Orthopaedics & Traumatology: Surgery & Research (2012) **98**, 265—274

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ORIGINAL ARTICLE

One-year prospective comparative study of three large-diameter metal-on-metal total hip prostheses: Serum metal ion levels and clinical outcomes

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Accepted: 3 November 2011

KEYWORDS
Total hip replacement;
Metal-on-metal implant;
Pain;
Chromium;
Cobalt

Summary
Introduction: The good clinical outcomes and low wear obtained with 28-mm metal-on-metal implants for total hip replacement prompted the development of large-diameter heads that more closely replicated the normal hip anatomy, with the goal of improving prosthesis stability. However, the blood release of metal ions due to wear at the bearing surfaces and the high rate of groin pain seen with large-diameter implants are causing concern. To determine whether these events are related to the geometry and metal composition of the prosthesis components, we conducted a prospective study of clinical outcomes and serum chromium and cobalt levels 1 year after implantation of three different acetabular cups.
Hypothesis: Serum levels of metal ions are comparable with different types of large-diameter metal-on-metal total hip prostheses.
Patients and methods: We compared 24 Durom™ cups (D), 23 M2a Magnum™ cups (M2a), and 20 Conserve Total™ (C) cups regarding serum chromium and cobalt levels, Postel-Merle d'Aubigné (PMA) scores and Oxford Hip Scores (OHS), as well as radiographic cup orientation and position at 1-year follow-up. Mean age was 66 years (45—85 years), mean body mass index was 28 Kg/m^2 (18—45), patients were almost equally divided between males and females, and the reason for hip replacement was primary hip osteoarthritis in 65 patients and avascular necrosis in two. Metal ions were assayed in serum from blood drawn through non-metallic catheters, using mass spectrometry.
Results: Dislocation occurred in two patients (one D and one M2a) and revision to change the bearing couple was required in two patients in the D group. Serum cobalt levels in the C group were significantly higher ($P = 0.0003$) than in the two other groups (7.5 μg/L versus 2.7 μg/L with D and 2.2 μg/L with M2a). Clinical outcomes were better in the M2a group (PMA, 17.7 [16—18]; and OHS, 15.2 [12—30]; $P < 0.05$). The PMA score and OHS were 17.5 (16—18) and 18.2 (12—42), respectively, with D; and 16.75 (10—18) and 22.2 (12—42), respectively, with C cups.

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1877-0568/$ - see front matter
doi:10.1016/j.otsr.2011.11.009

When all three cup models were pooled, serum ion levels were higher in patients with pain than without pain (chromium, 7.1 μg/L versus 2.1 μg/L [$P = 0.002$], and cobalt, 8 μg/L versus 2.6 μg/L [$P = 0.0004$]).
Discussion: Serum chrome and cobalt levels increased after metal-on-metal total hip replacement, and the increase was greater with large-diameter implants than previously reported with 28-mm implants. Persistent pain was significantly associated with higher metal ion levels, with a probable cobalt cut-off of about 8 μg/L. Differences in modular head-neck concepts may explain the observed variations.
Level of evidence: III, prospective comparative study.

Introduction

Metal-on-metal (MOM) implants were reintroduced for total hip replacement (THR) by Weber in 1988 [1] based on the excellent outcomes [2,3] reported with first-generation MOM implants [4] and on the recognition that failure of early MOM implants was ascribable to early aseptic loosening [5,6], tribologic factors, and suboptimal manufacturing processes [4,6]. The excellent outcomes with 28-mm MOM implants led to the development of larger-diameter variants with the goal of increasing implant longevity [7] and diminishing dislocation rates by increasing head diameter [8]. MOM implants constitute a valuable alternative in young patients with high levels of activity [9—11]. The cobalt-chromium alloys used for MOM implants have very low volumetric wear rates but nevertheless release metal particles in far greater amounts than do metal-on-polyethylene implants [12]. Released metal particles undergo oxidation, reabsorption, and release into the blood [13]. Patients with MOM implants have higher serum levels of released metal ions compared to patients who either have no implants or have cemented or cementless metal-on-polyethylene or ceramic implants [14]. The passage of metal ions into the blood has raised concern about possible hypersensitivity issues, carcinogenic effects, and foetal toxicity in pregnant women. The available epidemiological studies have failed to confirm these suspected adverse effects [15—25].

The main objective of this prospective comparative non-randomised study was to compare outcomes with three commercially-available large-diameter MOM acetabular cups regarding serum levels of cobalt (tCo) and chromium (tCr) 1 year after implantation, with the goal of evaluating the impact of manufacturing decisions regarding tribologic features and modular junctions. Our secondary objectives were to assess the rate of persistent pain and to compare clinical outcomes across implants. Our working hypothesis was that serum metal ion levels would be comparable across the three total hip prosthesis models involving large-diameter components and an MOM bearing couple.

