Aseptic Loosening of Metal-on-Metal (MOM) Total Hip Arthroplasties (THA) with Large-Diameter Heads

13

Christoph H. Lohmann, G. Singh, G. Goldau, T. Müller, B. Feuerstein, M. Rütschi, and H. Meyer

Large-diameter metal-on-metal (MOM) bearing surfaces evolved directly from the success of hip surface replacement using MOM bearing surfaces. In cases of failed femoral components with well-fixed acetabular components, large-diameter bearing surfaces served well as revision implants compatible with standard stems to avoid cup revision. Reduced dislocation rates with large-diameter bearings and potentially reduced wear (Lombardi et al. 2011) due to increased fluid-film lubrication prompted their use in primary THA. However, unacceptably high revision rates, early aseptic loosening, adverse tissue reactions and pseudotumour formation and increased metal ion release have been observed in large-diameter MOM THAs (Smith et al. 2012; Bolland et al. 2011; Langton et al. 2010; Barrett et al. 2012; Hasegawa et al. 2012; Bosker et al. 2012; Berton et al. 2010; Matthies et al. 2011). The possible reasons for this phenomenon are failure to achieve optimum fluid-film lubrication, edge loading and impingement, increased torque from the large head as

C.H. Lohmann (✉) • G. Goldau • T. Müller • H. Meyer
Department of Orthopaedic Surgery,
Otto-von-Guericke-University, Magdeburg, Germany
e-mail: lohmannch@t-online.de

G. Singh
Department of Orthopaedic Surgery, Otto-von-Guericke-University,
Magdeburg, Germany

University Orthopaedics, Hand and Reconstructive Microsurgery Cluster,
National University Health System, Singapore, Singapore

B. Feuerstein
Institute for Mechanical Engineering, Magdeburg-Stendal
University of Applied Sciences, Magdeburg, Germany

M. Rütschi
Department of Orthopaedic Surgery, Loretto Hospital,
Freiburg, Germany

K. Knahr (ed.), *Total Hip Arthroplasty*,
DOI 10.1007/978-3-642-35653-7_13, © EFORT 2013

well as corrosion and wear at the cone-taper interface leading to deposition of large amounts of metal wear debris in the periprosthetic tissues.

13.1 Evolution of Large-Diameter Metal-on-Metal Bearing Surfaces

The use of metal-on-metal (MOM) bearing surfaces in total hip arthroplasty (THA) is not a new phenomenon. The McKee-Farrar (Brown et al. 2002; Howie et al. 2005) and Ring (Bryant et al. 1991) implants had MOM bearing surfaces in the 1960s. The subsequent advent of the Charnley hip (Jacobsson et al. 1996) in the 1970s led to a frameshift in clinical practice, with early promising results leading to most surgeons abandoning MOM bearing surfaces for metal-on-polyethylene (MOP). Advances in the understanding of osteolysis secondary to polyethylene wear particles coupled with the phenomenon of younger patients with higher activity demands undergoing THA surgery led to a quest for hard-on-hard bearing surfaces and the reintroduction of MOM hips in the late 1980s. Second-generation MOM with high-carbon cobalt-chrome alloy bearing surfaces were developed and the first of these was introduced into clinical practice by Weber in 1988 (Weber 1992). These were thought to have low-wear profiles and therefore increased implant longevity especially in the young patient. Large-diameter MOM heads (36-mm diameter or larger) evolved directly from the success of hip surface replacement as salvage implants which were compatible with standard stems in cases of failed femoral components with well-fixed acetabular components, in an attempt to avoid cup revision. Large-diameter bearings then gained popularity in an attempt to reduce the dislocation risk in revision as well as primary THA. They were also shown to increase the stability and reduce the risk of dislocation of THA (Lombardi et al. 2011) by increasing the distance the prosthetic head has to travel to dislocate. The risk of impingement was also thought to be reduced with large heads, thus theoretically reducing metallic wear debris in MOM hips (Fig. 13.1).

