Wear Measurement and Analysis of Explanted Acetabular Cups

M. S. Uddin*

School of Engineering, University of South Australia, Adelaide, Australia
*Corresponding author. Email: Mohammad.Uddin@unisa.edu.au

1. Background and objective

Wear is recognised as the prime cause for aseptic loosening failure of hip implants. Wear analysis, hence, is an important tool to determine underlying wear mechanisms, which will consequently enhance the life of the implants. Until now, no unique measurement standards except for ISO-14242-2 which is particularly designed for *in vitro* volumetric wear measurement, were available for explanted hip joints. As an alternative, coordinate measuring machine (CMM) is growly applied in high precision metrology, offering an opportunity to capture minute traceable amount. This paper will present wear measurement and analysis of retrieved conventional XPE (cross-linked PE) and 2nd generation XPE3 cups using a CMM. An expanded uncertainty budget analysis was performed to assess the performance of CMM wear measurement.

2. Materials and method

Total five retrieved acetabular cups of different radii were measured by a CMM, where two cups were made of XPE and three of XPE3; all of which were manufactured by Zimmer Inc. The cup retrieval varied between 3 and 10 years after surgery (Table 1). The CMM (MicroXcel, Brown & Sharp) used has maximum axial positioning error: D=4.5+4L/1000 (D in µm, L in mm), which is within the specification for volumetric measurement prescribed by ISO-14242-2. The CMM probe scans the inner surface of the cup, giving 3D coordinates of the scanned points. The mesh spacing of the scanning paths was about 0.25mm, leading to 15,000 points. Initially the CMM scanning of having at least ten points was performed on different 'unworn' regions of the cup to determine the reference geometry (surface) of the pre-worn cup. The whole cup was then scanned with predefined scanning paths. The difference between the reference (pre-worn) and measured (worn) geometric surfaces was calculated, providing actual wear amount. The process was repeated three times and their average was taken as the final wear value. In order to assess the CMM measurement, three uncertainty contributors were considered, which formed a total expanded uncertainty budget, U as: $U = k\sqrt{(u_{cal}^2 + u_p^2 + u_w^2)} + |c|$ where, k = coverage factor, u_{cal} = uncertainty of the calibration of the calibrated artefact, u_p=uncertainty of the wear measurement procedure as assessed in calibration uncertainty, u_w=uncertainty of materials and manufacturing tolerance of the cups, c=uncertainty for mesh spacing of scanning paths.

3. Results and discussion

As shown in Fig.1, the XPE3 cups show lower linear and volumetric wear progression compared to XPE cups. A representative wear map showing linear wear distribution on the Cup #1 is depicted in Fig.2. The wear results are consistent with those obtained from clinical studies on explants [1], supporting the efficacy of CMM measurements. Table 1 summarizes measured wear values and the corresponding uncertainty components for the cups studied. A coverage factor k=2 for an approximate coverage probability of 95% was adopted to estimate uncertainty values.

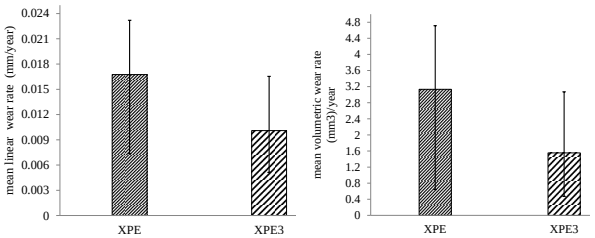

Fig. 1 Linear and volumetric wear rate

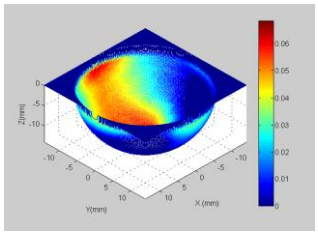

Fig. 2 Wear map on the Cup #1 (in mm)

Table 1 Measured wear and corresponding uncertainty

Work specimen	Nominal diameter, mm	Number of years before retrieval	Linear wear, mm	Uncertainty for linear wear, U_L (mm)	Volumetric wear (mm^3)	Uncertainty for volumetric wear, U_V (mm^3)
Cup # 1 (XPE)	28.16	3	0.069	0.00128	13.8016	1.825
Cup # 2 (XPE)	36.32	10.5	0.079	0.00212	9.8425	3.125
Cup # 3 (XPE3)	36.08	4	0.062	0.00212	13.3233	3.125
Cup # 4 (XPE3)	32.12	6	0.050	0.00186	7.1093	2.624
Cup # 5 (XPE3)	28.16	3	0.020	0.00128	0.42435	1.825

It can be suggested that uncertainty has a significant influence on the wear measurement by CMM. A special care has to be taken in the process starting from calibration of the probe and artefact to the design of scanning paths and digital processing of points.

4. References

[1] McCalden, R.W. et al., "Wear Rate of Highly Cross-Linked Polyethylene in Total Hip Anthroplasty: A Randomised Controlled Trial," J. Bone Joint Surg, 91, 4, 2009, 773-82.