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ORIGINAL STUDY

Inclination but not anatomical reconstruction is related with higher cobalt levels in MoM hip arthroplasty

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Metal on Metal total hip arthroplasty is associated with elevated serum cobalt levels. In this study we investigate if there is a relation between the inclination and anteversion angle of the cup and the anatomical reconstruction of the hip on the serum cobalt level.

Postoperative cobalt serum levels were measured in 250 patients with the M2a-38 cup and Taperloc stem combination. On standardized radiographs inclination and anteversion angle, lower limb length, lateral offset and center of rotation distance were evaluated. A difference of more than 5 millimeter compared to the preoperative situation was considered as a non-anatomical reconstruction.

For every 10 degrees increase in inclination the cobalt level increased 14% (p = 0.036). Women with the same cup inclination angle showed 34% higher cobalt levels than men (p = 0.013). No relation was found between the anteversion angle, anatomical reconstruction and the serum cobalt levels.

A higher inclination of the cup leads to higher serum cobalt levels, but a non-anatomical reconstruction has no influence on serum cobalt levels.

Keywords : arthritis; hip arthroplasty ; metal on metal ; cobalt ; anatomical reconstruction.

INTRODUCTION

The constant need to improve implant survival led to the revival of Metal on Metal (MoM) bearings in total hip arthroplasty (THA). The advantages of this type of hard bearing prosthesis was a lower wear profile *(8)*. Moreover, the large femoral head component, allows for an increase in range of motion and a lower dislocation rate *(4)*. Contrary to expectations and early studies, a disproportionate high early failure rate on both resurfacing and stemmed large head prosthesis was recently found *(23)*. Different complications of MoM THA are mentioned in the literature such as pseudotumors, high serum and local metal ion levels and adverse tissue reaction *(5,12,18)*.

The development of pseudotumors in patients with a MoM bearing prosthesis are related to elevated serum metal ions *(3)*. Furthermore, high local

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Level of Evidence: Level IV case series

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exposure of metal ions around the periprosthetic tissue can result in an aseptic lymphocyte dominated vasculitis-associated lesion (ALVAL) *(5)*. Another concern is that elevated levels of metal ions can induce systemic complications *(20)*. De Haan et. al. previously found higher levels of metal ions in patients with steeply-inclined acetabular components *(6)*. Some authors report the threshold value of 50 degrees for the maximal cup inclination while changes in anatomical reconstruction of the artificial hip expressed by deviation in lower limb length, lateral offset and change in anatomical center point of rotation are also likely to influence of release of metal ions *(10)*.

Also other factors are known that lead to elevated metal ions levels in metal-on-metal hip arthroplasty. Insufficient and excessive cup anteversion is related to higher cobalt levels *(13,16)*. Also gender plays a role in cobalt serum levels *(13,21,25)*.

In this study our primary objective is to investigate if there is a relation between the inclination and anteversion angle of the acetabular component and the serum cobalt levels. The secondary goal is to investigate the influence of the anatomical reconstruction of the hip on the serum cobalt levels..

METHODS

Between February 2008 and January 2011, a consecutive series of 377 uncemented primary MoM THA in 351 patients with a M2a-38 and Taperloc stem combination (Biomet, Warsaw, IN, USA) was performed at the Meander Medical Centre. The bearing couple consisting of monoblock acetabular cup with a 38 mm fixed size head design and was implanted in all cases. All patients were subjected to a pre-defined screening protocol after the first concerns of the MoM THA and the clinical results were reported *(22)*.

For this radiological evaluation study, we selected from our cohort all unilateral MoM total hip arthroplasty patients. Indication for the operation was osteoarthritis and a standardized radiograph was available, on which the measurements could be performed.

