Accepted Manuscript

Corrosion on the Acetabular Liner Taper from Retrieved Modular Metal-on-Metal Total Hip Replacements

Trevor C. Gascoyne MSc, Richard M. Dyrkacz MSc, Thomas R. Turgeon MD, MPH, FRCSC, Colin D. Burnell MD, FRCSC, Urs P. Wyss PhD, Jan-M. Brandt Dipl.-lng, PhD

PII: S0883-5403(14)00395-7
DOI: doi: 10.1016/j.arth.2014.05.027
Reference: YARTH 54023

To appear in: *Journal of Arthroplasty*

Received date: 17 April 2014
Revised date: 27 May 2014
Accepted date: 31 May 2014

Corrosion on the Acetabular Liner Taper from Retrieved Modular Metal-on-Metal Total Hip Replacements

[1]Trevor C. Gascoyne MSc, [3]Richard M. Dyrkacz MSc, [1,2]Thomas R. Turgeon MD, MPH, FRCSC, [1,2]Colin D. Burnell MD, FRCSC, [1,3] Urs P. Wyss PhD, [1,2,3]Jan-M Brandt Dipl.-Ing, PhD
[1]Orthopaedic Innovation Centre
Concordia Hip and Knee Institute
1155 Concordia Avenue, R2K 2M9
[2]Department of Surgery, Orthopaedics
University of Manitoba
[3]Department of Mechanical Engineering
University of Manitoba
Winnipeg, Manitoba, Canada
Corresponding author:
Jan-M. Brandt
Director of Tribology
Orthopaedic Innovation Centre
Ph: (204)-926-1290
Fx: (204)-940-2263
jbrandt@orthoinno.com

Corrosion on the Acetabular Liner Taper from Retrieved Modular Metal-on-Metal Total Hip Replacements

Abstract:

Eight retrieved metal-on-metal total hip replacements displayed corrosion damage along the cobalt-chromium alloy liner at the taper junction with the modular Ti alloy acetabular shell. Scanning electron microscopy indicated the primary mechanism of corrosion to be grain boundary and associated crevice corrosion, which may have been accelerated through mechanical micromotion and galvanic corrosion as a result of dissimilar alloys. Coordinate measurements revealed up to 4.3 mm^3 of the cobalt-chromium alloy taper surface was removed due to corrosion, which is comparable to previous reports of corrosion damage on head-neck tapers. The acetabular liner-shell taper appears to be an additional source of metal corrosion products in modular total hip replacements and patients with these prostheses should be closely monitored for signs of adverse reaction towards corrosion by-products.

Keywords: Total hip arthroplasty, metal-on-metal, acetabular shell, taper, corrosion.

Introduction:

In recent years, metal-on-metal (MoM) total hip replacements (THR) and hip resurfacings have come under increasing scrutiny due to high revision rates and adverse patient outcomes (1). Elevated levels of metal ions in the blood (2, 3) have been associated with adverse tissue reactions to metal-on-metal wear and corrosion particles, such as acute lymphocytic vasculitis associated lesions or pseudotumors (4). These adverse tissue reactions to metal-on-metal wear and corrosion particles (5) have resulted in many MoM joint articulations being removed from the arthroplasty market (6, 7). Several reports (5, 8, 9) have linked the issues with MoM hip articulations with the release of metal ions and wear/corrosion particles from the implant. The source of these ions and particles, however, is not solely from the head-cup articulation, but also from both corrosion and fretting wear of the taper junctions which exist in contemporary modular total hip replacements (10, 11). The femoral head-neck taper interface is a documented source of metal ion release due to corrosion wear (11, 12), as is the femoral stem-neck junction in recently introduced modular neck designs (10, 13). An additional taper junction commonly exists between a MoM liner and the acetabular shell in modular acetabular cup designs, and has very recently been indicated to be a source of corrosion products and metal ions through corrosion processes (14). The present study examines the liner-shell taper junction as a further source of *in vivo* metal corrosion products and metal ions in contemporary, modular MoM bearings.

