Surface roughness of retrieved femoral heads in CoCr-Polyethylene Hip Bearings – A retrieval assessment with 11-17 years follow-up

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Introduction

Metal-on-polyethylene (MPE) bearings have been the gold standard in total hip arthroplasty (THA) for over 40 years. However, even for the improved polyethylenes steadily gathering a reputation of very high wear resistance, it is also clear that there are additional issues to consider (Fig. 1). It is well documented that impingement of metal-on-polyethylene (MPE) is a serious risk that can damage the polyethylene liner, produce additional wear debris and also lead to 3rd-body abrasion and roughening of the femoral head.¹⁻³ Adding to these risks is the contemporary use of larger femoral heads with the consequence of adjusting to thinner polyethylene liners once believed to be a contraindication in cup design.⁴ The superior surface finish of CoCr implants mated with polyethylene bearings is believed to be one factor in the longevity of metal-on-polyethylene bearings (MPE). However, it may be that under long-term conditions *in vivo*, these 3rd body-wear particles eventually degrade the MPE surfaces.^{2,5-7}

The two-body and three-body wear mechanisms associated with MPE is an unavoidable risk given the nature of the hip mechanics. Studies of cup impingement have documented an incidence ranging 45-68%. However in MOM studies, impingement evidence has climbed to 96%.⁸ We therefore sought evidence of roughening damage to the femoral heads as a result of 3rd-body wear. A study of MPE retrievals with average 12-years

Fig. 1 Introduction to the risks of the different modes of debris production: i) neck-to-cup impingement wear, ii) head pressure on contra-coupe rim of liner, iii) backside wear by pistoning liner, iv) bead shedding, v) metal debris shed from taper junction, vi) metal debris emitted by femoral-stem construct and vii) micro-separation and subluxation wear.

follow-up (N = 35 cases)⁹ described CoCr roughness averaging 62nm (Ra= 41-80nm). A subsequent retrieval study (N=43: 6-years) with half the follow-up time described much lower roughness of 10nm (Ra), with roughness for non-worn surfaces reported as low as 3nm.¹⁰

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The 1st goal of this study was determine if femoral heads became rougher or smoother in MPE bearings with time (10-20 years). The 2nd goal was to determine if CoCr roughness simulated in laboratory tests was an adequate representation of that occurring in-vivo.

Fig. 2 Methods

Methods

The MOM cases were performed by various surgeons and revised in the Orthopedic Dept. of Loma Linda University. The analytical studies were conducted in the DARF Retrieval Center. Six CoCr femoral heads were chosen with 11-17 years duration. Except for one 26mm head, all were 28mm and mated with non-cemented, metal-backed acetabular shells with conventional polyethylene liners. All studies conducted at DARF Center were of a non-destructive nature for loaned MOM. Implants were scrutinized for any impingement damage and liners mounted on heads to check geometry of any damage sites. Implant 3D-geometry was studied by CMM, wear patterns were imaged by SEM and energy dispersive spectroscopy (EDS). Surface roughness was analyzed by white-light interferometry (WLI).

Unique to the DARF Center, the first step in the analysis was to determine which areas the patient habitually walked on in the head and cup. Here the main-wear zones (Fig. 1: MWZ) were uniquely defined as “normal”. Accordingly, the remaining areas were defined as non-wear zones (NWZ) and these were also studied for clues to “abnormal” wear damage. These areas were mapped visually and optically on each femoral head and cup. Surface roughness was assessed by interferometry (Newview 600, Zygo Inc) for both MWZ (12 data points) and NWZ areas (6 data points). Care was taken to exclude areas of protein contamination

Fig. 3 Mapping of MWZs on MPE

Fig. 4. SEM imaging CoCr

from such roughness surveys.^{8,11} In addition, any abnormal wear damage of a local nature was excluded from such roughness surveys and profiled separately in greater detail. SEM imaging was used to confirm wear topography (MA 15, Zeiss Inc) and any metal contamination (EDS, Bruker Inc). The extent of the surface areas was then determined using standard spherical algorithms and their locations marked for additional microscopic analyses (Fig. 1).