A total of 250 patients with unilateral MoM hip arthroplasty with a M2a-38 and Taperloc stem combination (Biomet, Warsaw, IN, USA) were eligible for the analyses, for demographics see Table I. One hundred and one patients were excluded from the study. Sixteen patients (16 THA) did not complete the screening (9 patients (9 THA) deceased, 4 patients (4 THA) underwent revision surgery before the pre-defined screening and 3 patients (3 THA) were lost to follow up). 52 patients (78 THA) were excluded because of MoM THA on both sides. In 13 patients (13 THA) the radiograph was not reliable for measurements (teardrop not visible, osteonecrosis of the hip, 6 patients (6 THA) did not undergo a pre-operative radiograph at our institution, 12 patients (12 THA) were excluded because of a collum fracture (if there was no displacement of the fracture patient were included) or surgery in the past of the hip area (intertrochantic osteotomy). One patient (1 THA could not straighten his leg and in one patient (1 THA) the prosthesis had been removed because of an infection. This study has been approved by the institutional medical ethical review board and is registered under the number TWO 13-33.

Table I — Demographics

N=250 patients	Mean	Standard deviation
Age at surgery (years)	67.3	7.5
Follow up (months)*	29.6	9.9
BMI (kg/m^2)	27.6	4.4
Males	28.5	4.0
Females	27	4.6
Cupsize (mm)	54.7	3.6
	Count	**%**
Females	150	60.0
Left	164	65.6

During the standardized outpatient visit patients were subjected to standard clinical investigations. These include physical examination, patient reported outcome measures (PROM)-questionnaires, blood analyses and hip radiographs. Blood samples were collected in a metal free container. Serum cobalt levels were determined with the use of an AAnalyst 800 Atomic Absorption Spectrophotometer (Perkin Elmer, Waltham, MA, USA). Cobalt serum levels above 5µg/l were used as cut off value for normal values in patients with a MoM implant *(11)*.

Pre-operative a standard posterior anterior (AP) radiograph was performed with the patient in

supine position with both feet in 15-20 degrees internal rotation. Post-operative at six weeks a standard radiograph of the pelvis was made.

The calibration of the post-operative radiograph was performed with the size of the acetabular component. We used a PACS system of IMPAX with an orthopaedic-Tools AGFA 7 Healthcare NV, Mortsel, Belgium. A perfect matching circle was drawn around the outside of the acetabular component, for calibration. The calibration of the pre-operative radiograph was performed with the distance of the line between the most inferior point of the teardrop to the most inferior point of the teardrop on the contralateral side. The length of this line was measured on the calibrated post-operative radiograph. The pre-operative radiograph was calibrated using this line (fig.1).

The lower limb length, lateral offset and center of rotation distance (CORD) were measured according to Patel on the pre-and post-operative calibrated radiographs (fig.2) *(19)*. Also the inclination angle of the acetabular cup was measured (fig.2). The anteversion was measured according the Woo and Morrey's method *(26)*.

Difference in leg length, lateral offset and center of rotation distance of more than 5 millimeter compared to the preoperative situation were considered as a non-anatomical reconstruction. The groups were analyzed with a logistic regression analyses.

A part of the measurements (n = 20) was repeated after two months to determine the intra observer reliability of the measurement of the radiograph on the same radiographs. To determine the reliability of the procedure we took 20 pictures of the same patients one year later in follow up. These cases were randomly chosen and the observer (CS) was blinded for the first measurement.

The relation between the inclination angle of the acetabular component and the serum cobalt level is the primary outcome measurement in this study and the secondary outcome measurement is the relation between the anatomical reconstruction of the hip and the serum cobalt levels.

Reliability of the radiological measurements and the procedure was evaluated by calculating interclass correlation coefficient (ICC). Cobalt levels were not normally distributed so these variables were transformed on a log 10 scale resulting in distributions which were not markedly skewed. For ease of interpretation we back transformed to the original scale. A logistic regression analyses was used to assess the relation between patients with an anatomical reconstruction and a non-anatomical reconstruction with serum cobalt levels. The anteversion angle was analyzed by dividing patients in three groups (insufficient < 10°, normal 10°-20° and excessive > 20°). Logistic regression will be used to analyze if there is a difference between the serum cobalt in patients with a normal anteversion versus insufficient an excessive anteversion. Also a linear regression model was used for the analyses of the anteversion angle as described below.