Methods and Materials:

Thirty-six MoM THRs with modular acetabular cups were retrieved from patients undergoing revision total hip arthroplasty and were collected at our institution between November 2011 and May 2013 as part of the local implant retrieval analysis program. The retrievals were placed in 10% formalin solution for 48 hours following surgery, neutralized, and manually cleaned using a soft-bristled nylon brush. Eight of these 36 cobalt-chromium (CoCr) alloy liners from MoM articulations displayed large, visibly corroded areas of liner-shell taper corrosion as well as visible material removal. These eight retrievals are the focus of the present study. All relevant patient data was collected (Table 1), available pre-operative X-rays were compiled and the inclination angle of the acetabular cup was measured by one consulting surgeon (TT), as previously described by Brandt et al., (15). Samples of whole blood were available for four patients at their last follow-up visit prior to their revision surgery, and were collected as part of the standard of care for patients with a MoM THR at our institution. The blood samples were analyzed for cobalt and chromium metal ions (Table 1) using an inductively coupled plasma mass spectrometer (London Laboratory Services Group, London Health Sciences Centre, London, ON).

The liner taper junction of each retrieval was scored visually for damage by three independent observers using a modified version of the method and criteria used by Dyrkacz et al., 2013 (16), based on the scoring method initially introduced by Goldberg et al. (17). The liner taper area was divided into four quadrants. Each quadrant was scored for the severity of corrosion present (0 to 3) and for the area of coverage (0 to 3), these numbers were multiplied to obtain a damage score for each quadrant, and all quadrants were summed to obtain a total damage score out of a maximum of 36. The taper area for all liners was reverse engineered using a coordinate measuring machine (CMM, PRISMO Navigator S-ACC 795, Zeiss, Oberkochen, Germany) to approximate the volume of material that was removed due to corrosion. Between 115,611 and 143,157 individual points were obtained at 0.1 mm spacing via a series of circular traces using a 5 mm diameter ruby-ball stylus. Each taper area was reconstructed in Geomagic Studio (Geomagic Inc., Morrisville, NC) using the data collected from the CMM. An ideal cone was fit to the taper area using a least-squares algorithm to approximate the initial geometry of the taper junction. The volume of the corrosion scar was calculated as the deviation between the ideal cone and the damaged area of the taper surface.

High magnification images were obtained of corroded areas on select acetabular liners from two different manufacturers (case 3 and case 8) using a scanning electron microscope (JSM-6610LV, JEOL USA Inc., Peabody, MA) at varying magnification. Intraclass correlation (R_{ICC}) was performed to determine the agreement between the corrosion damage scores from the three observers (SPSS Version 21; SPSS Inc., Chicago, IL) (15).

Results:

Clinical and retrieval analysis data for these eight cases was tabulated (Table 1). The MoM THRs were retrieved after an average of 3.4 years (95% CI; 2.3-4.5 years) in patients with an average age of 58 (95% CI; 45.3-70.7) at primary surgery, and body-mass index (BMI) of 31.6 kg/m^2 (95% CI; 26.0-37.2 kg/m^2). The intraclass correlation between observer damage scores was strong (R_{ICC}=0.775, p<0.001). The corroded areas of the liner tapers which can be seen as dull, greyed patches in contrast to the more polished taper surfaces (Figure 1).

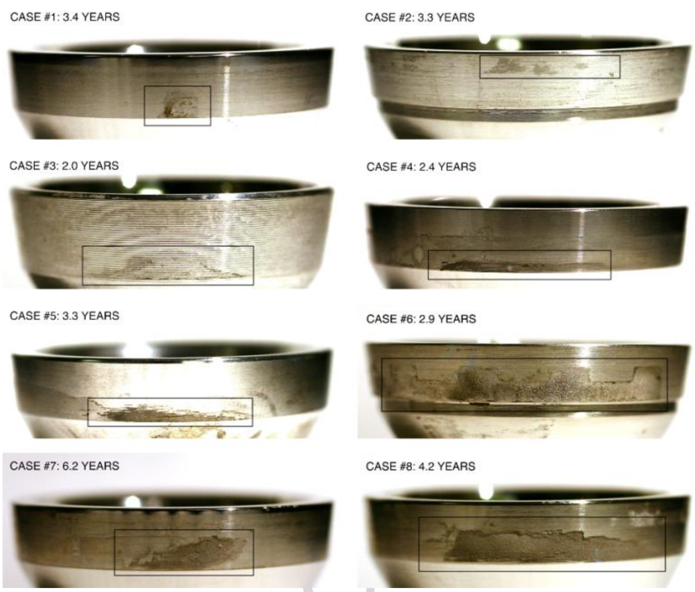

Figure 1: Photographs of the 8 cases of liner corrosion with implantation period.

