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ORIGINAL STUDY

Pinnacle® modular metal-on-metal articulation in primary total hip arthroplasty: mid-term results of 195 cases

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Studies concerning Pinnacle® modular metal-on-metal (MoM) total hip arthroplasty (THA) show better results than for most other MoM THAs. The goal of this study was to report on the revision rate, clinical outcome and metal ion levels regarding this specific prosthesis.

Retrospectively selected patients were evaluated clinically, and Visual Analogue Score for pain (VAS), Harris Hip Score (HHS) and Hip disability and Osteoarthritis Outcome Score (HOOS) were determined. Blood metal ion levels were measured.

195 patients were included (mean follow-up 6.4 years). MoM related revision was performed in 5.1%. Clinical outcome was good, with a mean VAS of 6.7 out of 100, HHS of 88.9 and HOOS of 80.7. Five year survival was 96.6%, eight year survival decreased to 90.0%. No correlation could be found between metal ion levels and outcome.

Although clinical outcome was good, overall survival of the Pinnacle® MoM is unacceptably low compared to MoP survival.

Keywords : total hip arthroplasty ; Pinnacle ; metal-on-meta l; functional outcome.

INTRODUCTION

Metal-on-metal (MoM) total hip arthroplasty (THA) has been used for several decades. Despite theoretical advantages – larger diameter femoral heads, decreased dislocation and enabled full-film lubrication *(8,9,21,42)* – associated with metal-on-metal (MoM) bearings, there has been rising concern about the long-term outcome of these prostheses. Large national joint registries showed disappointing results regarding the average revision rate of MoM bearings *(16,39)*.

Besides a poor outcome of revision rates, concerns remain regarding the elevated cobalt and chromium ion levels in patients with MoM articulations *(1,6,9,28,40)*. With unknown effects of long-term exposure and a possible correlation between high metal ion levels and poor outcome of the total hip arthroplasty (THA), measurement of these metal ion levels has become a hot topic concerning the follow-up of MoM THAs *(6,35,44)*. Local soft-tissue changes are not the only reasons for

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concern; systemic effects regarding mutagenicity, teratogenicity and carcinogenicity are also thought to play a role in long-term exposure to elevated metal ion levels *(10,23,34,48)*.

Guidelines have been issued by several national authorities regarding the follow-up of MoM articulations *(14,38,46)*. Measurement of blood ion levels is advocated in certain situations as a screening tool for increased wear and malfunctioning of the THA. However, these levels are to be interpreted while keeping the results from other diagnostic and clinical tests in consideration. The Medicines & Healthcare products Regulatory Agency (MHRA) in the United Kingdom and the Federal Agency for Medicines and Health Products (AFMPS) in Belgium both recommend standard metal ion testing in symptomatic patients and those with a femoral head diameter of 36mm or larger *(14,38)*. The cut-off value indicating potential soft-tissue reaction for both cobalt and chromium was set at 7 µg/L. This value, however, is not supported by clinical studies and is only valid for unilateral hip replacement; guidelines considering bilateral MoM prostheses are not available *(44)*.

European Consensus published reference values of cobalt without clinical concern at less than 2 µg/L. The threshold value for clinical concern is expected to be within the range of 2 to 7 µg/L whereas exact levels have still to be determined within this range *(19)*. Moreover the U.S. Food and Drug Administration states: "The FDA believes there is not enough evidence in the U.S. to demonstrate a correlation between a metal ion level and the presence of localized lesions, clinical outcomes and/or the need for revision surgery", further advocating the interpretation and association of ion levels with clinical and radiological data to determine the status of the patient's arthroplasty *(46)*.

Previous studies reported good short- to mid-term results regarding revision rate and clinical outcome of the Pinnacle® modular MoM THA *(2,12,1324,30)*. The goal of this study was to report the clinical outcome, cobalt and chromium ion levels, radiographic outcome and revision rates of this specific prosthesis. Our data was compared with the previous results of this specific prosthesis and with the outcome of MoM THAs in general. Lastly, statistical analysis was performed to demonstrate a possible correlation between metal ion levels and clinical outcome.