A linear regression model was used to analyze the relation between serum cobalt with the post-

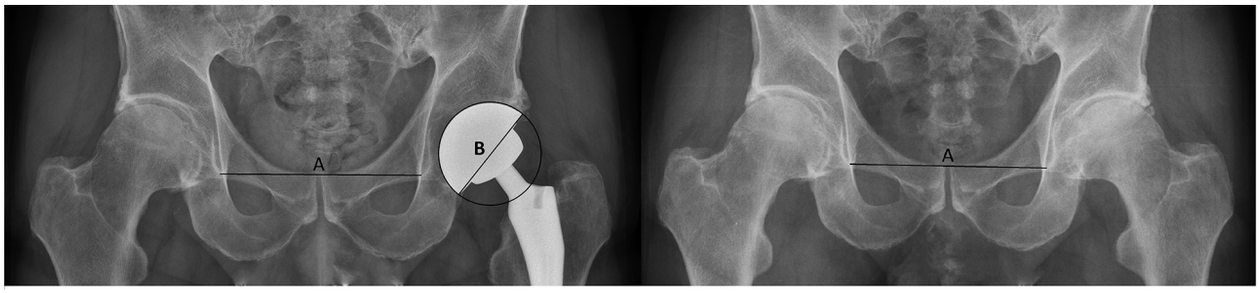

Fig. 1. — Anteroposterior radiograph of the pelvis on which we demonstrate the technique for the calibration of the X-rays. On the left picture the post-operative X-ray is shown. First a perfect fitting circle is drawn around the acetabular component. With the diameter (B) the post-operative X-ray is calibrated. After calibration of the post-operative X-ray the interteardrop line (A) is drawn between the inferior aspect of the teardrops. The distance of the interteardrop line has been measured. On the right picture the pre-operative X-ray is showed, the size of the interteardrop line (A) is used to calibrate the pre-operative X-ray.

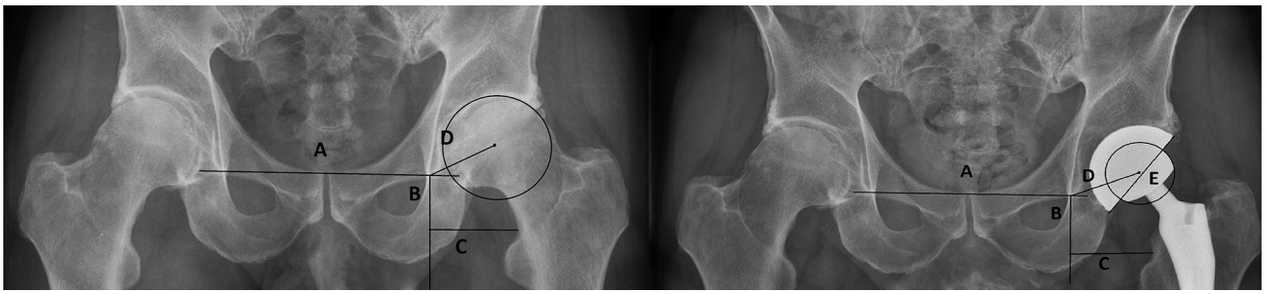

Fig. 2. — Left picture. Measurement performed on the pre-operative X-ray after calibration. First a line was drawn through the inferior aspect of the teardrop on both sides (A). A perpendicular line was drawn from the inferior aspect of the teardrop (B). On line B a line perpendicular was drawn till the superior part of the trochanter minor (C). Line B is called the Lower Limb Length and line C is the lateral offset. A perfect circle was drawn in the acetabulum. The center of this circle the center point of rotation. From this point a line is drawn to the superior aspect of the teardrop (D) this line is called the Center of Rotation Distance (CORD).