MOM bearing surfaces were not without problems, the main concerns being elevated metal ions in blood, urine and solid organs, potential hypersensitivity including pseudotumour formation and aseptic lymphocyte-dominated vasculitis-associated lesion (ALVAL) reactions, potential carcinogenesis, teratogenicity and early aseptic loosening (Smith et al. 2012; Bozic et al. 2012; Morrey et al. 2011; Catelas and Wimmer 2011; Delaunay et al. 2010; Browne et al. 2010; Mann et al. 2012; Haddad et al. 2011; Shetty and Villar 2006; MacDonald 2004; Amstutz and Grigoris 1996; Fabi et al. 2012; Gonzalez et al. 2011). Large-diameter heads, which theoretically should increase fluid-film lubrication and reduce wear in addition to increasing stability, had paradoxically higher revision rates and failed earlier in the context of MOM hips (Smith et al. 2012). Smith et al. (2012) reported an analysis of 400,000 primary THA procedures (out of which 31,171, 8 %, had stemmed MOM hips) from the National Joint Registry of England and Wales, which showed that larger head sizes increased implant failure rates for MOM hips. Overall 5-year revision rate for MOM prostheses was 6.2 % and 5-year MOM revision rates for 28-mm and 52-mm heads in men aged 60 years were 3.2 and 5.1 %, respectively. In contrast, they reported that ceramic-on-ceramic bearing surfaces with large heads

Fig. 13.1 Plain anteroposterior radiograph of a patient with large-diameter MOM THA with osteolysis at the greater trochanter

did better than conventional 28-mm head sizes. Potential reasons for this rather surprising observation include failure to achieve optimum fluid-film lubrication, edge loading, increased torque from the large head or corrosion and wear at the cone-taper interface (head-neck junction). Perhaps these phenomena represent inevitable adverse consequences of modularity superimposed on a simple exchange of the conventional MOP bearing on a stem for a large MOM bearing.

Certain MOM designs such as the ASR hip (Bernthal et al. 2012) have had unacceptably high revision rates and have been withdrawn from the market. This has perhaps led to the assumption among some that the failure of MOM hips is exclusively an implant-specific phenomenon. Alison Smith and colleagues (2012) reported that large-head MOM failure is a class effect and is not implant specific. We believe that both phenomena prevail-implant-specific failures in addition to an overall class effect, as exemplified by the ASR hip. Despite the data that has recently emerged, MOM bearing surfaces are still being used rather extensively. In 2009, 35 % of THA surgeries in the United States had MOM bearings. At present, there are more than 500,000 patients with implanted MOM hips in the USA and more than 40,000 in the UK (Smith et al. 2012).

13.2 Modularity in Large-Diameter MOM THA

In general, modular THA implant designs confer distinct advantages such as increased intraoperative flexibility, adjustment of leg length and offset via the head-neck taper and femoral anteversion via the neck-stem taper. This potentially leads to optimal restoration of soft tissue tension and biomechanics of the replaced hip. Other advantages of modularity include decreased implant inventory and the ability to remove the femoral head at revision surgery to improve exposure or change head size without component removal (Srinivasan et al. 2012). However, multiple modular junctions represent additional sites for implant failure through fretting and crevice corrosion and release of metal particles. This may lead to instability and, in the worst-case scenario, dissociation at the modular interface (Jacobs et al. 1995). Retrieval studies have demonstrated that even with modern taper designs and corrosion-resistant materials, fretting movement and corrosion may result at modular interfaces. This is especially so when mixed metals are used, i.e. acetabular cup and head components made from cobalt-chrome alloys coupled with titanium stems (Kop and Swarts 2009). Malviya et al. (2011) reported an increase in whole blood metal ion levels in patients with large-diameter metal-on-metal hip arthroplasties and suggested that this phenomenon may be due to micromotion at the head-neck junction or excess stem micromotion (Malviya et al. 2011).

In the context of large-diameter MOM hip arthroplasties, exchanging the bearing couple from MOP to MOM and subsequently increasing the head size results in an increased sliding distance of the bearing couple and moment arm from the cone-taper to the joint line. The behaviour of the stem may also be affected as there are documented differences in the frictional torque of MOM and MOP bearing surfaces, with MOM bearings having increased torque on the trunnion. Edge-loading, low clearance and psoas impingement are other problems which have been described in the context of large diameter MoM hips (Underwood et al. 2012, Brockett et al. 2008, Browne et al. 2011, Cobb et al. 2011). Superimposed on these complex alterations in biomechanics are the inherent problems of modular interfaces, as discussed above.