PATIENTS AND METHODS

Reviewing all MoM THAs performed between May 2004 and September 2007 using the Pinnacle® modular MoM THA at our institution, 211 THAs met the inclusion criteria and were eligible to participate in this study. Inclusion criteria consisted of all patients undergoing THA for primary or secondary hip osteoarthritis. Reasons for exclusion included a history of inflammatory joint diseases, primary or secondary malignancy in the hip, the need for bone grafting, neurological disorders limiting normal rehabilitation and revision THA. All THAs were performed by the senior author (MM) in a single institution using an anterolateral approach with normal clinical and radiographic follow-up scheduled yearly after surgery. Eventually 6 patients were lost to follow-up. 10 patients, who all met the criteria of minimum 5-year follow-up, deceased before all technical and clinical data could be acquired. Reviewing the electronic patient files and consulting the relatives, we were able to conclude that none of these 10 patients had problems regarding the prosthesis. 195 patients (195 hips) were available for follow-up (147 patients at the outpatient clinic). The mean follow-up was 6.4 (5.0–8.4) years. Primary indications for THA were osteoarthritis in 92.4% (195 hips), avascular necrosis in 4.8% (10 hips) and developmental dysplasia of the hip in 2.8% (6 hips). The population consisted of 74 men (36%) and 137 women (64%) with a mean age of 57.6 (26.6–86.6) years at time of surgery.

Pinnacle® acetabular cups (DePuy, Warsaw, Indiana, USA) were implanted in all patients, with cup sizes ranging from 52mm to 66mm. The Pinnacle® acetabular cup is a porous-coated titanium shell, fitted with the proprietary Variable Interface Prosthesis taper technology to accommodate polyethylene, ceramic and metal liners. All cup sizes were matched with Ultamet™ (DePuy, Warsaw, Indiana, USA) ball and liner for MoM articulation, which are manufactured from

forged high-carbon wrought alloy. All femoral heads had a diameter of 36 mm. For the femur, custom cemented IMP-stems (Advanced Custom Made Implants, Leuven, Belgium) made from a titanium aluminium vanadium preform were used *(5)*.

We retrospectively reviewed all electronic patient files regarding weight, length, body-mass index, ASA-score (American Society of Anesthesiologists score), smoking and comorbidities (e.g. diabetes mellitus, renal failure and rheumatoid arthritis) at time of surgery. All patients were invited by telephone for follow-up with a description of study protocol. Clinical, radiographic and biochemical follow-up was performed at the outpatient clinic (September 2012) in 147 patients available to come to the hospital (PT and SC) after having given written consent. Harris Hip Score (HHS), Hip disability and Osteoarthritis Outcome Score (HOOS) and Visual Analogue Score (VAS) for pain were collected for each patient at follow-up, together with clinical data regarding possible complications such as squeaking, grinding, groin pain, dislocation and revision *(20,25,36)*. Patients were evaluated for Trendelenburg gait and sign. Patients who were not able to come to the hospital were sent a questionnaire including the previous mentioned scores and were also questioned if they suffered any problems regarding their THA.

The radiographic evaluation of the THA on standing pelvic, anteroposterior and lateral views of the treated hip was done independently by the two senior authors of this article. Signs of femoral osteolysis were reported according to the femoral zones described by Gruen et al. *(18)*. Similarly, signs of acetabular osteolysis were reported according to the acetabular zones described by DeLee and Charnley *(7)*. Patients with only radiolucent lines in femoral zones 1 or 7 or in acetabular zone 1 were not reported as abnormal. MRI or ultrasound were not included in the study protocol.

Metal ion measurements were obtained at latest follow-up and processed in collaboration with the Centre for Medical Analyses (CMA, Herentals, Belgium). Blood samples were collected at follow-up and processed the same day. An inductively coupled plasma-mass spectrometry (ICP-MS) technique was used, using the PerkinElmer Elan DRC II inductively coupled plasma-mass spectrometer and the PerkinElmer Autosampler ESI SC-Fast (PerkinElmer, Waltham, Massachusetts, USA). Detection limits were reported by the laboratory as being 0.1 µg/L for cobalt and 0.5 µg/L for chromium.