The approximate volume of metal removed from the liner rim was computed through reverse engineering (Table 1; Figure 2). SEM micrographs were obtained of two different acetabular liners (case #8 - Articuleze®, DePuy Synthes, Warsaw, IN, Figure 3; case #3 - Conserve®, Wright Medical Technologies, Arlington, TN; Figure 4) to ascertain the primary mode of corrosion.

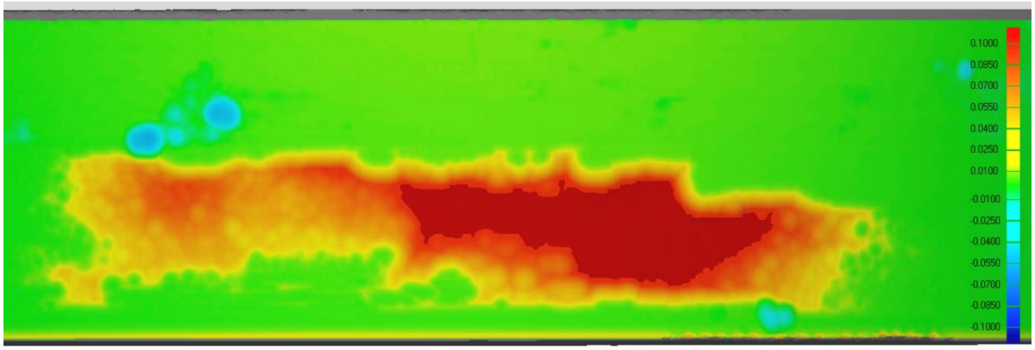

Figure 2: Colour deviation map of the corrosion scar of case #8.

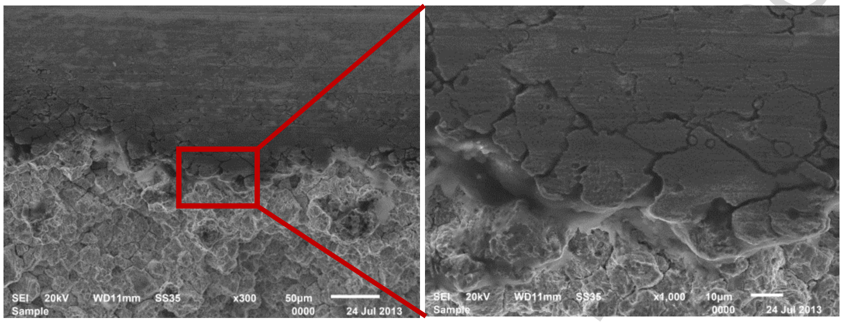

Figure 3: SEM micrographs of case #8 at 300x and 1000x magnification demonstrating crevice corrosion at the grain boundaries.

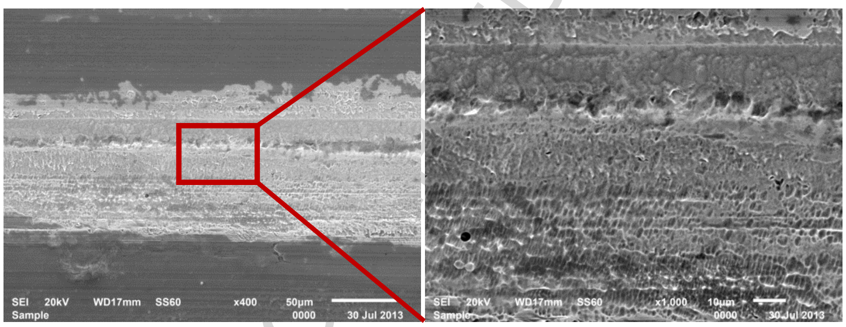

Figure 4: SEM micrographs of case #3 at 400x and 1000x magnification showing corrosion pits.