Right picture. Measurements are performed on the post-operative X-ray after calibration. First a line was drawn through the inferior aspect of the teardrop (A). A perpendicular line was drawn from the inferior aspect of the teardrop (B). On line B a line perpendicular was drawn till the superior part of the trochanter minor (C). Line B is called the Lower Limb Length and line C is the lateral offset. A perfect circle was drawn around the head of the prosthesis. The exact middle point of this circle we call the center point of rotation. From this point a line is drawn to the superior aspect of the teardrop (D) this line is called the Center of Rotation Distance (CORD). From the inferior aspect of the acetabular component a line was drawn towards the superior part of the acetabular component (E). The angle between this line and line A is called the inclination angle.

operative inclination and anteversion angle, the deviation in lower limb length, lateral offset and CORD (corrected for age, gender and cup size). The results of the linear regressions are presented with the regression coefficient (beta) and 95% Confidence Interval (CI). The results of the logistic regression are shown with the 95% CI. For all tests, a two-tailed significance level of 0.05 was used. SPSS software (IBM Corp., version 20, Armok, NY, USA) was used for the analyses.

RESULTS

The reliability for measuring post-operative cup inclination angle (ICC = 0.74, p = < 0.001) was good. An excellent reliability for the pre- and post-operative measurements of the lower-limb length (pre-operative ICC = 0.95, p = < 0.001 and post-operative ICC = 0.94, p = < 0.001), lateral offset (pre-operative ICC = 0.95, p = < 0.001, post-operative ICC = 0.94, p = <0.001) and for the center of rotation in distance (pre-operative ICC = 0.94, p = < 0.001, post-operative ICC = 0.96, p = < 0.001) was found.

An excellent reliability for the procedure measurements of the inclination angle (ICC = 0.95, p= < 0.001), lower-limb length (ICC = 0.82, p= < 0.001), lateral offset (ICC = 0.84, p = < 0.001) and for the center of rotation in distance (ICC = 0.91, p = < 0.001) was found. The reliability for the procedure of the inner teardrop line (ICC = 0.78, p = <0.001) was good.

The mean cup inclination angle was 44.4 degrees (SD 6.7) with a range of 23.9-63.8 degrees. The mean cup anteversion angle was 17.1 degrees (SD 10.2) with a range of 1.0-56.0 degrees. The mean limb length discrepancy comparing pre- and postoperative values was -5.0mm and the mean difference of the lateral offset was 3.1mm (table II).

A significant association (beta 1.014, p = 0.036) was found between the post-operative inclination angle and the cobalt values. Thus, for ten degrees increase in inclination an increase of 14% cobalt level was found. No significant relation has been found for the post-operative anteversion angle (table III). No significant differences were found between the mean cobalt values of 89 patients with a normal anteversion (5.4µg/l (sd 5.1) versus 73 patients with an insufficient anteversion (5.3 µg/l (sd 4.5) p=0.962 and normal versus 88 patients with excessive anteversion (6.3 µg/l (sd 8.4) p = 0.363.

Table II . — Measurements pre-and post-operative

Measurements (mean, sd)	Pre-operative	Post-operative	Mean (difference)
	All patients	All patients	All patients
Inclination (degrees)		44.4° (6.7)	
Anteversion (degrees)		17.1° (10.2)	
Lower limb length (mm)	31.7 (7.1)	36.7 (6.8)	5.0
Lateral offset (mm)	46.8 (7.0)	43.9 (7.3)	-3.1
Center of rotation in distance (mm)	38.0 (4.1)	36.1 (4.0)	-1.9