The study cohort was divided in a well- and a poorly-performing group according to 5 criteria: a HHS higher than 95, no radiographic abnormalities, no patient-reported hip problems, no abnormal clinical findings and no further surgery scheduled (well-performing group). These criteria are identical to those used by Van Der Straeten et al. *(44)*, except for the contact patch to rim distance. Mean cobalt and chromium values were compared between both groups. Further statistical analysis was done, comparing mean clinical outcome scores in respect to cobalt and chromium cut-off values. The cut-off values used in this study consisted of the 7.0µg/L for cobalt and chromium, as proposed by the AFMPS and the MHRA *(14,38)*, as well as the 4.0 µg/L and 4.6 µg/L for cobalt and chromium respectively, found by Van Der Straeten et al. to have a 95% specificity in predicting poor function *(44)*.

Fisher's Exact and Mann-Whitney U tests were used to compare categorical and continuous variables between groups of prostheses, respectively. Implant survival was estimated using Kaplan-Meier survival analysis. We defined failure as revision of the implant for any reason. Kaplan-Meier estimates were used to depict a survival curve for the percentage of patients being free of revision. Deceased patients and patients without revision at the last follow-up were censored. P-values smaller than 0.05 were considered statistical significant. All analyses were performed using the SAS System for Windows (version 9.2, SAS Institute Inc., Cary, NC, USA. Copyright© 2002 SAS Institute Inc.)

Approval was received from the Ethical Committee of the University Hospitals Leuven (approval number B322201216037). The data collection and patient contacts were handled according to the ethical standards in the 1964 Declaration of Helsinki.

RESULTS

In 195 patients available for follow-up, there were 15 failures of THA which needed revision surgery, resulting in a revision rate of 7.7%. The most common reason for revision of the THA was osteolysis (7 hips, metallosis). Other reasons for revision surgery were periprosthetic joint infection (3 hips), adverse reaction to metal debris (ARMD) (3 hips, metallosis) and traumatic periprosthetic fracture (2 hips). The reason for revision was based on clinical data (including pre-operative joint aspiration, cultures and determination of serum infection parameters) and radiographic data preoperatively and was confirmed postoperatively using histology and cultures. Serum metal ion levels were not routinely measured preoperatively. When these MoM THAs were revised, the bearing surface was altered in all patients. These data imply that 5.1% (10/195) of THAs had to undergo revision arthroplasty due to MoM bearing surface related problems. Mean time between primary and revision THA was 4.6 (1.1-8.2) years.

For the 180 non-revised hips the average VAS for pain was 6.7 out of 100 (95% CI, 4.9-8.6). Clinical outcome was further investigated using the HHS and HOOS with mean scores of 88.9 (95% CI, 87.0-90.7) and 80.7 (95% CI, 78.1-83.3), respectively.

No dislocations of the hip were reported. A grinding sensation was present in 2 hips (1.1%) and 3 other patients reported audible squeaking (1.6%). All 5 patients noted that these complications were not to the extent that they would consider revision surgery.

Table I. — Femoral and acetabular osteolysis in the study cohort.

Femoral component (Gruen 1979) (18)	N:	Acetabular component (DeLee and Charnley 1976) (7)	N:
Zone 1	10	Zone 1	3
Zone 2	7	Zone 2	1
Zone 3	5	Zone 3	1
Zone 4	3		
Zone 5	4		
Zone 6	7		
Zone 7	10		

Radiographic evaluation for osteolysis and fixation of the prosthesis showed 10 cases of femoral osteolysis (5.6%) and 4 cases of acetabular osteolysis (2.2%). Osteolysis per zone is summarized in Table I.