Results

After 11 to 17 years duration (Table 1: average 13 years), the MWZ on femoral heads covered 292-774mm² in area (Table 2: average = 558mm²), representing a x2.7-fold variation. Relating these MWZ areas to the hemispherical surface area of the head, these patients had walked on 24-63% of the available surface area (45% on average). SEM imaging revealed the typical carbide pattern (size < 10µm), small pits and fine micron-size,

Fig. 5. SEM imaging typical CoCr head.

Fig. 6. SEM imaging "worst case" CoCr head.

Explant #	Manufacturer	Reason for Revision	F/U (yrs)	MWZ area	MWZ %	MWZ Ra (nm)	NWZ Ra (nm)	MWZ/ NWZ
1 (44F)	Zimmer	osteolysis	17	699	56	11	6	1.8
2 (58F)	IOI	osteolysis	15	391	32	11	6	1.8
3 (67F)	BC	cup migration	12	634	51	8	4	2.0
4 (83M)	Zimmer	osteolysis	12	774	63	10	5	2.0
5 (91F)	DePuy	osteolysis	11	557	45	13	6	2.2
6 (59M)	DePuy	osteolysis	11	292	24	10	4	2.5
Averages (n=6)			13	558	45	10.5	5.2	2.0

Table 1 MPE explants with patient demographics

surface scratches. There was no evidence of the large micro-grooves ($> 40\mu\text{m}$ width, $> 0.5\mu\text{m}$ depth) commonly identified on MOM retrievals.

The surface roughness of the MWZ areas appeared exceedingly smooth at 8-13nm ($R_a = 11$ average roughness) and only slightly larger than the range 4-6nm for the NWZ (average $R_a = 5\text{nm}$). Individual profiles of such worn surfaces showed peaks and valleys within $\pm 10\text{nm}$ range and occasional scratches penetrating 30nm into the CoCr surface (Fig. 5). Representing the 'worst case' scenario in this study, some areas revealed scratches with peaks and valleys within the $\pm 30\text{nm}$ range, some as wide as $20\mu\text{m}$ (Fig. 6).

Discussion

Micro-imaging revealed that femoral surfaces in these MPE bearings appeared excellent even with 11-17 years of use in vivo. The appearance of

the micron-size pits and fine surface scratches on these CoCr bearings were typical of 3rd-body abrasion created by release of small surface carbides. Totally absent in this MPE study were the micro-grooves created in MOM bearings by large CoCr particles acting as third-body abrasives.⁸ The latter phenomenon are believed to be a consequence of impingement between femoral necks and exposed CoCr liners.^{8,12} Thus our study illustrated that CoCr femoral head surfaces used with polyethylene liners may become only slightly rougher with long-term implantation. These data were therefore supportive of a previous retrieval study with a mean follow-up of 7 years.¹⁰ It was noted that such roughness grades

Fig. 7. Comparison of published surface roughness studies (ranking system redrawn from study by Sorimachi et al).

remained well below the ASTM guideline¹³ for even a new THA bearing (Fig. 7: Ra = 50nm). Therefore, our conclusion was that this level of CoCr roughness could not be a contributor to long-term wear and osteolysis in these patients with metal-on-polyethylene bearings.

The mapping of habitual wear areas on the CoCr heads revealed that MPE patients walked on an average of 45% of the femoral head hemisphere. In MOM bearings, the area of habitual wear was noted to be slightly larger at 55% of the hemisphere.⁸ These new MPE data indicated that the patients walked similarly on MPE and MOM bearings, despite the fact that the cups represent remarkably different hardness and contact mechanics.⁸ The design preference for the American surgeon is to use a polyethylene liner inside a metal acetabular-shell ('press-fit' cup). Thus the protective polyethylene cup rim may be of considerable benefit if impingement and subluxation presents.¹⁴

Significance and Conclusions

1. Our study showed the surface finish of 28mm CoCr femoral heads (Ra < 15nm) used in combination with polyethylene liners can remain excellent into the 2nd decade of use.
2. With modular metal shells there is the added risk of cup-impingement and possible damage to the polyethylene liner. However we found no evidence of the large microgrooves typically produced in MOM bearings by circulating metal particulates, i.e. 3rd-body abrasion.
3. The wear area assessments showed that these patients walked on their MPE bearings in a very similar way to patients with MOM bearings.