13.3 Corrosion at the Cone-Taper Interface

Modular mixed-metal THA designs allow combination of the wear resistance of cobalt-chrome femoral heads with the flexibility of titanium stems. Collier and colleagues (1992) studied the cone-taper interface of 139 retrieved modular hip arthroplasties sent by 87 surgeons and found that in mixed-metal systems there was evidence of time-dependent corrosion at the taper interface whereas there was no evidence of corrosion among the implants which had components made from the same alloy. In an earlier study, Collier et al. (1991) discussed that the crevice provided between the head and neck will function as a corrosion site if it is wide enough to allow aqueous intrusion but sufficiently narrow to maintain a stagnant zone. As corrosion progresses in this zone, oxygen is depleted, resulting in an excess of positively charged metal ions in the aqueous environment of the crevice. This is then balanced by the migration of negatively charged chloride ions resulting in the

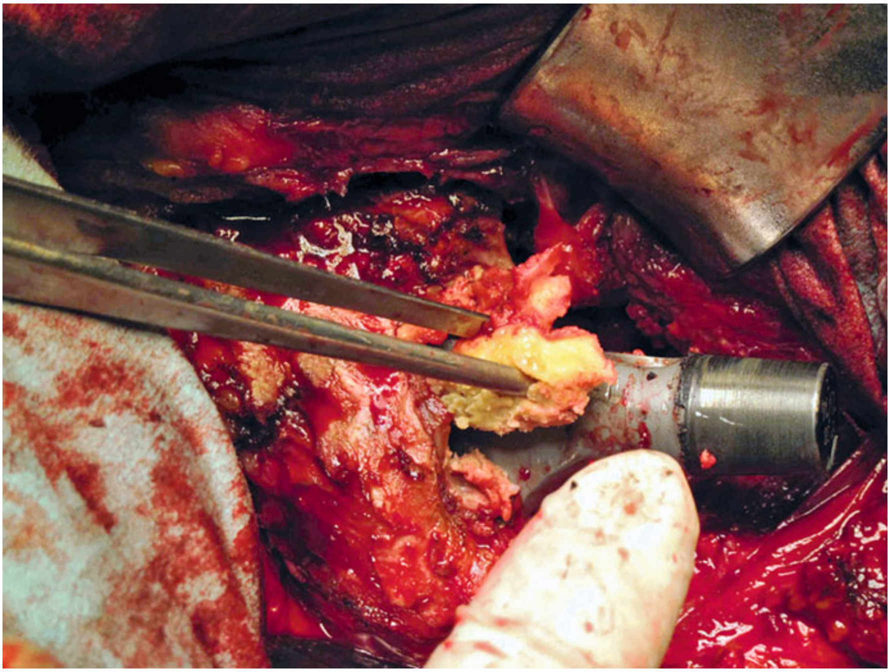

Fig. 13.2 Intraoperative photograph showing corrosion of the taper and necrotic periprosthetic tissue resembling thick pus in gross appearance. Cultures were sterile

production of hydrochloric acid which is capable of dissolving both the otherwise stable cobalt and titanium alloys (Collier et al. 1992; Collier et al. 1991).

A mixed-alloy combination has been thought to be resistant to galvanically accelerated crevice corrosion in the context of hip arthroplasty. However, (Collier et al. 1992) reported that in a detailed examination of the results of some these studies, there were indications for the potential for corrosion. Although titanium and its alloys reportedly develop a protective layer by passivation, it is evident that a combination of different metals like iron and cobalt-chrome or titanium and cobalt-chrome produces an electrochemical potential. Willert et al. (2005) reported that the passivation layer of the alloy safely protects the release of ions and may inhibit electrochemical conduction. However, micromotion may damage and initiate electrochemical dissolution of the protective layer leading to galvanic corrosion in the context of mixed metals. Wear as well as corrosion debris may be released from the surface as a result of continued fretting corrosion and oscillating micromotion (Fig. 13.2).

It has been shown that corrosion occurs at the cone-taper interface but most of the studies in the literature are focussed on implants using conventional 28-mm heads (Gill et al. 2012; Cook et al. 1994; Huber et al. 2009). The authors believe that corrosion occurring at the cone-taper interfaces of large-diameter MOM THAs leads to instability at the cone-taper junction, deposition of metal wear and corrosion debris in the periprosthetic tissues and consequent early aseptic loosening and failure. In the authors' series of 114 revisions of large-diameter MOM THAs with a mean duration