Biochemical data regarding cobalt and chromium levels was gathered in 147 patients. Mean cobalt and chromium levels were 9.8 µg/L (95% CI, 5.0-13.9 µg/L; range, <0.1-148 µg/L) and 7.0 µg/L (95% CI, 4.26-9.8 µg/L; range, <0.5-132 µg/L), respectively. Median metal ion levels were 1.5 µg/L for cobalt and 2.4 µg/L for chromium. No statistical significance could be found when comparing mean metal ion levels between the well- and poorly-performing groups: mean chromium levels were 7.5 (SD 20.8) µg/L and 6.8 (SD 14.8) µg/L, respectively (p=0.823). Mean cobalt levels for the good and

Table II. — Statistical analysis concerning clinical outcome scores

Group	N:	VAS (SD)	p:	HHS (SD)	HOOS (SD)	p:
Cr* ≥ 4.6	29	0.72 (1.46)	0.941	87.86 (14.71)	79.72 (17.22)	0.822
Cr* < 4.6	118	0.70 (1.32)		88.54 (12.71)	78.86 (18.88)	
Co** ≥ 4.0	9	0.89 (1.27)	0.677	90.33 (12.69)	81.56 (12.03)	0.674
Co** < 4.0	138	0.70 (1.35)		88.28 (13.14)	78.86 (18.87)	
Cr* ≥ 7.0	21	0.71 (1.38)	0.98	87.90 (13.13)	77.38 (16.90)	0.661
Cr* < 7.0	126	0.71 (1.34)		88.49 (13.12)	79.30 (18.81)	
Co** ≥ 7.0	8	1.00 (1.31)	0.528	91.50 (13.04)	83.13 (11.84)	0.521
Co** < 7.0	139	0.69 (1.35)		88.23 (12.10)	78.79 (18.82)	

* Cr=Chromium; ** Co=Cobalt

poor-performing group were 9.2 (SD 28.9) µg/L and 9.6 (SD 26.9) µg/L, respectively (p=0.922). Similarly, when comparing mean clinical outcome values between the groups divided by the cut-off values of 7.0 µg/L and 4.6 µg/L for chromium, and 7.0 µg/L and 4.0 µg/L for cobalt, no statistical significances could be found, as summarized in Table II. Kaplan-Meier survival for the THA was calculated to be 96.6% (95% CI, 93.2-98.4%) at 5 years post-operatively. Eight years after THA, Kaplan-Meier survival decreased to 90.0% (95% CI, 81.8-94.6%) (Figure 1).

DISCUSSION

Second generation MoM THAs were introduced with the expectation of added advantages over metal-on-polyethylene (MoP) THA because of new tribological improvements *(22,31,41)*. However, concerns remained regarding possible complications with the use of these MoM bearings. Excess wear of the MoM bearing surface, resulting in pathological soft-tissue changes due to ARMD and leading to the need for revision surgery has been described by several authors *(15,26)*.

Regarding follow-up of MoM THA, metal ion level measurements are advocated by several authorities. The 7 µg/L cut-off value set by the MHRA and the AFMPS has been the subject of studies, all showing poor sensitivity, specificity and

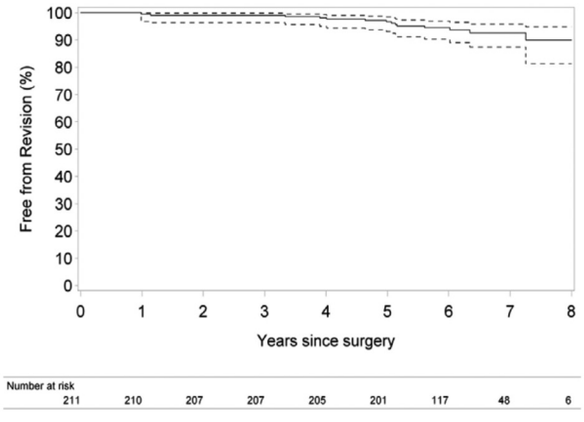

Fig. 1. —Kaplan-Meier estimates for the percentage of patients free from revision during the follow-up period. The dashed lines represent the 95% confidence interval for the curve