Table III. — Outcome of the linear regression analysis

Post-op inclination angle	1.014 (1.000-1.028)	0.036	1.4%
Post-op anteversion angle	1.000 (0.993-1.009)	0.806	0.0%
Difference in Lower Limb Length	1.012 (0.995-1.028)	0.158	1.2%
Difference in lateral offset	1.012 (0.998-1.026)	0.108	1.2%
Difference in CORD	1.007 (0.977-1.038)	0.626	0.7%

lineair regression is corrected for age, gender and cup size

Table IV. — Outcome of the anatomical reconstruction

	Number of patients	Mean Cobalt (SD)	p-value
Lower Limb Length			
Normal	101	6.6(8.2)	
≥5 millimeter lengthening	15	5.6(5.6	0.67
≥5 millimeter shortening	134	5.1(4.5)	0.08
Lateral offset			
Normal	119	5.9(7.2)	
≥5 millimeter lengthening	98	6.0(5.9)	0.90
≥5 millimeter shortening	33	4.0(3.5)	0.14
CORD			
Normal	207	5.7(6.1)	
≥5 millimeter lengthening	40	5.5(7.3)	0.82
≥5 millimeter shortening	3	5.7(2.1)	0.99

Women with the same inclination angle showed a beta of 1.34 (p = 0.013), indicating 34% higher cobalt serum levels than men (figure 3).

No significant relation between the cobalt values and the deviation in lower limb length, lateral offset or CORD was found (table III).

No differences have been found in the patients with more than 5 millimeter positive or negative displacement compared to patients with an anatomical reconstruction as considered normal (Table IV).

DISCUSSION

Although this study presents a large series of patients with MoM THA with good intra rater reliability of the radiographic measurements, some limitations exist. First, no preoperative Cobalt serum levels were available. Therefore, serum cobalt levels between 0.04-0.64µg/l were considered normal as described earlier *(11)*. Secondly, the radiographs were not calibrated with an external calibration object, but with the acetabular component in situ.

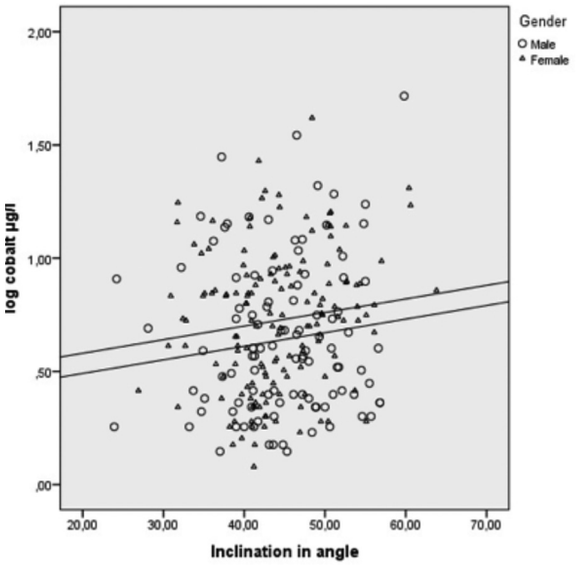

Fig. 3. — Differences between men and woman in inclination angle and cobalt values. Upper line is the line for woman and the bottom line are the men

However the founded ICC was good to excellent as well for the measurement as for the procedure.

The post-operative inclination angle of the acetabular component is associated with cobalt serum values. For every ten degrees increase of cup inclination the cobalt serum increases 14%. Women with the same acetabular cup inclination angle compared to men have 34% higher cobalt levels, which also was observed by others *(21,25)*. Placement of the cup in the safe zone is important, even more in women.

These higher values in women may be explained by differences in lean body mass between men and woman, cellular or extra-cellular storage or renal excretion. Others account the differences in hip anatomy and head/neck ratio between gender as a reason *(9,24)*. Remarkably, anatomical reconstruction does not influence the cobalt levels, but this does not explain the differences between the sexes. In our cohort the anteversion angle does not influence the cobalt levels.

De Haan et. al. *(6)* found higher cobalt levels only in patients with a cup inclination angle above 55 degrees. In this study a ten degrees increase in inclination caused an increase of 14% in serum cobalt level . Hart et. al. reported a positive relation between edge-loading and elevated serum cobalt levels. They also stated that edge loading exists in patients with an inclination angle below 55 degrees *(10)*. Contrary, other studies did not find a relation between inclination and cobalt serum levels *(7,17)*. Although cup inclination was associated with elevated cobalt serum levels, other changes in the postoperative anatomical orientation of the hip joint that could affect wear like differences in lower limb length, lateral offset and center point of rotation were not associated with serum cobalt levels.