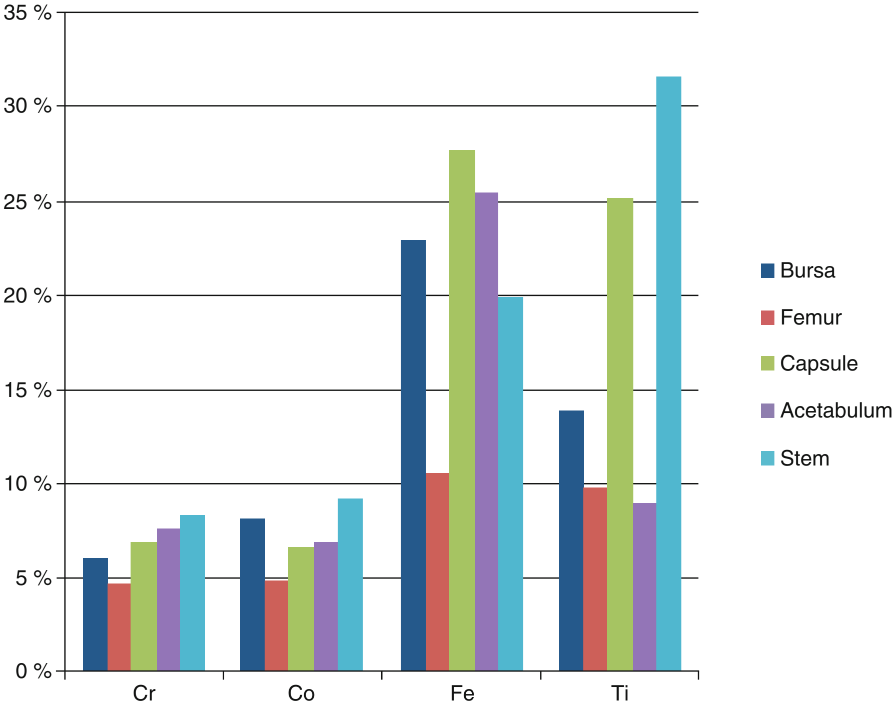

Fig. 13.3 Element analysis showing the relative proportions of different metals in the periprosthetic tissue samples

of implantation of 46 months, 107 retrieved implants (94 %) had corrosion as well as gross instability at the cone-taper interface (the heads were loose on the taper). Electrochemical studies on the stem and head adapter showed an open circuit potential in normal saline suggesting galvanic corrosion. Periprosthetic tissues were processed by routine histology and immunological responses to metal wear debris were examined. Periprosthetic tissue metal content was also analysed, and titanium as well as iron was detected at higher levels compared with cobalt and chromium. This is most likely due to abrasive wear at the failed cone-taper junction. Head size did not correlate with periprosthetic tissue metal content (Meyer et al. 2012) (Fig. 13.3).

13.4 Tissue Responses in Failed Large-Diameter MOM THAs

Immune responses to particulate wear debris are the subject of much controversy and not fully understood. There appears to be a complex interplay of immunological processes which contribute to periprosthetic osteolysis, metal hypersensitivity and aseptic loosening of endoprostheses. Most of the current literature (Barrett et al. 2012; Goodman 2007; Lohmann et al. 2007; Ng et al. 2011) emphasises two key responses – a nonspecific macrophage-mediated granulomatous response which lacks immunological memory and is also seen in foreign body granulomatous reactions (e.g. suture