positive predictive value in predicting soft tissue damage *(14,17,33,35,38)*. There are, however, some indications of a correlation between high levels of cobalt and chromium and arthroplasty performance. Malek et al. found a statistical significant elevation of mean cobalt and chromium levels in patients positive for soft-tissue reaction on MARS-MRI ($p < 0.001$) (35). Van Der Straeten et al. found a similar correlation when comparing well-functioning with poorly-functioning patients in hip resurfacing. The difference in mean cobalt and chromium levels was statistical significant between the two groups, with elevated levels in the poorly-functioning group ($p < 0.001$) *(44)*.These results, all found in hip resurfacing arthroplasty, were not replicated in this study on 36 mm MoM hip arthroplasty: no statistical significance was found between the mean metal ion levels concerning the well- and poorly-performing groups). MRI was not standardly performed, which might have confirmed the correlation with ion levels. Furthermore, no significant differences could be found between patients with low and high metal ion levels when comparing clinical outcome scores. These data support that metal ion levels alone are a poor diagnostic tool for the outcome of MoM THA. Ion levels should always be considered combined with clinical and radiographic data *(17,46)*.

Following the recall of the ASR XL prosthesis, there was a rise in concern regarding the revision rate of MoM THAs in general *(4,43,45)*. Extensive data regarding the average revision rate of THAs is available in the National Joint Registry for England and Wales *(39)*. MoM THAs have the highest revision rate of all bearing surfaces (17.13-20.18% after 10 years, compared to 2.15-5.77% for all other THAs). The 10 year revision rate of all MoM resurfacing arthroplasties is 12.63% *(39)*. These data were confirmed in a recent meta-analysis, with a revision rate of 19 per 1000 patient-years for MoM, and 4 per 1000 patient-years for ceramic-on-ceramic *(29)*.

The Pinnacle® MoM arthroplasty has lower revision rates than the MoM group as a whole (Table III). Our results with the Pinnacle® MoM are in line with these findings, with a revision rate of 7.7% with a mean follow-up of 6.4 years, and a survival of 96.6% at 5 years post-operatively, and 90.0% 8 years after surgery.

Reasons for revision of MoM bearing surfaces differ from those of MoP couples. A higher incidence of revision due to loosening/osteolysis, infection and ARMD is seen in MoM articulations. Revision rates from the Australian registry showed revision of MoM bearings for metal related pathology in 8.0%, for loosening/osteolysis in 4.9%, and for infection in 1.9% of the patients, at 14 year follow-up. For MoP, these rates are 0.0%, 2.5% and 0.9%, respectively *(16)*. When comparing these data to our findings, we see a similar to lower rate of revision for the abovementioned reasons with 3.6%, 1.5% and 1.5%, respectively. The theoretical advantage of a lower rate of dislocation is being confirmed in our study cohort: no dislocations were seen, resulting in a dislocation rate of 0.0%.

The performance of MoM articulations in clinical outcome scores, as reported by several studies, is comparable to those of MoP articulations. Engh et al. compared MoM with MoP with 3 different scores. They reported a HHS of 95 and a WOMAC of 88 for MoM, comparable to MoP *(11)*. MacDonald et al. reported a HHS of 91.6 (SD 11.5) at minimum 2 years follow-up (mean 3.2 years) *(32)*. Zijlstra et al. found a comparable HHS of 87 (SD 13) at 10 years follow-up *(49)*. In all these studies there was no difference between MoM and MoP articulations. These results were confirmed by Qu et al., after performing a meta-analysis of prospective randomized studies *(40)*. Data regarding our study cohort confirmed these results, showing good clinical outcome with a HHS of 88.9 (95% CI, 87.0-90.7) in the patients without revision.

Based on our data it can be concluded that the functional and pain scores of the Pinnacle® MoM THA are comparable with those of MoM and MoP THAs in general. No correlation could be found between metal ion levels and the clinical and radiographic outcome of the THA. Metal ion levels alone are an insufficient diagnostic tool in the follow-up of MoM THA, and should be carefully considered together with clinical and radiographic data.

Although Pinnacle® MoM seems to perform better than MoM THAs in general in terms of survival, revision rates of Pinnacle® MoM THAs are unacceptably high in contrast with MoP THAs.