Table1: Summary of clinical and laboratory information collected for each retrieved MoM liner.

Case	Gender	Age @ SX	BMI (kg/m^2)	Implantation Period (yrs)	Reason for Revision	Cup Inclination	Co (µg/L)	Cr (µg/L)	MoM Liner (Manufacturer)	Damage Score	Taper ½ Angle (°)	Corrosion Scar (mm^3)
1	Male	64	26.3	3.4	Periprosthetic fracture	51°	-	-	Ultamet® (DePuy Synthes)	4.0	5.0	<0.01
2	Male	78	25.7	3.3	1-Stage infection	44°	-	-	R3® (Smith & Nephew)	10.7	9.0	<0.01
3	Female	61	28.2	2.0	High metal ion levels	42°	71.55	27.97	Conserve® (Wright Medical)	5.3	9.4	0.01
4	Male	47	42.4	2.4	1-Stage infection	46°	-	-	Ultamet® (DePuy Synthes)	13.7	5.0	0.02
5	Male	65	38.5	3.3	1-Stage infection	55°	-	-	Ultamet® (DePuy Synthes)	6.3	5.0	0.14
6	Male	63	29.3	2.9	Aseptic loosening	55°	1.83	3.83	R3® (Smith & Nephew)	12.0	9.0	0.26
7	Male	26	37.2	6.2	Aseptic loosening	43°	0.39	0.55	Ultamet® (DePuy Synthes)	5.3	4.9	0.22
8	Male	56	25.3	4.2	1-Stage infection	44°	0.97	0.58	Ultamet® (DePuy Synthes)	9.7	5.0	4.28

Discussion:

The MoM liners in the present study were mainly revised for various reasons. In only one case (case #3) did high metal ion levels directly result in revision surgery (Table 1). This case showed little indication for the cause of such high ion levels at the acetabular liner-shell taper, as it had an acceptable acetabular cup angle of 42° (18), a short implantation period of 2 years, and small amounts of surface damage on the liner taper junction. It is speculated that the articulating surfaces of this implant are the primary cause of the high metal-ion levels seen; however, this remains to be examined.

Cases 5 - 8 showed measurable amounts of corrosion (Table 1), yet none had exceptionally high levels of blood/plasma metal ions. The largest volume of corrosion was found on a liner that was implanted for 4.2 years in a 56 year old male patient with a BMI of 25 kg/m^2 (Figure 2). No evidence was found of issues relating to his MoM THR as he presented with low pre-revision metal ion levels and was revised due to infection. Only one case (case #3) showed evidence of an adverse local tissue reaction to metal debris which was noted upon revision surgery. As mentioned above, various sources such as the head-neck taper connection and wear at the articulating surface are well known to contribute to the overall metal debris, metal ion, and corrosion particle generation in modular MoM bearings.

The mechanism of corrosion of the taper junction in the Articuleze® (DePuy Synthes, Warsaw, IN) liners is considered to be grain boundary crevice corrosion (14), as suggested by the SEM images (Figure 3). It is likely that the corrosion mechanism was somewhat accelerated due to the small amount of micromotion along the liner taper junction (14, 19), but more substantially by galvanic corrosion due to the differences in electro-potential when dissimilar alloys are paired such as the CoCr alloy liner and titanium acetabular shell (14, 17). Energy dispersive spectroscopy (INCA 250 & Xmax 20, Oxford Instruments America, Concord, MA) was also performed concurrently with SEM imaging to assess ion leaching of the CoCr alloy liner (16). Some selective leaching of molybdenum and cobalt was noted while chromium composition remained largely unchanged; a similar finding to that of Dyrkacz et al. (16).