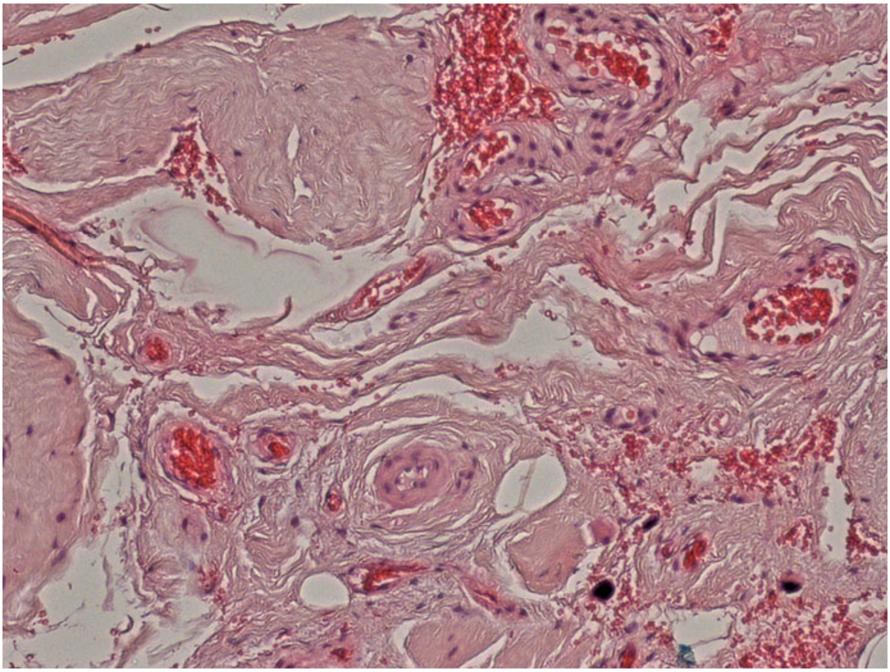

Fig. 13.4 Histology slide of retrieval tissue demonstrating vasculitis and haemorrhage

material) and a T-cell-mediated type IV hypersensitivity reaction which involves diffuse and perivascular lymphocytic infiltrates. This latter type of response involves a specific antigen, co-stimulatory molecules, an antigen presenting cell and T lymphocytes. The lymphocyte-dominated response is adaptive and has immunological memory and is also seen in several autoimmune disease processes (Goodman 2007; Lohmann et al. 2007). Histologic findings common to both types of responses include vasculitis with perivascular and intramural lymphocytic infiltration of the postcapillary vessels, swelling of the vascular endothelium, recurrent localised bleeding and necrosis. A host of inflammatory cytokines such as interleukin-6 (IL-6), prostaglandin E_2 (PGE_2) and tumour necrosis factor alpha (TNFα) have been implicated in the pathways leading to periprosthetic osteolysis (Fig. 13.4).

Lymphocyte-dominated responses have been seen in failed 28-mm MOM hips. In our histological analysis of periprosthetic tissue specimens taken from 114 revision large-diameter MOM hips, there were only nine cases which displayed a lymphocyte-dominated type of response (Meyer et al. 2012). All other cases had a predominantly foreign body type of response and areas of necrosis with macrophages being the most numerous cell type. This may be attributed to the fact that in the studies with 28-mm heads, the cone-taper interfaces were more stable, resulting in a different profile of released particulate wear debris (Fig. 13.5).

Immunological reactions to metal wear debris can result in early aseptic loosening and, if not recognised, may result in devastating necrosis of surrounding muscle and bone. Barrett et al. (2012) suggested that MOM THA with second-generation