REFERENCES

1. **Akrawi H, Hossain F, Niculescu S** *et al.* Midterm results of 36 mm metal-on-metal total hip arthroplasty. *Indian J Orthop* 2016 ; 50 : 256-62.
2. **Barrett WP, Kindsfater KA, Lesko JP.** Large-diameter modular metal-on-metal total hip arthroplasty. Incidence of revision for adverse reaction to metallic debris. *J Arthroplasty* 2012 ; 27 : 976-83.
3. **Bernasek TL, Polikandriotis JA, Levering MF** *et al.* Five- to ten-year outcomes for modular metal-on-metal total hip arthroplasty. *J Arthroplasty* 2013 ; 28 : 1231-4.
4. **Bernthal NM, Celestre PC, Stavrakis AI, Ludington JC, Oakes DA.** Disappointing short-term results with the depuy asr xl metal-on-metal total hip arthroplasty. *J Arthroplasty* 2012 ; 27 : 539-44.
5. **Colen S, Dalemans A, Schouwenaars A, Mulier M.** Outcome of custom-made IMP femoral components of total hip arthroplasty: a follow-up of 15 to 22 years. *J Arthroplasty* 2014 ; 29 : 397-400.
6. **Delaunay C, Petit I, Learmonth ID, Oger P, Vendittoli PA.** Metal-on-metal bearings total hip arthroplasty: The cobalt and chromium ions release concern. *Orthop Traumatol Surg Res* 2010 ; 96 : 894-904.
7. **DeLee JG, Charnley J.** Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res* 1976; 121 : 20-32.
8. **Dowson D, Hardaker C, Flett M, Isaac GH.** A hip joint simulator study of the performance of metal-on-metal joints: Part II: Design. *J Arthroplasty* 2004 ; 19 : 124-30.
9. **Dumbleton JH, Manley MT.** Metal-on-metal total hip replacement: What does the literature say? *J Arthroplasty* 2005 ; 20 : 174-88.
10. **Dunstan E, Ladon D, Whittingham-Jones P, Carrington R, Briggs TWR.** Chromosomal aberrations in the peripheral blood of patients with metal-on-metal hip bearings. *J Bone Joint Surg* 2008 ; 90 : 517-22.
11. **Engh CA, MacDonald SJ, Sritulanondha S** *et al.* 2008 John Charnley award: Metal ion levels after metal-on-metal total hip arthroplasty: A randomized trial. *Clinical Orthopaedics and Related Research* 2009 ; 467 : 101-11.
12. **Engh CA, Sritulanondha S, Korczak A** *et al.* No difference in reoperations at 2 years between ceramic-on-metal and metal-on-metal tha: a randomized trial. *Clin Orthop Relat Res* 2016 ; 474 : 447-55.
13. **Engh Jr CA, Ho H, Engh CA.** Metal-on-metal hip arthroplasty: does early clinical outcome justify the chance of an adverse local tissue reaction*? Clin Orthop Relat Res* 2010 ; 468 : 406-12.
14. **Federal Agency for Medicines and Health Products B** (AFMPS). Metal-metal hip prosthesis: monitoring of the patients. 2015. Available from: http://www.fagg-afmps.be/sites/default/files/downloads/150330 rec MoM 26-08-2015 NL.pdf or http://www.afmps.be/sites/default/files/downloads/Lettre envoyée-FR-2012-04-19.pdf

