Radiographic Wear Measurements in a Cementless Metal-Backed Modular Cobalt-Chromium Acetabular Component

Robert L. Barrack, MD,* Carlos Lavernia, MD,† Edward S. Szuszcwewicz, MD,* and Jaswin Sawhney, MD*

Abstract: Linear polyethylene wear was measured radiographically and correlated with direct measurements of wear from 21 of 24 liners retrieved at revision. An optical comparator was used to assess linear wear using the shadowgraph technique. Postoperative and prerevision radiographs were reviewed to measure the amount of linear wear radiographically. Seven radiographic methods described in the literature were used: 5 were manual techniques, and 2 techniques used a computer-assisted digitizer. Linear regression analysis showed that there was a statistically significant correlation between the radiographic measurements compared with the direct measurement for 4 of the 5 manual techniques but only 1 of the 2 computerized techniques. Based on these results, radiographic wear measurements of cementless, modular components should be considered qualitative rather than quantitative. There is a significant difference in the measurements obtained among various published techniques. The addition of computer digitization to enhance manual methodology does not improve accuracy. Key words: wear, THA, polyethylene, Livermore.

Osteolysis has emerged as a leading problem in total hip arthroplasty. Accelerated polyethylene wear generally is believed to be a major cause of osteolysis, and polyethylene wear generally is perceived as the limiting factor in the longevity of total hip components. Acetabular components in total hip arthroplasty frequently are evaluated for polyethylene wear, which usually is assessed by a radiographic technique.

The techniques of Livermore, Charnley, and others were described and validated in the era of the 1-piece, all-polyethylene acetabular component [1–3]. Since then, many additional wear measurement techniques have been introduced. Techniques have ranged from relatively simple, single radiograph techniques to highly technical methods that require complex computer software and three-dimensional radiographic studies. Each technique has advantages and pitfalls.

Charnley and Halley [2] introduced 2 different radiographic wear measurement techniques. The uniradiographic technique attempts to measure radiographic wear based on a single radiograph. The duoradiographic technique compares current radiographic measurements with postoperative radiographic measurements to determine wear. Ohlin
and Selvik [4] compared direct measurement of linear wear with radiographic assessment with the uniradiographic and duoradiographic techniques. Ohlin and Selvik [4] obtained a correlation coefficient of 0.64 and 0.69. Wroblewski [5] also showed good correlation between these techniques and direct measurements. Both techniques have been criticized, however, because they reference the wire incorporated into the all-polyethylene acetabular component [6–8]. Unless the wire marker is within 10° of the coronal plane, errors in measurement may occur [9].

The Livermore technique is probably the best recognized radiographic wear measurement technique [3]. This technique was used initially to measure wear of all-polyethylene cemented acetabular components but referenced the cement–polyethylene interface; this eliminated the problem of referencing the wire marker. First the wear vector is determined. Comparing current radiographic measurements with postoperative radiographic measurements, the change in the distance between the femoral head (FH) and the cement–polyethylene interface along this vector is the measured wear. The Livermore technique has been found to correlate well with direct measurements, having a mean discrepancy of only 0.075 mm [3].

Two other variations of the Livermore technique have been introduced [10]. One variation uses a digitizer to measure the distances along the wear vectors, and the other uses a digitizer to determine the centers of the FH and the acetabular components, then determines the linear wear based on those calculations. Martell and Berdia [10] found the computer-Livermore technique to be far more accurate than the standard Livermore and manual Livermore-digitizer techniques. Measuring a known amount of wear, the computer-Livermore technique was within an average of 0.01 mm of the actual wear (SD ± 0.21) [10]. Advantages and pitfalls of each of these 2 techniques are comparable to the Livermore technique except that a digitizer assists with determining the wear measurements.

Two final measurement techniques use the opening face of the acetabular component as the reference. The tangential technique [11] compares current radiographic measurements with postoperative radiographic measurements, whereas the Dorr technique [12] bases its measurements on a single radiograph. Both techniques essentially calculate wear as the change in position of the FH relative to the acetabular face reference line. To our knowledge, no correlations have been made between these measurement techniques and direct wear measurements.

Several other techniques have been introduced using special radiographic studies with computer equipment and software in an attempt to improve edge detection and determine three-dimensional wear vectors more accurately [13,14]. The disadvantage to these techniques is that they often require special radiographic techniques with expensive equipment that is not readily available to most practicing orthopaedic surgeons. Table 1 presents a summary of the different radiographic techniques.

