to whether or not the extent of wear of the acetabular cup can be accurately assessed from the clinical radiographs.⁸⁻¹¹ Some studies have shown good a correlation between the radiographic measurements and direct measurements made on the retrieved cups.^{4,7} Devane, et al.^{12,13} described a computer-assisted technique for the three dimensional analysis of polyethylene wear in porous-coated anatomic acetabular components. They reported an accuracy of ± 0.15 millimeters on the basis of an analysis of a phantom model with predetermined amounts of wear.

The aim of this study was to use an apparatus that simulated varying amounts of wear to both evaluate and compare the accuracy of the four methods of measuring acetabular cup wear from radiographs, using an apparatus that simulated the varying amounts of wear.

MATERIALS AND METHODS

Design of wear simulator

The apparatus consisted of a 54 mm titanium alloy cup with a pure titanium fiber mesh porous

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coating, and a 28 mm cobalt chromium alloy femoral ball, both from a Harris Galante I system (Zimmer, Warsaw, Indiana). Both components were mounted on a Plexiglas frame. The base plate corresponded to the plane of the A-P radiographs. The cup could be oriented in any desired angle of the anterior (anteversion) and lateral opening (abduction) of the cup face. The superior wear was simulated by advancing the micrometer by any desired value, and displacing the attached femoral ball into the vacant acetabular cup. A constant amount of anterior wear (1.45 mm) was produced by the anterior elevation of the ball and any additional superior wear was added to this.

The ball was positioned concentrically within the cup for the zero wear radiographs. The samples were divided into 16 groups with a combination of the angle of abduction (40 and 50), the angle of anteversion (5 and 20), the distance from beam center to femoral head (3 and 5 inches) and direction of wear (only superior, superior and anterior). Sixty-four random values of superior wear between 0.5 and 4 mm were obtained from a database and each group contained four cases. The wear simulator was simply placed on top of a cassette and the beam center was marked using a coin. For each combination of abduction angles, the anteversion angles and distances from the beam center to femoral head, an initial X-ray (standard anteroposterior view) was taken at the zero point of wear. The femoral head was then advanced a distance into the cup selected randomly and another X-ray was taken. The source to cassette distance was 40 inches.

Manual measurements of wear

On the basis of the technique reported by Livermore et al.,⁴ a transparent overlay with a set of concentric circles was used to determine the center of the head, and a perpendicular line was drawn through the center. A compass was not used to locate the minimum distance between this center and outer surface of the cup, because the wear direction was constantly vertical. The distance between the femoral head and the cup margin (b) was measured using a digital caliper, which was accurate to 0.01 mm. A line was drawn connecting the lateral opening of the cup, and the

distances (a and c) between the head and cup were measured.¹⁴ The center of the femoral head was marked with a No 11 blade. Finally the angle (Alpha) between the perpendicular line through the femoral center and the line connecting the opening of the cup was measured (Fig. 1). A correction factor was calculated for the radiographic magnification. The femoral head was measured and compared with its actual size (correction factor=actual head diameter/measured head diameter).

Charnley duoradiographic method= $(c-b)/2-(c^0-b^0)/2$
 Livermore, et al. method= $b-b^0$
 Dorr and Wan method= $(c-a)/2-(c^0-a^0)/2$

The zero values (a^0 , b^0 and c^0) were the measurements of the zero wear radiographs for each test. Clinically, these are the measurements from the three months radiographs, which are then believed to be the result of creep. Single observer blinded to the aims of this study conducted all the measurements.

Devane's method

A Magic scan with a transmissible light source was used to scan the radiographs into the

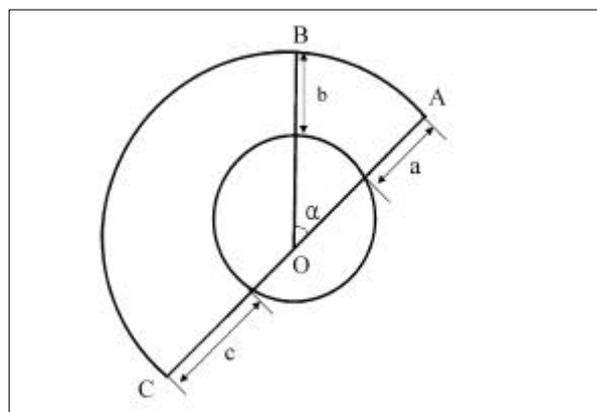


Fig. 1. Schematic diagram of the measurement techniques of acetabular cup wear.