15. **Glyn-Jones S, Pandit H, Kwon Y-M** *et al.* Risk factors for inflammatory pseudotumour formation following hip resurfacing. *J Bone Joint Surg Br* 2009 ; 91 : 1566-74.
16. **Graves S, Steiger R De, Lewis P** *et al.* Hip and Knee Arthroplasty. Australian Orthopaedic Association National Joint Registry. 2015. Available from: https://aoanjrr.sahmri.com/documents/10180/217745/Hip and Knee Arthroplasty
17. **Griffin WL, Fehring TK, Kudrna JC** *et al.* Are metal ion levels a useful trigger for surgical intervention? *J Arthroplasty* 2012 ; 27 : 32-6.
18. **Gruen TA, McNeice GM, Amstutz HC.** "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* 1979 ; 141 : 17-27.
19. **Hannemann F, Hartmann A, Schmitt J** *et al.* European multidisciplinary consensus statement on the use and monitoring of metal-on-metal bearings for total hip replacement and hip resurfacing. *Orthop Traumatol Surg Res* 2013 ; 99 : 263-71.
20. **Harris WH.** Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 1969 ; 51 : 737-55.
21. **Howie DW, Holubowycz OT, Middleton R.** Large Articulation Study Group. Large femoral heads decrease the incidence of dislocation after total hip arthroplasty: a randomized controlled trial. *J Bone Joint Surg Am* 2012 ; 94 : 1095-102.
22. **Jacobs M, Gorab R, Mattingly D, Trick L, Southworth C.** Three- to six-year results with the ultima metal-on-metal hip articulation for primary total hip arthroplasty. *J Arthroplasty* 2004 ; 19 : 48-53.
23. **Keegan GM, Learmonth ID, Case CP.** Orthopaedic metals and their potential toxicity in the arthroplasty patient: A review of current knowledge and future strategies. *J Bone Joint Surg Br* 2007 ; 89 : 567-73.
24. **Kindsfater KA, Sychterz Terefenko CJ, Gruen TA, Sherman CM.** Minimum 5-year results of modular metal-on-metal total hip arthroplasty. *J Arthroplasty* 2012 ; 27 : 545-50.
25. **Klässbo M, Larsson E, Mannevik E.** Hip disability and osteoarthritis outcome score. An extension of the Western Ontario and McMaster Universities Osteoarthritis Index. *Scand J Rheumatol* 2003 ; 32 : 46-51.
26. **Kwon YM, Ostlere SJ, McLardy-Smith P** *et al.* "Asymptomatic" pseudotumors after metal-on-metal hip resurfacing arthroplasty. Prevalence and metal ion study. *J Arthroplasty* 2011 ; 26 : 511-8.
27. **Lainiala O, Eskelinen A, Elo P** *et al.* Adverse reaction to metal debris is more common in patients following MoM total hip replacement with a 36 mm femoral head than previously thought: Results from a modern MoM follow-up programme. *Bone Joint J* 2014 ; 96B : 1610-7.
28. **Langton DJ, Sidaginamale RP, Avery P** *et al.* Retrospective cohort study of the performance of the Pinnacle metal on metal (MoM) total hip replacement: a single-centre investigation in combination with the findings of a national retrieval centre. *BMJ Open* 2016 ; 6 : e007847.
29. **Lee Y-K, Yoon B-H, Choi YS** *et al.* Metal on metal or ceramic on ceramic for cementless total hip arthroplasty: a meta-analysis. *J Arthroplasty* 2016; 31 : 2637-2645.
30. **Liudahl AA, Liu SS, Goetz DD, Mahoney CR, Callaghan JJ.** Metal on metal total hip arthroplasty using modular acetabular shells. *J Arthroplasty* 2013 ; 28 : 867-71.
31. **Lombardi Jr AV, Mallory TH, Alexiades MM** *et al.* Short-term results of the M2a-taper metal-on-metal articulation. *J Arthroplasty* 2001 ; 16 : 122-8.
32. **MacDonald SJ, McCalden RW, Chess DG** *et al.* Metal-on-metal versus polyethylene in hip arthroplasty: a randomized clinical trial. *Clin Orthop Relat Res* 2003 ; 406 : 282-96.
33. **MacNair RD, Wynn-Jones H, Wimhurst JA, Toms A, Cahir J.** Metal ion levels not sufficient as a screening measure for adverse reactions in metal-on-metal hip arthroplasties. *J Arthroplasty* 2013 ; 28 : 78-83.
34. **Mäkelä KT, Visuri T, Pulkkinen P** *et al.* Risk of cancer with metal-on-metal hip replacements: population based study. *BMJ* 2012 ; 345 : e4646.
35. **Malek IA, King A, Sharma H** *et al.* The sensitivity, specificity and predictive values of raised plasma metal ion levels in the diagnosis of adverse reaction to metal debris in symptomatic patients with a metal-on-metal arthroplasty of the hip. *Bone Joint J* 2012 ; 94-B : 1045-50.
36. **Marchetti P, Binazzi R, Vaccari V** *et al.* Long-term results with cementless fitek (or fitmore) cups. *J Arthroplasty* 2005 ; 20 : 730-7.
37. **Matharu GS, Theivendran K, Pynsent PB** *et al.* Outcomes of a metal-on-metal total hip replacement system. *Ann R Coll Surg Engl* 2014 ; 96 : 530-5.
38. **Medicines and Healthcare products Regulatory Agency** (MHRA). Medical Device Alert, All metal-on-metal (MoM) hip replacements. 2010. Available from: http://www.jisrf.org/pdfs/mediacl-device-alert.pdf
39. **National Joint Registry.** 12th Annual Report. Vol. 12, 12th Annulary Report. 2015. Available from: http://www.njrcentre.org.uk/njrcentre/Portals/0/Documents/England/Reports/12th annual report/NJR Online Annual Report 2015.pdf
40. **Qu X, Huang X, Dai K.** Metal-on-metal or metal-on-polyethylene for total hip arthroplasty: a meta-analysis of prospective randomized studies. *Arch Orthop Trauma Surg* 2011 ; 131 : 1573-83.
41. **Saito S, Ryu J, Watanabe M, Ishii T, Saigo K.** Midterm results of metasul metal-on-metal total hip arthroplasty. *J Arthroplasty* 2006 ; 21 : 1105-10.
42. **Smith SL, Dowson D, Goldsmith AA.** The effect of femoral head diameter upon lubrication and wear of metal-on-metal total hip replacements. *Proc Inst Mech Eng H* 2001 ; 215 : 161-70.
43. **de Steiger RN, Hang JR, Miller LN, Graves SE, Davidson DC.** Five-year results of the ASR XL Acetabular