A possible explanation is found in the retrieval studies of which some describe an asymmetric wear profile at the femoral taper which is possibly created by a togging mechanism *(1)*. Bishop et. al. wrote that this togging wear is probably created by turning moments resulting from the joint force vector acting medially to the center of the taper connection, in conjunction with joint friction moments *(2)*. This results in fretting with subsequent corrosion which is facilitating a galvanic reaction and thus can induce an increase of the corrosion when a combination of different metal is used *(14,15)*. This mechanism seems not to be influenced by the anatomical reconstruction, since serum cobalt values were equal in both groups.

From a mechanically point of view, only large outliers of a non-anatomical reconstruction probably influence postoperative pain and rehabilitation.

In conclusion: In metal on metal total hip arthroplasty a higher inclination of the acetabular component leads to higher serum cobalt levels, but a non-anatomical reconstruction and cup anteversion had no influence on serum cobalt levels. Woman showed higher cobalt levels than men; independent from cup inclination, head size (all 38 mm) or other biomechanical parameters.

REFERENCES

1. **Bishop N, Witt F, Pourzal R** *et al.* Wear patterns of taper connections in retrieved large diameter metal-on-metal bearings. *J Orthop Res* 2013 ; 31 : 1116-1122.
2. **Bishop NE, Hothan A, Morlock MM.** High friction moments in large hard-on-hard hip replacement bearings in conditions of poor lubrication. *J Orthop Res* 2013 ;3 1 : 807-813.