Most sockets currently implanted in the United States are modular cementless acetabular components. Osteolysis has been reported most frequently with these components. It now generally is accepted that although osteolysis has a multifactorial cause, the number of biologically active wear particles is a major factor. Early detection of significant

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<th>Comparison With Actual Wear</th>
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<td>Accuracy 0.2 mm (P &lt; .001) [3,5]</td>
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<td>Duoradiographic [2,4,5]</td>
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<td>Tangential [11]</td>
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<td>Shaver computer edge detection [13]</td>
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<td>Accuracy ± 0.15 mm [18]</td>
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NA, not available.

*Zimmer, Warsaw, IN.
†OTI, Timonium, MD.
‡Sulzer Orthopaedics, Austin, TX.
wear of the articulating surfaces may alert the clinician of an impending problem. To be able to quantify articular surface wear reasonably based on standard radiographic studies using a technique or techniques that do not require any special equipment would be advantageous. The question remains: How accurate are these radiographic techniques when applied to modular cementless components? A study was undertaken to determine how accurate various radiographic measurements are compared with actual determination of wear from retrieved liners. We also sought to determine how different techniques of measuring wear compared with each other.

**Material and Methods**

A consecutive series of 24 retrieved LSF (Long Term Stable Fixation; Implant Technology, Timonium, MD) cementless acetabular components were studied. Of the 24 components, 21 formed the study group. Three cases were excluded because the liner was destroyed or damaged severely *in situ* or at the time of revision. The diagnoses at revision were progressive osteolysis in 11 cases, thigh pain in 6 cases, infection in 2 cases, and recurrent dislocation in 2 cases. All acetabular components were well fixed at the time of revision. In cases revised for thigh pain, the acetabular component was revised if there was any damage to the bearing surface. This component was known to have a high rate of progressive lysis at 5 to 10 years [11]. Rather than just perform a liner change with a modular component of suboptimal design by present standards, the acetabular component was changed. In the cases revised for recurrent dislocation, the acetabular component was revised to obtain a more optimal component position.

The LSF acetabular component is made of cobalt-chromium alloy and is a full hemisphere. The component has 3 layers of sintered beads and 5 radial holes for screw placement and 1 polar hole. The acetabular liner is hemispherical and has dimples that correspond to the location of the screw heads to allow for clearance. There is a peripheral groove locking mechanism (Fig. 1). The LSF acetabular liner sits in a cobalt-chromium alloy shell and has a cuff that sits against the rim of the shell. The FH is not concentric with the acetabular shell when implanted; the center of the FH extends half the thickness of the cuff lateral to the geometric center of the acetabular shell (using the face of the acetabular shell as the reference vertical plane). The thickness of each cuff could be measured directly because the components had been retrieved. The femoral component is cobalt-chromium alloy with a proximal circumferential coating and undercoated medial collar [11]. A 32-mm head was used in all cases, and screws were used through the shell in 18 of 21 cases.

Standard low anteroposterior hip non-weight-bearing radiographs with a 40-inch tube-to-film distance were used, which is standard protocol for our radiology department. Postoperative and prerrevision radiographs were evaluated for wear using 7 methods—5 manual methods and 2 computer-assisted methods. A single observer (E.S.S.), experienced in analyzing total hip arthroplasty radiographs, collected all data points in this study. The observer was not a part of the surgical team involved in any of the cases presented. Descriptions of the 7 measurement techniques follow:

1. Livermore technique (Fig. 2A) [3]: On the prerevision radiograph, a transparent overlay of concentric circles is used to determine the FH center of rotation (COR). A compass is used to determine the FH COR and the minimum distance between the FH COR and the acetabular shell outer diameter (OD). The FH is not concentric with the acetabular shell when implanted; the center of the FH extends half the thickness of the cuff lateral to the geometric center of the acetabular shell (using the face of the acetabular shell as the reference vertical plane). The thickness of each cuff could be measured directly because the components had been retrieved. The femoral component is cobalt-chromium alloy with a proximal circumferential coating and undercoated medial collar [11]. A 32-mm head was used in all cases, and screws were used through the shell in 18 of 21 cases.

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2. Manual Livermore technique—digitizer [10]: This technique is identical to the Livermore tech-
nique with 1 exception. Instead of manually measuring the distance between the FH COR and the acetabular OD on the postoperative and prerevision radiographs, the digitizer (Research Metrics, Orthographics, Inc, Salt Lake City, UT) is used to measure the distances.