System and the ASR Hip Resurfacing System: an analysis from the Australian Orthopaedic Association National Joint Replacement Registry. *J Bone Joint Surg Am* 2011 ; 93 : 2287-93.

44. **Van Der Straeten C, Grammatopoulos G, Gill HS** *et al.* The 2012 Otto Aufranc Award: The interpretation of metal ion levels in unilateral and bilateral hip resurfacing. *Clin Orthop Relat Res* 2013 ; 471 : 377-85.
45. **U.S. Food and Drug Administration (FDA).** Implants and prosthetics: Recalls. 2014. Available from: http://www.fda.gov / MedicalDevices / ProductsandMedicalProcedures/ ImplantsandProsthetics / MetalonMetalHipImplants / ucm241770.htm
46. **U.S. Food and Drug Administration (FDA).** Information for Orthopaedic Surgeons about Metal-on-Metal Hip Implant Surgery. 2015. Available from: http://www.fda.gov / MedicalDevices / ProductsandMedicalProcedures /ImplantsandProsthetics / MetalonMetalHipImplants / ucm241667.htm
47. **Varnum C, Pedersen AB, Mäkelä K** *et al.* Increased risk of revision of cementless stemmed total hip arthroplasty with metal-on-metal bearings. *Acta Orthop 2015* ; 86 : 491-7.
48. **Visuri TI, Pukkala E, Pulkkinen P, Paavolainen P.** Cancer incidence and causes of death among total hip replacement patients: a review based on Nordic cohorts with a special emphasis on metal-on-metal bearings. *Proc Inst Mech Eng Part H J Eng Med* 2006 ; 220 : 399-407.
49. **Zijlstra WP, Van Raay JJ, Bulstra SK, Deutman R.** No superiority of cemented metal-on-metal over metal-on-polyethylene THA in a randomized controlled trial at 10-year follow-up. *Orthopedics* 2010 ; 33 : 154-61.