3. **Bosker BH, Ettema HB, Boomsma MF.** *et al.* High incidence of pseudotumour formation after large-diameter metal-on-metal total hip replacement: a prospective cohort study. *J Bone Joint Surg Br* 2012 ; 94 : 755-761.
4. **Burroughs BR, Hallstrom B, Golladay GJ, Hoeffel D, Harris WH.** Range of motion and stability in total hip arthroplasty with 28-, 32-, 38-, and 44-mm femoral head sizes. *J Arthroplasty* 2005 ; 20 : 11-19.
5. **Campbell P, Ebramzadeh E, Nelson S** *et al.* Histological features of pseudotumor-like tissues from metal-on-metal hips. *Clin Orthop Relat Res* 2010 ; 468 :2321-2327.
6. **De HR, Pattyn C, Gill HS, Murray DW, Campbell PA, De SK.** Correlation between inclination of the acetabular component and metal ion levels in metal-on-metal hip resurfacing replacement. *J Bone Joint Surg Br* 2008 ; 90 : 1291-1297.
7. **Emmanuel AR, Bergin KM, Kelly GE** *et al.* The Effect of Acetabular Inclination on Metal Ion Levels Following Metal-on-Metal Hip Arthroplasty. *J Arthroplasty* 2013.
8. **Goldsmith AA, Dowson D, Isaac GH, Lancaster JG**. A comparative joint simulator study of the wear of metal-on-metal and alternative material combinations in hip replacements. *Proc Inst Mech Eng H* 2000 ; 214 : 39-47.
9. **Grammatopoulos G, Pandit H, Murray DW, Gill HS.** The relationship between head-neck ratio and pseudotumour formation in metal-on-metal resurfacing arthroplasty of the hip. *J Bone Joint Surg Br* 2010 ; 92 : 1527-1534.
10. **Hart AJ, Buddhdev P, Winship P, Faria N, Powell JJ, Skinner JA.** Cup inclination angle of greater than 50 degrees increases whole blood concentrations of cobalt and chromium ions after metal-on-metal hip resurfacing. *Hip Int* 2008 ; 18 : 212-219.
11. **Hart AJ, Sabah SA, Bandi AS** *et al.* Sensitivity and specificity of blood cobalt and chromium metal ions for predicting failure of metal-on-metal hip replacement. *J Bone Joint Surg Br* 2011 ; 93 : 1308-1313.
12. **Hart AJ, Satchithananda K, Liddle AD** *et al.* Pseudotumors in association with well-functioning metal-on-metal hip prostheses: a case-control study using three-dimensional computed tomography and magnetic resonance imaging. *J Bone Joint Surg Am* 2012 ; 94 : 317-325.
13. **Hart AJ, Skinner JA, Henckel J, Sampson B, Gordon F.** Insufficient acetabular version increases blood metal ion levels after metal-on-metal hip resurfacing. *Clin Orthop Relat Res* 2011 ; 469 : 2590-2597.
14. **Jacobs JJ, Gilbert JL, Urban RM.** Corrosion of metal orthopaedic implants. *J Bone Joint Surg Am* 1998 ; 80 : 268-282.
15. **Koerten HK, Onderwater JJ, Koerten EW, Bernoski FP, Nelissen RG.** Observations at the articular surface of hip prostheses: an analytical electron microscopy study on wear and corrosion. *J Biomed Mater Res* 2001 ; 54 : 591-596.
16. **Langton DJ, Sprowson AP, Joyce TJ** *et al.* Blood metal ion concentrations after hip resurfacing arthroplasty: a comparative study of articular surface replacement and Birmingham Hip Resurfacing arthroplasties. *J Bone Joint Surg Br* 2009 ; 91 : 1287-1295.
17. **Maurer-Ertl W, Friesenbichler J, Sadoghi P, Pechmann M, Trennheuser M, Leithner A.** Metal ion levels in large-diameter total hip and resurfacing hip arthroplasty--preliminary results of a prospective five year study after two years of follow-up. *BMC Musculoskelet Disord* 2012 ; 13 : 56.
18. **Pandit H, Glyn-Jones S, McLardy-Smith P** *et al.* Pseudotumours associated with metal-on-metal hip resurfacings. *J Bone Joint Surg Br* 2008 ; 90 : 847-851.
19. **Patel SR, Toms AP, Rehman JM, Wimhurst J.** A reliability study of measurement tools available on standard picture archiving and communication system workstations for the evaluation of hip radiographs following arthroplasty. *J Bone Joint Surg Am* 2011 ; 93 : 1712-1719.
20. **Prentice JR, Clark MJ, Hoggard N** *et al.* Metal-on-Metal Hip Prostheses and Systemic Health: A Cross-Sectional Association Study 8 Years after Implantation. *PLoS One* 2013 ; 8 : e66186.
21. **Savarino L, Cadossi M, Chiarello E, Baldini N, Giannini S**. Do ion levels in metal-on-metal hip resurfacing differ from those in metal-on-metal THA at long-term followup? *Clin Orthop Relat Res* 2013 ; 471 : 2964-2971.
22. **Smeekes C, Ongkiehong B, van der Wal B** *et al.* Large fixed-size metal-on-metal total hip arthroplasty: higher serum metal ion levels in patients with pain. *Int Orthop* 2014.
23. **Smith AJ, Dieppe P, Vernon K, Porter M, Blom AW.** Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet* 2012 ; 379 : 1199-1204.
24. **Traina F, De CM, Biondi F, Pilla F, Tassinari E, Toni A.** Sex differences in hip morphology: is stem modularity effective for total hip replacement? *J Bone Joint Surg Am* 2009 ; 91 Suppl 6 : 121-128.
25. **Vendittoli PA, Mottard S, Roy AG, Dupont C, Lavigne M.** Chromium and cobalt ion release following the Durom high carbon content, forged metal-on-metal surface replacement of the hip. *J Bone Joint Surg Br* 2007 ; 89 : 441-448.
26. **Woo RY, Morrey BF.** Dislocations after total hip arthroplasty. *J Bone Joint Surg Am* 1982 ; 64 : 1295-1306.