Numerous reports have indicated that taper junctions of modular femoral heads can be a significant source of corrosion product release, resulting in adverse local tissue reactions as well as systemic toxicity from metal ion build-up (5, 10, 12). In the presented cases, up to 4.3 mm^3 (case #8) was released from the liner-shell taper junction into the joint cavity and the body. The rate of corrosion on this liner taper surface (1.02 mm^3/yr) is comparable to head-neck taper corrosion rates reported in the literature; 0.01 to 3.15 mm^3/yr (20), 0.59 to 4.87 mm^3/yr (21), and an average of 1.9 mm^3/yr (22). The similarity of corrosion rates between these taper junctions indicates that liner-shell tapers may pose the same risk to patients as head-neck taper corrosion.

While the use of MoM THRs has sharply declined in recent years (1), the liner corrosion reported in the present study could become an issue for other THR designs in which a modular acetabular shell and liner are joined by a taper junction. Such designs, as noted in some dual-mobility THRs and ceramic liners with an external metal taper, should therefore be used at the surgeon's discretion when specifically indicated to reduce potential detrimental metal debris reactions in their patients.

Limitations of this study include the small number of samples displaying corrosion at the taper interface between the acetabular liner and shell as we were not able to associate liner-shell corrosion with any discernible patient reactions. Blood metal ion levels were available for only 4 of the 8 cases included in this study which limits our ability to associate liner taper corrosion with systemic metal ion levels.

The present study identifies a new source of corrosion product release for MoM THRs. Although this study was not able to demonstrate a link between liner-shell taper corrosion and discernible patient reactions (blood ion levels, adverse tissue reactions), the evidence presented indicates that corrosion at this taper interface may have similar implications to corrosion of the head-neck taper interface (5, 10, 23). Therefore, patients with modular metal-on-metal THRs should be very closely monitored for signs of adverse reactions to the release of metal corrosion products in addition to metal wear debris.

Acknowledgements

Funding was provided by the University of Manitoba through their annual Department of Surgery Research Grant.

References

1. Singh G, Meyer H, Ruetschi M, Chamaon K, Feuerstein B, Lohmann CH. Large-diameter metal-on-metal total hip arthroplasties: A page in orthopedic history? Journal of biomedical materials research Part A. 2013 Mar 25. PubMed PMID: 23529961.
2. Sidaginamale RP, Joyce TJ, Lord JK, Jefferson R, Blain PG, Nargol AV, et al. Blood metal ion testing is an effectivescreening tool to identify poorly performing metal-on-metal bearingsurfaces. Bone & joint research. 2013;2(5):84-95. PubMed PMID: 23836464. Pubmed Central PMCID: 3670540.
3. Vendittoli PA, Roy A, Mottard S, Girard J, Lusignan D, Lavigne M. Metal ion release from bearing wear and corrosion with 28 mm and large-diameter metal-on-metal bearing articulations: a follow-up study. The Journal of bone and joint surgery British volume. 2010 Jan;92(1):12-9. PubMed PMID: 20044673.
4. Kwon YM, Thomas P, Summer B, Pandit H, Taylor A, Beard D, et al. Lymphocyte proliferation responses in patients with pseudotumors following metal-on-metal hip resurfacing arthroplasty. Journal of orthopaedic research : official publication of the Orthopaedic Research Society. 2010 Apr;28(4):444-50. PubMed PMID: 19834954.
5. Whitehouse MR, Endo M, Masri BA. Adverse Local Tissue Reaction Associated With a Modular Hip Hemiarthroplasty. Clinical orthopaedics and related research. 2013 Jun 29. PubMed PMID: 23813241.
6. DePuy O. Statement on Discontinuation of ULTAMET ® Metal-on-Metal and COMPLETE™ Ceramic-on-Metal Hip Systems. DePuy-Synthes Press Release. 2013 May 16, 2013.
7. Nephew Sa. Voluntary market withdrawal of hip component. Smith and Nephew Orthopaedics. 2012 June 1, 2012.
8. Bozic KJ, Browne J, Dangles CJ, Manner PA, Yates AJ, Jr., Weber KL, et al. Modern metal-on-metal hip implants. The Journal of the American Academy of Orthopaedic Surgeons. 2012 Jun;20(6):402-6. PubMed PMID: 22661570.
9. Langton DJ, Jameson SS, Joyce TJ, Gandhi JN, Sidaginamale R, Mereddy P, et al. Accelerating failure rate of the ASR total hip replacement. The Journal of bone and joint surgery British volume. 2011 Aug;93(8):1011-6. PubMed PMID: 21768621.
10. Gill IP, Webb J, Sloan K, Beaver RJ. Corrosion at the neck-stem junction as a cause of metal ion release and pseudotumour formation. The Journal of bone and joint surgery British volume. 2012 Jul;94(7):895-900. PubMed PMID: 22733942.
11. Cooper HJ, Della Valle CJ, Berger RA, Tetreault M, Paprosky WG, Sporer SM, et al. Corrosion at the head-neck taper as a cause for adverse local tissue reactions after total hip arthroplasty. The Journal of bone and joint surgery American volume. 2012 Sep 19;94(18):1655-61. PubMed PMID: 23289127. Pubmed Central PMCID: 3444948.
12. Kop AM, Swarts E. Corrosion of a hip stem with a modular neck taper junction: a retrieval study of 16 cases. The Journal of arthroplasty. 2009 Oct;24(7):1019-23. PubMed PMID: 18835686.