3. Computer Livermore technique [10]: This techniques uses the computer/digitizer to determine the FH COR, the acetabular OD, and the distance between the 2 for the postoperative and prerevision radiographs. For each radiograph, 3 points are digitized along the FH silouhette and the outer surface of the acetabular shell. The computer calculates the best-fit circles (with their CORs) for FH and the acetabular shell. The changes in the CORs for the FH and the acetabular shell can be used to measure wear, by calculating the minimum distance between 2 circles (w) using the following

\[
\text{linear wear} = \frac{|l_{1}' - SS'|}{2}
\]

**Fig. 2.** Schematic depictions of different wear measurement techniques. (A) Livermore. (B) Uniradiographic. (C) Duoradiographic. (D) Dorr. (2A from Livermore et al.; 2B and C from Charnley and Halley; 2D from Dorr and Wan with permission.)
The linear wear is calculated as the change in the polyethylene thickness \( (w_{\text{postop}} - w_{\text{prerev}}) \).

4. Uniradiographic technique (Fig. 2B) [2]: This technique requires only a prerevision radiograph, and the measurements do not need to be corrected for radiographic magnification. The narrowest measurement in weight-bearing area between the FH OD and the acetabular OD is subtracted from the widest measurement in the non-weight-bearing zone. The difference between the 2 distances is divided by 2 and gives the calculated linear wear.

5. Duoradiographic technique (Fig. 2C) [2]: The narrowest measurement in the weight-bearing zone between the FH OD and the acetabular OD is determined on the prerevision radiograph. The distance between the FH OD and the acetabular OD in the same zone is measured on the postoperative radiograph. The difference in the distances represents the linear wear when corrected for magnification factors.

6. Tangential technique [11]: Using the face of the acetabular shell as the reference, a tangential line to the superior aspect of the FH is drawn as well as to the superior aspect of the acetabular shell (ie, each line is a tangent to the respective circle, and it is perpendicular to the line that crosses the face of the acetabulum at its widest margin). The distance between the 2 tangential lines is calculated for the postoperative and the prerevision radiographs. The change in distance between these 2 lines, after correcting for magnification, is calculated as the linear wear.

7. Dorr technique (Fig. 2D) [12]: This technique requires only the prerevision radiograph. The acetabular face reference line (as previously described) is drawn on the radiograph. Along the acetabular reference line, the distance between the superior aspect of the FH and the superior aspect of the acetabulum \( (S' - S) \) is measured. The distance along the line between the inferior aspect of the FH and the inferior aspect of the acetabulum \( (I' - I) \) is measured. Linear wear is calculated based on the formula: Linear wear = \((I' - I - S' - S)/2\), after distances have been corrected for magnification.

Magnification was corrected by using the diameter of the FH as a reference. The center of the FH was marked using concentric circles, and measurements were taken.

The actual amount of linear polyethylene wear was measured from the retrieved polyethylene inserts directly by creating molds of the articular surfaces using vinyl polysiloxane (Imprint; 3M Corporation, Minneapolis, MN) (Fig. 3A). The shadowgraph technique was done within hours of creating the molds so that no appreciable shrinkage would occur before measurement (Fig. 3B). An optical comparator was used to assess linear wear using the shadowgraph technique described by Kabo et al [15] (Fig. 3C) The calculation of wear is based on the cylinder created by the FH as it wears in a particular direction. The linear wear is calculated by determining the height of the cylinder, and the volumetric wear is calculated by determining the volume of the cylinder. The direct measurement technique was defined as the gold standard, and radiographic measurements were compared with the shadowgraph measurement of linear wear.

Correlation coefficients were calculated between the different radiographic techniques and the direct measurement of linear wear. Linear regression analysis was used to evaluate the data, and \( P < .05 \) was considered significant.
Results

The raw data for each individual radiographic technique are summarized in Table 2. In general, nearly all of the radiographic wear techniques over-estimated linear wear compared with the shadowgraph technique. Only the Livermore technique had an average measured wear that was below the average measured wear based on the shadowgraph technique. Linear regression analysis showed that there was a statistically significant correlation between the radiographic measurements compared with the direct measurements for 4 of the 5 manual techniques. The manual-digitizer Livermore technique, in which the points were determined manually but distance was measured with a digitizer, also showed a significant correlation with actual measurements ($r = 0.51; P = 0.017$), whereas the completely computer-digitized technique did not ($r = 0.35; P = 0.12$). The Livermore technique showed a strong trend toward significance ($r = 0.36; P = 0.10$) but did not achieve statistical significance. The strongest correlation existed for the Dorr technique ($r = 0.72; P = 0.00022$) followed by the uniradiographic technique ($r = 0.67; P = 0.00085$) (Table 3).

Discussion

The results of the present study showed that there are significant differences between various radiographic measurements and actual polyethylene wear. Computer assistance did not improve the accuracy of the wear measurements; on the contrary, the lowest correlation coefficients were observed in computer-assisted methods. This poor accuracy probably can be attributed to a difficulty in defining the edge of the FH with a cobalt-chromium alloy component [13,16]. Depending on the amount of acetabular component anteversion, only a small portion of the FH in the inferior quadrant may be clearly visible. The ability to digitize the margin of the FH accurately and derive the center of rotation is less accurate because of this situation.