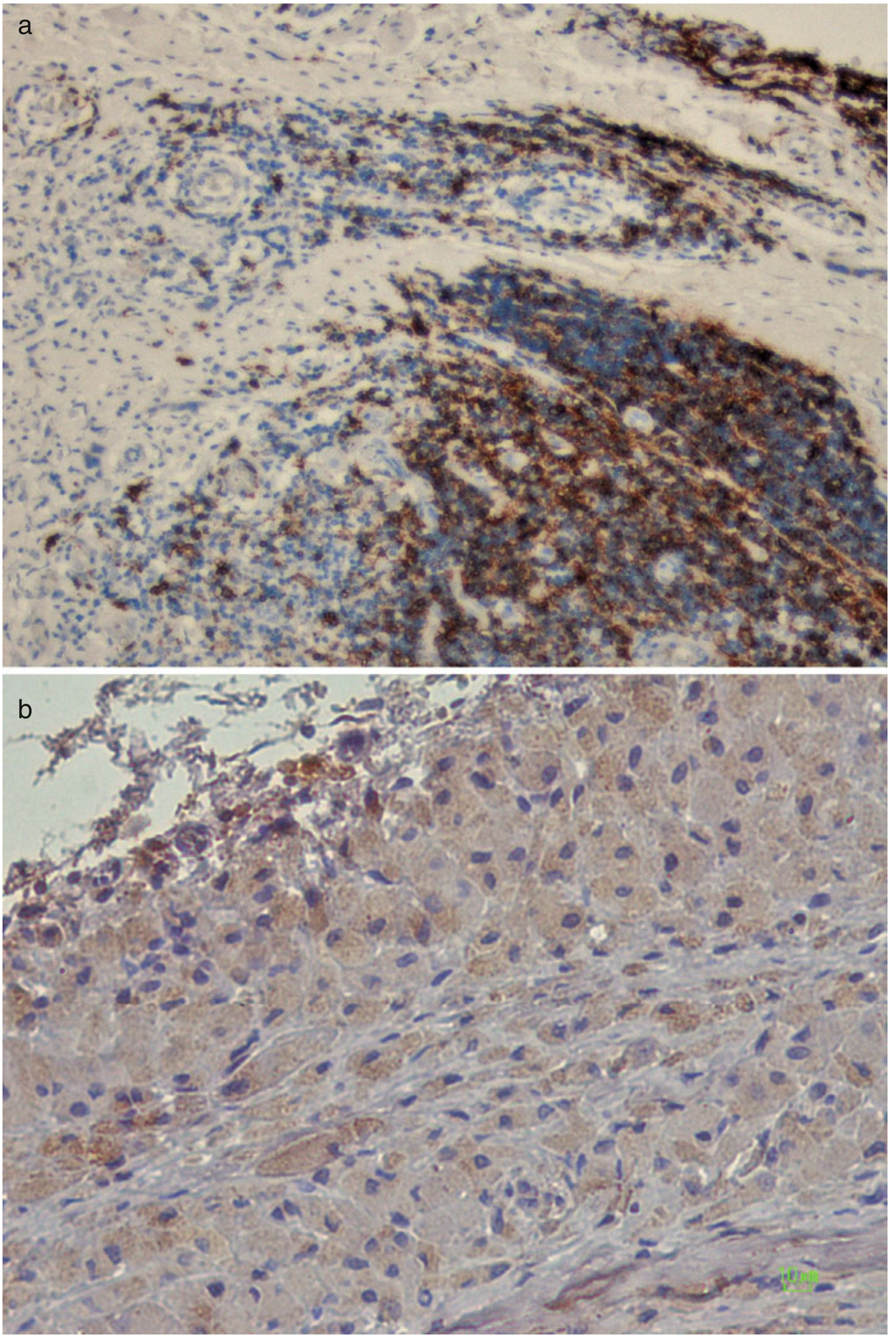

Fig. 13.5 Immunohistochemistry of retrieval tissue (**a**) CD20 antibody staining for B cells, 10 × magnification, and (**b**) CD68 antibody staining for cells of the monocyte-macrophage lineage, 20 × magnification

modular designs is a reasonable choice for selected patients, but surgeons using these implants must be aware of the potential for adverse reaction to metallic debris (ARMED). This includes metallosis, pseudotumours and ALVAL. Further research is necessary to better characterise the immunological reactions to metal particles and wear debris. The authors are of the view that large-diameter MOM THA should not be used in primary THA, given the potential problems and high revision rates secondary to aseptic loosening.

13.5 Summary

In summary, large-diameter MOM bearing surfaces have a significantly higher revision rate and early failure due to aseptic loosening. The key mechanisms contributing to this are likely to be failure to achieve optimum fluid-film lubrication, edge loading and impingement, increased torque forces and corrosion at the cone-taper interface leading to instability and loosening as well as deposition of large amounts of metal particulate debris in the periprosthetic tissues. Immunological responses to metal wear debris are still a subject of ongoing research, and at present, the authors do not recommend the use of large-diameter MOM bearing surfaces for primary THA.

References

Amstutz HC, Grigoris P (1996) Metal on metal bearings in hip arthroplasty. Clin Orthop Relat Res 329 (Suppl.):S11–S34(Review)

Barrett WP, Kindsfater KA, Lesko JP (2012) Large-diameter modular metal-on-metal total hip arthroplasty: incidence of revision for adverse reaction to metallic debris. J Arthroplasty 27(6):976.e1–983.e1

Bernthal NM, Celestre PC, Stravrakis AI, Ludington JC, Oakes DA (2012) Disappointing short-term results with the Depuy ASR XL metal-on-metal total hip arthroplasty. J Arthroplasty 27(4):539–544, Epub 13 Oct 2011

Berton C, Girard J, Krantz N, Migaud H (2010) The Durom large diameter head acetabular component: early results with a large diameter metal-on-metal bearing. J Bone Joint Surg Br 92-B:202–208

Bolland BJRF, Culliford DJ, Langton DJ, Millington JPS, Arden NK, Latham JM (2011) High failure rates with a large diameter hybrid metal-on-metal total hip replacement: clinical radiological and retrieval analysis. J Bone Joint Surg Br 93(5):608–615

