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A simple method of measuring the wear of explanted acetabular component inserts

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Objectives

The determination of the volumetric polyethylene wear on explanted material requires complicated equipment, which is not available in many research institutions. Our aim in this study was to present and validate a method that only requires a set of polyetheretherketone balls and a laboratory balance to determine wear.

Methods

The insert to be measured was placed on a balance, and a ball of the appropriate diameter was inserted. The cavity remaining between the ball and insert caused by wear was filled with contrast medium and the weight of the contrast medium was recorded. The volume was calculated from the known density of the liquid. The precision, inter- and intraobserver reliability, were determined by four investigators on four days using nine inserts with specified wear (0.094 ml to 1.626 ml), and the intra-class correlation coefficient was calculated. The feasibility of using this method in routine clinical practice and the time required for measurement were tested on 84 explanted inserts by one investigator.

Results

In order to get the mean for all investigators and determinations, the deviation between the measured and specified wear was -0.08 ml (SD 0.12; -0.21 to 0.11). The interobserver reliability was 0.989 ml (95% confidence interval (CI) 0.964 to 0.997) and the intraobserver reliability was 0.941 for observer 1 (95% CI 0.846 to 0.985), 0.983 for observer 2 (95% CI 0.956 to 0.995), 0.939 for observer 3 (95% CI 0.855 to 0.984), and 0.934 for observer 4 (95% CI 0.790 to 0.984). The mean time required to examine the samples was two minutes (SD 2; 1 to 5).

Conclusion

The method presented here was shown to be sufficiently precise for many settings and is a cost-effective and quick method of determining the volumetric wear of explanted acetabular components. However, the measurement of wear for scientific purposes will probably continue to involve more accurate and dedicated laboratory equipment.

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Article focus

- Determination of polyethylene wear on explanted inserts.
- Measurement without dedicated expensive instruments.
- Materials needed: reference balls and a laboratory balance.

Key messages

- Presented method is cost-effective, robust and quick.

- For many settings sufficiently precise wear measurement of explants.

Strengths and limitations

- Method is applicable in almost every clinic.
- In low wear the measurement has limited accuracy; the method cannot replace high precision measurements for scientific purposes.
- Reference balls (28 mm, 32 mm, 36 mm) are needed and must be calibrated once.

Introduction

The determination of wear after total hip arthroplasty (THA) in routine clinical settings is usually performed on radiographs using dedicated software.^{1,2} Given that the direction of wear is not parallel to the anteroposterior plane in most cases, 2D techniques usually underestimate the amount of wear. It can be determined more accurately using radiostereometry (RSA), as the vector of penetration of the femoral head can be determined three-dimensionally.^{3,4}

The volumetric measurement of polyethylene wear using explanted components has been carried out by many authors.⁵⁻⁸ High accuracy can be achieved using dedicated instruments. Up to now, the benchmark has been an optical measurement of the deviation from sphericity using a microscope^{9,10} or CT scanning.¹¹⁻¹³ The technical equipment, including the software, required for this is not only expensive and complicated to use, but also only available in a few research institutions specialising in orthopaedics. CT scanning is precise enough to determine wear on explants.^{11,14-16} Coordinate-measuring machines allow a high precision and are used in laboratories specialised in wear experiments.¹⁷⁻¹⁹ In comparison with CT, the wear is not measured directly but calculated as a difference taken from a known geometry based on the spatial position of several points.

Nevertheless, the accuracy of both CT and a coordinate-measuring machine is limited by the propagation of errors resulting from mathematical equations using many values and data from different acetabular component insert manufacturers.

In contrast, measuring the weight of a liquid of known density introduced into the insert only requires a balance for determining the volume of the cavity and is a direct method without the propagation of error. However, it is limited by the fact that it determines the absolute volume up to the outer rim. In order to calculate wear, the specific design of the inlay must be known as it may not be a perfect hemisphere. A tilted position during measurement also causes a significant loss of liquid, and this limits the accuracy.

Thus, a fluid displacement method is preferred by some authors.²⁰⁻²⁴ In this technique, a ball of the former diameter of the head is placed into the insert, and the remaining cavity is filled with liquid. This technique should therefore be more robust than a tilted probe position and should work independently of the geometry of the insert, given that it is part of a sphere. To the best of the authors' knowledge, this method too, has not been validated against given wear, and no data have been published on inter- and intraobserver reliability.

The aim of this study was to validate the volumetric determination of wear using a reference ball and to determine precision, inter- and intraobserver reliability, the feasibility its use in routine clinical practice and the time required for measurement.

Materials and Methods

The reference balls (22 mm, 28 mm, 32 mm and 40 mm) were made from polyetheretherketone (PEEK) (KGM Kugelfabrik, Fulda, Germany). Their diameter was checked with a micrometer, and the values were corrected after noting the deviation from the perfect of the actual volume of the ball. The liquid chosen was the contrast medium Ultravist-300 (Bayer AG, Leverkusen, Germany), in order to be able to detect the liquid film and any unfilled cavities by means of CT. For validation of the gravimetric method of determining wear, the volume of the contrast medium was also determined by CT.