Charnley duoradiographic method= $(c-b)/2-(c^0-b^0)/2$

Livermore method= $b-b^0$

Dorr method= $(c-a)/2-(c^0-a^0)/2$

New method

wear= $(c-a)/2/0.77$ (alpha angle <45)

wear= $(c-a)/2/0.72$ (alpha angle >45)

The zero values (a^0 , b^0 and c^0) were the data of zero wear radiographs of each test.

computer in the form of a digital image. The digital images were stored in an 8bit Tagged Image File Format (TIFF) with a resolution of 200 pixels per inch. Wear was measured using a three-dimensional technique¹² where the initial and final radiographs were digitized with a computer by a single observer three times per each case.

RESULTS

Three dimensional wear test (combined anterior and superior wear)

The real value of three dimensional wear was calculated by the following formula: $((\text{anterior wear})^2 + (\text{superior wear})^2)^{1/2}$. Only Devane's method was able to measure the three dimensional wear (anterior combined with superior wear) with a reasonable accuracy. The mean measurement of the error using Devane's method was 0.21 mm (Table 1).

Two dimensional wear test (superior wear only) (Table 2)

Charnley duoradiographic method

On average, the Charnley method underestimated the extent of wear by 16.6%. The mean

measurement error was 0.35 mm, and the error increased as the amount of wear increased.

Dorr and Wan method

On average, Dorr and Wan's method underestimated the extent of wear by 25.4%. The mean measurement error was 0.56 mm, and the error increased as the amount of wear increased. In the group with the 50° abduction angle, the average error was 23%, whereas in the 40° group, the average error was 28%. The data from two groups showed a statistical significance (Student T-test, $p=0.03$).

Livermore et al method

The average error using Livermore, et al's method was 9.5%. The error with this method was random, which resulted in the extent of wear sometimes being overestimated or underestimated. The mean measurement error was 0.16 mm, and error increased as the extent of wear increased.

Devane's method

The average error using Devane's method was 9.5%. The mean measurement error was 0.15 mm, and error did not increase as amount of wear increased. The measurement error did not alter significantly by the abduction angle, the anteversion angle, or by the distance on the x-ray be-

Table 1. Mean Measurement Error of Three Dimensional (Anterior and Superior) Wear

	Average error	Range
Charnley method	0.88	0.55 - 1.25
Dorr and Wan method	0.98	0.62 - 1.42
Livermore et al method	0.49	0.01 - 0.49
Devane's method	0.21	0.01 - 0.64

Table 2. Mean Measurement Error of Two Dimensional (Only Superior) Wear

	Average error	Range
Charnley method	0.35	0.00 - 0.76
Dorr and Wan method	0.56	0.03 - 1.24
Livermore et al method	0.16	0.00 - 0.65
Devane's method	0.15	0.01 - 0.48

tween the beam center and the femoral ball center.

Clinical application of new method

The Dorr and Wan method was modified from the results of the experimental test.

New method

$$\text{wear}=(c-a)/2/0.77 \text{ (alpha angle } < 45)$$

$$\text{wear}=(c-a)/2/0.72 \text{ (alpha angle } > 45)$$

The accuracy of the measurement methods were compared with the actual thickness of the retrieved component measured directly. Seventeen acetabular components obtained by surgical retrieval were included. All the cups were made of metal covered by a polyethylene liner, Harris Galante cup (Zimmer, Warsaw, IN, USA) 9 hips, Anatomic medullay locking (Dupey, Warsaw, IN, USA) 6 hips and Omnifit (Osteonics, Alendale, New Jersey, USA) 2 hips. The direct measurements of the components was made with a Point tip micrometer (Mitutoyo, Osaka, Japan). The

worn area was identified as a finely polished area within the bearing surface and the thinnest portion was measured. The results were as follows (Table 3). Livermore's method estimated the extent of wear to within 22.4%, with a mean error of 0.21 mm. Devane's method estimated the extent of wear to within 12.1%, with a mean error of 0.14 mm. The new method (adjusted correction factor to Dorr method) estimated the extent of wear to within 13.4%, with a mean error of 0.17 mm.