The correlation coefficients obtained in the present study compare closely with those of Ohlin and Selvik [4], who also compared direct measure-

Table 2. Raw Data

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Table 3. Correlation of Direct Versus Radiographic Wear Measurements

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ment of linear wear with radiographic assessment with the uniradiographic and duoradiographic techniques. Ohlin and Selvik [4] obtained correlation coefficients of 0.64 with the uniradiographic technique and 0.69 with the duoradiographic technique compared with 0.67 and 0.53 in the present study.

A surprising finding of the present study was that the radiographic estimates of wear generally overestimated the wear compared with the actual measurements. This overestimation is probably not attributable to the fact that patients were not weight bearing at the time of the radiographs; Moore et al [17] showed that this does not affect radiographic wear measurements. Prior reports found that radiographic wear measurements underestimate rather than overestimate radiographic wear [18]. In an effort to clarify this issue, 3 modular acetabular LSF components were assembled as recommended by the manufacturer, then immediately sectioned with a diamond wheel to examine the interface between the liner and the metal shell. Direct caliper measurement of this interface revealed large gaps ranging from 0.1 to 0.6 mm. The extent of the gaps varied throughout the cup–liner interface and varied between specimens (Fig. 4). A substantial interface gap could lead to an increased radiographic measurement of wear, which would not be seen by direct measurement of the molds because that measures wear only on the articular surface. This phenomenon is not unique to this system but was reported commonly in many first-generation acetabular components. A study by Parsley [19] showed interface gaps in several modular acetabular components of early designs that measured 1.3 mm. In another study by Rosner et al [20], there was a wide variation in cup–liner conformity between different early-generation modular acetabular component designs. In measuring the distance between the metal shell and the polyethylene liner, Rosner et al [20] reported that there was a gap >0.2 mm over an area of 33% to 87% of the total area of the shell–liner interface. It is possible that the increased wear determined radiographically compared with direct measurement is because of a summation of creep and articular wear as opposed to articular wear alone. This creep could have been significant given the irregularities found at the polyethylene–cobalt-chromium alloy shell interfaces of the LSF component.

The weaknesses of this study are pertinent to the clinical application of radiographic wear measurements. First, because these components are cobalt-chromium alloy, visualization of the FH within the acetabular component can be difficult, depending on its anteversion. Empirically, it makes sense that regardless of the technique used, the more of the FH that can be visualized, the more accurate the positioning will be of the COR for the component. This difficulty probably had an effect regardless of which radiographic wear technique was used. Newer techniques that use computer software to

![Fig. 4.](image-url)
Radiographic Wear Measurements • Barrack et al. 827

Conclusion

The results of the present study show that radiographic measurements of polyethylene wear in LSF total hip arthroplasties are qualitative or semiquantitative at best. Several aspects of the LSF component may have contributed to potential errors. The acetabular component is cobalt-chromium alloy, making visualization of the FH more difficult. The LSF FH is not initially concentric with the acetabular shell because the polyethylene liner lateralizes the FH COR compared with the acetabular shell. This situation may induce error in measurement for techniques that assume initial concentricity between the FH and the acetabular shell. Finally the LSF appears to have significant gaps at the shell–polyethylene interface, causing creep to be interpreted as wear. Many, if not all, modular cementless acetabular components of early design share many of these features. Radiographic measurements are particularly prone to error, however, with early-generation modular designs, in which there was frequently a large gap present initially between the polyethylene liner and the metal shell. This gap disappears with time as the polyethylene liner creeps to conform to the liner shell. This phenomenon has been reported by Sychterz et al [21]. Additional problems that may affect the radiographic measurement of wear in other types of total hip components include the occurrence of lateral wear and difficulty with edge detection as well as having more than 1 major wear vector, as described by Yamaguchi et al [14].

There have been substantial changes in the design of modular cementless acetabular components. Newer generation components have eliminated the gaps between the liner and the shell, have increased the degree of liner–shell conformity, and have tighter tolerances. There have been substantial improvements in the ability to detect wear radiographically. Improved techniques, such as three-dimensional wear measurement [14,18] and the use of edge-detection technology [13] promise to improve the accuracy of radiographic wear measurements greatly. With improvements in component design and measurement technique, radiographic measurement will become a more reliable quantitative estimate of polyethylene wear in the future. It is imperative that these wear measurement techniques be validated with additional studies to confirm their accuracy.

References

828 The Journal of Arthroplasty Vol. 16 No. 7 October 2001

and polyethylene wear at 5–8 years in an unce-
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