The polyethylene-insert was positioned on polystyrene on a balance (GS 4100-2, Kern and Sohn GmbH, Balingen, Germany) in such a way that the equatorial plane was roughly parallel to the plane of the table. Then, a PEEK ball matching the internal diameter was placed into the insert and the balance was set to 0. The cavity remaining between the insert and the ball was filled with contrast medium and the weight was documented. Then, the insert on the polystyrene was placed into the CT scanner (BrightSpeed, GE, Boston, Massachusetts), scanned at the highest possible resolution (0.25 mm × 0.25 mm pixels at a feed rate of 0.625 mm, 16 Bit resolution, 120kV), and the Digital Imaging and Communications in Medicine data were transferred into OSIRIX (Version 5.8.2, Pixmeo, Bernex, Switzerland).

Using the 'grow region' function at a lower interval of 3000 and an upper interval of 3500 grayscales, the contrast medium filling the wear was segmented. The volume could then be determined directly by means of the 'region of interest volume' (Fig. 1).

The inter- and intraobserver reliability were determined on nine inserts with specified wear (0.094 ml to 1.626 ml), and the intra-class correlation coefficient (ICC) was calculated. The inserts were produced by the research department of Mathys AG (Bettlach, Switzerland), and their wear was determined by micro-CT prior to the experiment. The samples were measured by four investigators (LK, ER, SB, GM) independently of each other over four days. The feasibility of use in clinical practice and the time required to make a measurement were tested by one investigator (LK, ER, Sb or GM) on 84 inserts that had been explanted due to the indication insert exchange.

Results

In order to get the mean for all investigators and determinations, the deviation between the measured and specified wear was -0.08 (SD 0.12; -0.21 to 0.11). The interobserver reliability was 0.989 (95% confidence interval (CI) 0.964 to 0.997) and the intraobserver reliability was 0.941 for observer one (95% CI 0.846 to 0.985), 0.983 for observer two (95% CI 0.956 to 0.995), 0.939 for observer three (95% CI 0.855 to 0.984), and 0.934 for observer four (95% CI 0.790 to 0.984) (Table I). The

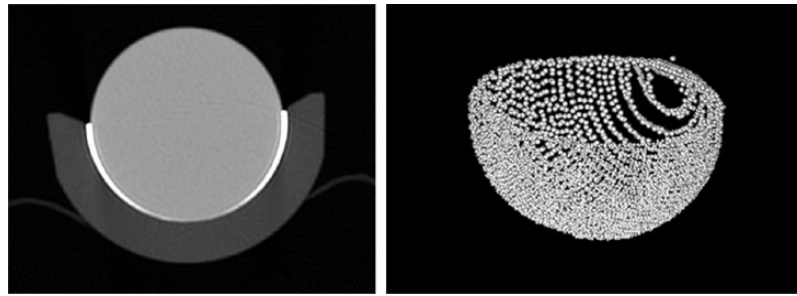


Fig. 1a

Fig. 1b

Imaging of contrast medium as a fingerprint of wear in the CT scan (a), segmentation and calculation of the volume (b).

Table I. Comparison of the given wear values and the mean values of replicate measurements taken from each observer

Given wear (ml)	Observer one (ml)	Observer two (ml)	Observer three (ml)	Observer four (ml)
0.094	0.022	0.452	0.352	0.223
0.115	0.179	0.509	0.352	0.244
0.127	0.187	0.44	0.309	0.229
0.174	0.291	0.405	0.366	0.303
0.251	0.315	0.511	0.496	0.441
0.477	0.38	0.461	0.459	0.595
0.86	0.704	0.884	0.907	0.759
1.242	1.136	1.139	1.147	1.101
1.626	1.486	1.683	1.599	1.614