Explant #	F/U (yrs)	MWZ area (mm ²)	MWZ %Hemi	MWZ Ra (nm)	NWZ Ra (nm)	MWZ/ NWZ
Ratio						
1 (44F)	17	699	56	11	6	1.8
2 (58F)	15	391	32	11	6	1.8
3 (67F)	12	634	51	8	4	2.0
4 (83M)	12	774	63	10	5	2.0
5 (91F)	11	557	45	13	6	2.2
6 (59M)	11	292	24	10	4	2.5
Mean (n=6)	13	558	45	11	5	2.0

Table 2: Summary of MWZ area calculations and head roughness (Ra) data (note 1,000nm = 1micron)

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References

1. Lundberg HJ, Liu SS, Callaghan JJ, Pedersen DR, O'Rourke MR, Goetz DD, Vittetoe DA, Clohisy JC, Brown TD. Association of third body embedment with rim damage in retrieved acetabular liners. Clin Orthop Relat Res 2007;465:133-9.
2. Heiner AD, Lundberg HJ, Baer TE, Pedersen DR, Callaghan JJ, Brown TD. Effects of episodic subluxation events on third body ingress and embedment in the THA bearing surface. J Biomech 2008;41-10:2090-6.
3. Lundberg HJ, Stewart KJ, Pedersen DR, Callaghan JJ, Brown TD. Problematic sites of third body embedment in polyethylene for total hip wear acceleration. J Biomech 2005.
4. Bartel DL, Bicknell VL, Wright TM. The effect of conformity, thickness, and material on stresses in ultra-high molecular weight components for total joint replacement. J Bone Joint Surg Am 1986;68-7:1041-51.
5. Wang A, Stark C, Dumbleton JH. Mechanistic and morphological origins of ultra-high molecular weight polyethylene wear debris in total joint replacement prostheses. Proc Inst Mech Eng [H] 1996;210-3:141-55.
6. Lundberg HJ, Stewart KJ, Pedersen DR, Callaghan JJ, Brown TD. Problematic sites of third body embedment in polyethylene for total hip wear acceleration. J Biomech 2006;39-7:1208-16.
7. Lundberg HJ, Stewart KJ, Callaghan JJ, Brown TD. Kinetically critical sites of femoral head roughening for wear rate acceleration in total hip arthroplasty. Clin Orthop Relat Res 2005-430:89-93.
8. Clarke IC, Donaldson TK, Burgett MD, Smith EJ, Bowsher J, Savisaar C, John A, Lazennec JY, McPherson E, Peters CL. Normal and Adverse Wear Patterns Created In-vivo on MOM Surfaces - a retrieval study representing four vendors. ASTM Symposium on Metal-on-Metal Total Hip Replacement. Phoenix, AZ 2012, In Press 2013
9. Hall RM, Siney P, Unsworth A, Wroblewski BM. The effect of surface topography of retrieved femoral heads on the wear of UHMWPE sockets. Med Eng Phys 1997;19-8:711-9.
10. Elfick AP, Hall RM, Pinder IM, Unsworth A. The influence of femoral head surface roughness on the wear of ultrahigh molecular weight polyethylene sockets in cementless total hip replacement. J Biomed Mater Res 1999;48-5:712-8.
11. Burgett M, Myant C, Cann P, Clarke IC, Donaldson TK. The Role of Protein Films on Hip Bearings Lubricated with Varied Protein Concentration. ORS. To be presented Jan 25 - 29, San Antonio, Texas, 2013.
12. Howie DW, McCalden RW, Nawana NS, Costi K, Percy MJ, Subramanian C. The long-term wear of retrieved McKee-Farrar metal-on-metal total hip prostheses. J Arthroplasty 2005;3:350-7.
13. ASTM. F2068-03: Standard Specification for Femoral Prostheses—Metallic Implants. ASTM, 2003.
14. Harris WH. Edge loading has a paradoxical effect on wear in metal-on-polyethylene total hip arthroplasties. Clin Orthop Relat Res 2012;470:3077-82.