13. Dunbar MJ. The proximal modular neck in THA: a bridge too far: affirms. Orthopedics. 2010 Sep;33(9):640. PubMed PMID: 20839691.
14. Higgs GB, Hanzlik JA, Macdonald DW, Gilbert JL, Rimnac CM, Kurtz SM, et al. Is Increased Modularity Associated With Increased Fretting and Corrosion Damage in Metal-On-Metal Total Hip Arthroplasty Devices?: A Retrieval Study. The Journal of arthroplasty. 2013 Aug 1. PubMed PMID: 23910820.
15. Brandt JM, Gascoyne TC, Guenther LE, Allen A, Hedden DR, Turgeon TR, et al. Clinical failure analysis of contemporary ceramic-on-ceramic total hip replacements. Proceedings of the Institution of Mechanical Engineers Part H, Journal of engineering in medicine. 2013 Aug;227(8):833-46. PubMed PMID: 23736992.
16. Dyrkacz RM, Brandt JM, Ojo OA, Turgeon TR, Wyss UP. The influence of head size on corrosion and fretting behaviour at the head-neck interface of artificial hip joints. The Journal of arthroplasty. 2013 Jun;28(6):1036-40. PubMed PMID: 23528551.
17. Goldberg JR, Gilbert JL, Jacobs JJ, Bauer TW, Paprosky W, Leurgans S. A multicenter retrieval study of the taper interfaces of modular hip prostheses. Clinical orthopaedics and related research. 2002 Aug(401):149-61. PubMed PMID: 12151892.
18. DePuy O. Pinnacle Hip Solutions: Polyethylene Surgical Technique. DePuy Synthes2013.
19. Gilbert JL, Buckley CA, Jacobs JJ. In vivo corrosion of modular hip prosthesis components in mixed and similar metal combinations. The effect of crevice, stress, motion, and alloy coupling. Journal of biomedical materials research. 1993 Dec;27(12):1533-44. PubMed PMID: 8113241.
20. Langton DJ, Sidaginamale R, Lord JK, Nargol AV, Joyce TJ. Taper junction failure in large-diameter metal-on-metal bearings. Bone & joint research. 2012 Apr;1(4):56-63. PubMed PMID: 23610672. Pubmed Central PMCID: 3626207.
21. Bishop N, Witt F, Pourzal R, Fischer A, Rutschi M, Michel M, et al. Wear patterns of taper connections in retrieved large diameter metal-on-metal bearings. Journal of orthopaedic research : official publication of the Orthopaedic Research Society. 2013 Jul;31(7):1116-22. PubMed PMID: 23440943.
22. Nassif NA, Nawabi DH, Stoner K, Elpers M, Wright T, Padgett DE. Taper Design Affects Failure of Large-head Metal-on-metal Total Hip Replacements. Clinical orthopaedics and related research. 2014 Feb;472(2):564-71. PubMed PMID: 23801060. Pubmed Central PMCID: 3890169.
23. Scully WF, Teeny SM. Pseudotumor associated with metal-on-polyethylene total hip arthroplasty. Orthopedics. 2013 May;36(5):e666-70. PubMed PMID: 23672921.