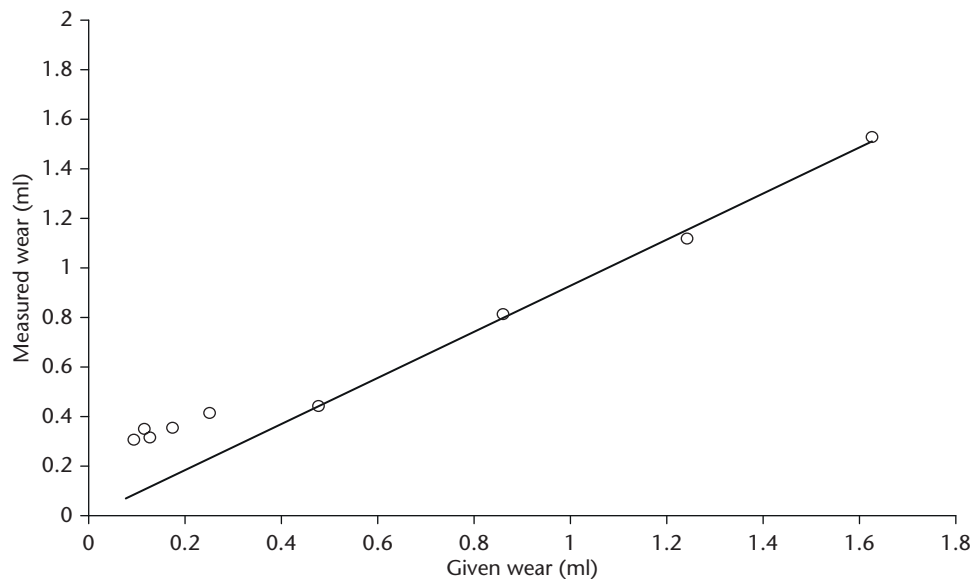


Fig. 2

Clear correlation was found between measured (mean value over all observers) and wear at volumes > 0.4 ml. Below this, the values showed a relevant spread.

mean time required to examine the samples was two minutes (SD 2; 1 to 5).

As a mean of all investigators and determinations, the deviation between the measured and specified wear was -0.08 (SD 0.12; -0.21 to 0.11). The relative deviation was dependent on the absolute volume of wear (Fig. 2). At > 0.4 ml, it was on the mean 4.7% (SD 95%); at < 0.4 ml, 120% (SD 220%), so that the use of the method of measuring wear volumes of < 0.4 ml does not appear to be practical.

In all cases, a continuous liquid film could be demonstrated in the CT scan, so that the cavity between the reference ball and insert was always filled. This led to a good correlation between gravimetrically and CT determined volumes of wear of $R(\text{Pearson}) = 0.938$ ($p < 0.0001$) and $R(\text{Spearman}) = 0.945$ ($p < 0.0001$), and an ICC of 0.296.

The mean wear of the explanted inserts was 0.83 ml (SD 0.38; 0.09 to 2.26); nine inserts (8%) showed wear of < 0.4 ml, so the gravimetric determination of wear could be conducted with sufficient accuracy in 92% of cases.

Discussion

The most important finding of this study was that the technique presented here allows a simple, fast and observer-independent measurement of the wear of explanted acetabular component inserts. Because the contrast medium is introduced into the insert, the wear is detected in full, independently of its geometric form. In contrast to 2D radiographic methods that calculate volumetric wear from the depth of penetration of the head, the method presented here also detects eccentric, nonlinear wear.

The correlation between the given and the measured wear was higher than that determined by Yun et al²⁵ comparing a radiographic method without any dedicated software with 3D laser scanning (between 0.89 and 0.93). Even established radiographic methods for the measurement of wear according to Dorr and Wan²⁶, Charnley and Halley²⁷ and Livermore et al²⁸ produced correlations between 0.7 and 0.8 according to measuring microscope data that is below the calculated correlation of 0.95 in this study.⁹

In contrast to the convincing values of the Spearman and Pearson ICCs shown in Table I, the ICC is lower than that determined by Dahl et al³ for RSA analyses (0.95). This indicates that filling an insert with liquid is more susceptible to differences experienced by the observers than it is when semi-automatically defining the position of RSA spheres in radiographs. In comparison with the data of Dahl et al,³ the precision of the method in the present work depended on the absolute amount of wear.

The accuracy of the method is also limited to the precision of the balance and the PEEK balls. Standard laboratory balances have a resolution and accuracy which exceed the inter- and intraobserver reliability determined here. The diameter of the PEEK balls should be measured once with a micrometer and used to correct the volume of the ball, otherwise a considerable systematic error can occur. In the case of a 32 mm ball, a deviation in diameter of 0.1 mm already leads to an error of 0.32 ml.

The CT scan performed in this study as a measure of validation of the method does not appear to be necessary, as the cavity between the ball and the insert was filled with contrast medium in all cases. A fluid with minimal meniscus formation, such as water with a drop of soap, should be used to minimise potential errors.

In conclusion, the method presented here is sufficiently accurate for many settings and is a cost-effective, observer-independent, and quick procedure for determining the volumetric wear of explanted acetabular components.

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Author Contribution

- L. Krakow: Measurements, Manuscript review, Statistics.
- A. Klockow: Production of reference balls, Manuscript review.
- E. Roehner: Measurements, Manuscript review.

- S. Brodt: Measurements, Manuscript review.
- H. Eijer: Manuscript review, CT measurements.
- J. Bossert: Manuscript review, CT measurements.
- G. Matziolis: Manuscript writing, Idea development.

Conflicts of Interest Statement

- A. Klockow is an employee at Mathys AG, the manufacturer who provided the inserts for the study.

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