Bosker BH, Ettema HB, Boomsma MF, Kollen BJ, Maas M, Verheyen CCPM (2012) High incidence of pseudotumour formation after large-diameter metal-on-metal total hip replacement: a prospective cohort study. J Bone Joint Surg Br 94-B:755–761

Bozic KJ, Browne J, Dangles CJ, Manner PA, Yates AJ Jr, Weber KL, Boyer KM, Zemaitis P, Woznica A, Turkelson CM, Wies JL (2012) Modern metal-on-metal hip implants. J Am Acad Orthop Surg 20(6):402–406, Review

Brockett CL, Harper P, Williams S, Isaac GH, Dwyer-Joyce RS, Jin Z, Fisher J (2008) The influence of clearance on friction, lubrication and squeaking in large diameter metal-on-metal hip replacements. J Mater Sci Mater Med 19(4):1575–1579

Brown SR, Davies WA, DeHeer DH, Swanson AB (2002) Long-term survival of McKee-Farrar total hip prostheses. Clin Orthop Relat Res (402):157–163

Browne JA, Bechtold CD, Berry DJ, Hanssen AD, Lewallen DG (2010) Failed metal-on-metal hip arthroplasties: a spectrum of clinical presentations and operative findings. Clin Orthop Relat Res 468:2313–2320

Browne JA, Polga DJ, Sierra RJ, Trousdale RT, Cabanela ME (2011) Failure of larger-diameter metal-on-metal total hip arthroplasty resulting from anterior iliopsoas impingement. J Arthroplasty 26(6):978.e5–e8

Bryant MJ, Mollan RA, Nixon JR (1991) Survivorship analysis of the ring hip arthroplasty. J Arthroplasty 6(Suppl.):S5–S10

Catelas I, Wimmer MA (2011) New insights into wear and biological effects of metal-on-metal bearings. J Bone Joint Surg Am 93(suppl 2):76–83

Cobb JP, Davda K, Ahmad A, Harris SJ, Masjedi M, Hart AJ (2011) Why large-head metal-on-metal hip replacements are painful: the anatomical basis of psoas impingement on the femoral head-neck junction. J Bone Joint Surg Br 93(7):881–885

Collier JP, Suprenant VA, Jensen RE, Mayor MB (1991) Corrosion at the interface of cobalt-alloy heads on titanium-alloy stems. Clin Orthop Relat Res 271:305–312

Collier JP, Suprenant VA, Jensen RE, Mayor MB, Suprenant HP (1992) Corrosion between the components of modular femoral hip prostheses. J Bone Joint Surg Br 74-B:511–517

Cook SD, Barrack RL, Clemow AJT (1994) Corrosion and wear at the modular interface of uncemented femoral stems. J Bone Joint Surg Br 76-B:68–72

Delaunay C, Petit I, Learmonth ID, Oger P, Vendittoli PA (2010) Metal-on-metal bearings total hip arthroplasty: the cobalt and chromium ions release concern. Orthop Traumatol Surg Res 96:894–904

Fabi D, Levine B, Paprosky W, Della Valle C, Sporer S, Klein G, Levine H, Hartzband M (2012) Metal-on-metal total hip arthroplasty: causes and high incidence of early failure. Orthopedics 35(7):e1009–e1016

Gill IPS, Webb J, Sloan K, Beaver RJ (2012) Corrosion at the neck-stem junction as a cause of metal ion release and pseudotumour formation. J Bone Joint Surg Br 94-B:895–900

Gonzalez MH, Carr R, Walton S, Mihalko WM (2011) The evolution and modern use of metal-on-metal bearings in total hip arthroplasty. Instr Course Lect 60:247–255

Goodman SB (2007) Wear particles, periprosthetic osteolysis and the immune system. Biomaterials 28:5044–5048

Haddad FS, Thakrar RR, Hart AJ, Skinner JA, Nargol AV, Nolan JF, Gill HS, Murray DW, Blom AW, Case CP (2011) Metal-on-metal bearings: the evidence so far. J Bone Joint Surg Br 93(5):572–579, Review

Hasegawa M, Yoshida K, Wakabayashi H, Sudo A (2012) Cobalt and chromium ion release after large-diameter metal-on-metal total hip arthroplasty. J Arthroplasty 27(6):990–996, Epub 8 Feb 2012

Howie DW, McCalden RW, Nawana NS, Costi K, Pearcy MJ, Subramanian C (2005) The long-term wear of retrieved McKee-Farrar metal-on-metal total hip prostheses. J Arthroplasty 20(3):350–357