DISCUSSION

Polyethylene is a visco elastic material, which has the potential for plastic deformation in addition to wear. Rose and Radin¹⁵ observed using a wear simulator that wear was primarily creep and that wear accounted for < 30% of the change in the polyethylene thickness. The acetabular component thickness measurements did not distinguish between creep and wear. Another limitation

Table 3. Clinical Validation of the New Method for the Wear Measurement

	Real value	Devane method	Livermore method	New method
Case 1	2.12	1.89	2.26	2.01
Case 2	0.78	0.73	0.84	0.63
Case 3	0.25	0.34	0.45	0.31
Case 4	0.95	0.81	0.75	0.54
Case 5	0.48	0.52	0.58	0.44
Case 6	0.21	0.22	0.35	0.19
Case 7	1.24	0.94	0.95	0.9
Case 8	1.58	1.39	1.24	1.75
Case 9	1.28	1.02	1.35	1.32
Case 10	0.34	0.44	0.51	0.43
Case 11	2.35	2.21	2.57	2.65
Case 12	3.24	3.12	3.57	3.57
Case 13	1.45	1.58	1.23	1.53
Case 14	2.86	3.01	3.24	2.97
Case 15	1.68	1.65	1.86	1.74
Case 16	3.89	4.23	3.57	4.1
Case 17	2.45	2.54	2.21	2.78

of the wear measurements is the pathway or the direction of wear. Several investigators recently noted that some retrieved implants showed more than one wear vector, and the clinical measurements for the wear-testing methods that assume a single direction of wear might underestimate the overall amount of volumetric wear.^{7,16,17}

The greater margins of error using the manual techniques is largely caused by the difficulties in determining the center of the femoral head, the direction of wear, and the often obscure margin between the femoral heads and the acetabular cup. Charnley's duoradiographic method was expected to underestimate the extent of wear by 20%.⁹ This is consistent with the results of the present study, in which Charnley's method underestimated wear by an average of 16.6%. In contrast to Charnley's method, the Livermore method is theoretically perfect, but its reproducibility has been low in clinical applications.^{18,19} In this study, because the direction of wear was only in the superior direction, measurement error using this method was minimized.

The Dorr and Wan method is very simple and reproducible because the measurement points are always clear. Barrack, et al.¹⁸ reported that the Dorr method showed a significant correlation with the direct measurement and the addition of computer digitization to enhance manual methodology does not improve the accuracy. However Pollock, et al.¹⁹ reported the inaccuracy of the Dorr method particularly in one case of penetration into the central portion of the cup. The original Dorr method considered wear to be horizontal, whereas the direction of wear was adjusted in the new method. The alpha angle is the angle of the wear direction and is vital to the accuracy of the new method. Determining the angle of the wear direction was not possible when the extent of wear was so small that the minimal thickness of the polyethylene was difficult to identify. Therefore this study recommends that the alpha angle (90 minus abduction angle of the cup) be calculated. This assumption would not result in large a margin of error when used to study groups of radiographs. The new method has a limitation when estimating the linear wear in the case of the extreme wear angle such as over 60° or less than 30°. However, the assumption of wear

being in the superior direction is acceptable because the direction of the acetabular cup wear has been shown to be 0.7 ± 40 degrees, generally in the superior direction.²⁰

This study confirmed that the assumption of a single direction of wear does underestimate the amount of wear. Only the method reported by Devane accurately measured multidirectional wear. However, the reproducibility of this accuracy requires good quality lateral radiographs, which were available for this study. Other limitations of the Devane method are the cost, the learning curve, and the labor intense measurements, since many physicians, and even research projects may not possess the required computer software.

The radiographic wear measurements were most completely and accurately performed using the computerized method reported by Devane. When this method is not available, manual methods can measure the unidirectional wear just as accurately. The Dorr and Wan technique is accurate if wear were assumed to be horizontal. The most versatile method is the new method because the values were as accurate as those using the method reported by Devane, because the angle of the wear direction was considered in the measurements. This new method could be used accurately to estimate the average wear in groups of patients.

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