Huber M, Reinisch G, Trettenhahn G, Zweymuller K, Lintner F (2009) Presence of corrosion products and hypersensitivity-associated reactions in periprosthetic tissue after aseptic loosening of total hip replacements with metal bearing surfaces. Acta Biomater 5:172–180

Jacobs JJ, Urban RM, Gilbert JL, Skipor AK, Black J, Jasty M, Galante JO (1995) Local and distant products from modularity. Clin Orthop Relat Res 319:94–105

Jacobsson SA, Djerf K, Wahlström O (1996) Twenty-year results of McKee-Farrar versus Charnley prosthesis. Clin Orthop Relat Res 329:S60–S68

Kop AM, Swarts E (2009) Corrosion of a hip stem with a modular neck taper junction. A retrieval study of 16 cases. J Arthroplasty 24(7):1019–1023

Langton DJ, Jameson SS, Joyce TJ, Hallab NJ, Natu S, Nargol AVF (2010) Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement: a consequence of excess wear. J Bone Joint Surg Br 92-B:38–46

Lohmann CH, Nuechtern JV, Willert HG, Junk-Jantsch S, Ruether W, Pflueger G (2007) Hypersensitivity reactions in total hip arthroplasty. Orthopedics 30(9):760–761

Lombardi AV Jr, Skeels MD, Berend KR, Adams JB, Franchi OJ (2011) Do large heads enhance stability and restore native anatomy in primary total hip arthroplasty? Clin Orthop Relat Res 469(6):1547–1553

MacDonald SJ (2004) Metal-on-metal total hip arthroplasty: the concerns. Clin Orthop Relat Res 429:86–93 (Review)

Malviya A, Ramaskandhan JR, Bowman R, Kometa S, Hashmi M, Lingard E, Holland JP (2011) What advantage is there to be gained by using large modular metal-on-metal bearings in routine primary hip replacement? A preliminary report of a prospective randomized controlled trial. J Bone Joint Surg Br 93-B:1602–1609

Mann BS, Whittingham-Jones PM, Shaerf DA, Nawaz ZS, Harvie P, Hart AJ, Skinner JA (2012) Metal-on-metal bearings, inflammatory pseudotumours, and their neurological manifestations. Hip Int 22(2):129–136

Matthies AK, Henckel J, Skinner JA, Hart AJ (2011) A retrieval analysis of explanted Durom metal-on-metal hip arthroplasties. Hip Int 21(6):724–731

Meyer H, Mueller T, Goldau G, Chamaon K, Ruetschi M, Lohmann CH (2012) Corrosion at the cone-taper interface leads to failure of large-diameter metal-on-metal total hip arthroplasties. Clin Orthop Relat Res 470(11):3101–3108

Morrey BF, Berry DJ, An K, Kitaoka HB, Pagnano MW (2011) Joint replacement arthroplasty basic science, hip, knee and ankle. In: Fourth Centennial Edition, Vol II. Wolters Klumer Health, Philadelphia, p 510–514

Ng VY, Lombardi AV, Berend KR, Skeels MD, Adams JB (2011) Perivascular lymphocytic infiltration is not limited to metal-on-metal bearings. Clin Orthop Relat Res 469:523–529

Shetty VD, Villar RN (2006) Development and problems of metal-on-metal hip arthroplasty. Proc Inst Mech Eng H 220(2):371–377 (Review)

Smith AJ, Dieppe P, Vernon K, Porter M, Blom AW (2012) Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. Lancet 379:1199–1204

Srinivasan A, Jung E, Levine BR (2012) Modularity of the femoral component in total hip arthroplasty. J Am Acad Orthop Surg 20(4):214–222

Underwood RJ, Zografos A, Sayles RS, Hart A, Cann P (2012) Edge loading in metal-on-metal hips: low clearance is a new risk factor. Proc Inst Mech Eng H 226(3):217–226

Weber BG (1992) Metal-metal total prosthesis of the hip joint: back to the future. Z Orthop Ihre Grenzgeb 130(4):306–309 (Article in German)

Willert HG, Buchhorn GH, Fayyazi A, Flury R, Windler M, Köster G, Lohmann CH (2005) Metal-on-metal bearings and hypersensitivity in patients with artificial hip joints. A clinical and histomorphological study. J Bone Joint Surg Am 87(1):28–36