Patients and methods

Implants

We compared three monoblock cups made of high-carbon cobalt-chromium alloys designed to minimize wear [26] (Fig. 1). (a). The Durom™ cup is a forged implant shaped as a truncated 165° hemisphere designed to maximize range of motion. Primary stability is ensured by press-fit fixation and three equatorial fins, with 2 mm of press-fit at the equator after reaming to 1 mm above the size of the cup. Secondary stability is achieved by bony ingrowth into a porous titanium surface coating (Porolock Ti VPS) plasma sprayed onto the alloy. The two-thirds spherical head has an open design when head size is 50 mm or more, to decrease weight. Clearance is 150 μ for diameters of 38 to 56 mm and slightly greater for larger diameters. In our study, the surgeons were free to choose between a cemented stem (Contact Evolution™ [Wright, Rueil Malmaison, France]) and a non-cemented stem (ProFemur L™ [Wright]) (Table 1). The titanium pivot and modular titanium neck constituted an additional interface with both cemented and non-cemented stems. The neck could be long or short, straight, anteverted, in varus, or both anteverted and in varus. The cobalt-chromium adapter sleeve ensuring the junction between the stem and head was available in three lengths (−4, 0 and +4 mm). (b) The M2a Magnum™ cup (Biomet, Valence, France) is a cast alloy component shaped as a full 180° hemisphere with a wall thickness of 7 mm at the pole and 4 mm at the rim. The cup is secured by impaction with 2 mm of press-fit. Four pairs of fins ensure rotational stability. Secondary stability is via a sprayed coat of porous titanium covered with hydroxyapatite. The two-thirds spherical head has a closed design, regardless of size, and is secured to the stem by a titanium adapter sleeve available in three sizes (−3.5, 0 and +3.5 mm). Clearance increases from the smallest to the largest cup size, from 75 μ to 150 μ. In our study, this implant was consistently used with a non-cemented Exception™ stem (Biomet, Valence, France) available as standard and lateralized offset options. (c) The Conserve Total™ (Wright, Rueil Malmaison, France) is also a cast alloy and is shaped as a truncated 170° hemisphere. It is secured with 1 mm of press-fit with no fins. Secondary stability is obtained using a porous titanium spray without added hydroxyapatite. The head is made of forged alloy and has an open design across the range of sizes. No adapter sleeve is used, because each head diameter is available in three neck lengths (−3.5 mm, 0 mm, and +3.5 mm). In contrast to the two other implants, the Conserve Total™ implant has a hemispherical head. In our study, the stems were the same as those used with the Durom™ implant. Table 1 reports the distribution of femoral stems by type of cup.

Figure 1 The three cups compared in this study: a: Durom™ (Zimmer, Etupes, France); b: M2a Magnum™ (Biomet, Valence, France); and c: Conserve Total™ (Wright, Rueil Malmaison, France).

Table 1 Femoral stems and junctions used with each type of acetabular cup. The difference was statistically significant ($P = 2.2 \cdot 10^{-6}$, Fisher's exact test).

Stem	Stem fixation	Stem alloy	Neck modularity	Durom™ (Cr-Co sleeve)	Magnum™ (Titanium sleeve)	Conserve™ (no sleeve)
Contact Evolution™ (Wright, Rueil Malmaison, France)	Cemented	Titanium	Modular	20	0	4
ProFemur L™ (Wright, Rueil Malmaison, France)	Cementless	Titanium	Modular	4	0	16
Exception™ (Biomet, Valence, France)	Cementless	Titanium	Monoblock	0	23	0

Patients

Starting in May 2008, all patients selected for THR using a large-diameter MOM prosthesis were entered into the study. The choice of the implant to use (Durom™, M2a Magnum™, or Conserve Total™) was at the discretion of the three participating surgeons (PM, AG and EH). Patients in all three implant groups were entered consecutively into the study. There were 24 patients in the Durom™ group, 23 in the M2a Magnum™ group, and 20 in the Conserve Total™ group. Exclusion criteria were the presence of other metallic implants (joint prostheses or internal fixation hardware), dental metal cavity fillings, and renal dysfunction. Only patients undergoing primary hip replacement surgery were included.

The postero-lateral approach was used in all patients. Ideal cup position was defined as 40°—45° abduction and 20° anteversion and ideal stem position as 15° anteversion. Table 2 gives the demographic details of the three groups.

Method

After 1 year of follow-up, each patient had a blood sample drawn through a non-metallic intravenous catheter and into plastic tubes to eliminate contamination by contact with metal. Cobalt was assayed using inductively coupled plasma mass spectrometry [27,28] and chromium using atomic absorption spectrometry, in serum, at the Amiens Teaching Hospital, France. Results were given in microgram per litre and nanomolecule per litre. Normal values were less than 0.53 μg/L (9 nmol/L) for cobalt and less than 0.26 μg/L (5 nmol/L) for chromium, and the quantification limits were 0.02 μg/L (0.3 nmol/L) and 0.05 μg/L (1 nmol/L), respectively. Values are reported as median (interquartile range and range), in compliance with current recommendations [28]

Clinical outcomes 1 year after surgery were assessed via the Postel-Merle d'Aubigné (PMA) score [29] and a patient self-questionnaires to determine and the 12-item Oxford Hip Score (OHS) [30]. In each group, we identified patients reporting persistent pain, even if mild or intermittent, which was sufficient to affect the PMA score.

An anteroposterior pelvis radiograph with the lower limbs in 15° of internal rotation was obtained 1 year after surgery. On the acetabular side of the joint, we measured cup abduction relative to the tear-drop line and we located the centre of rotation of the hip using the concentric-circles method. On the femoral side, we measured femoral offset [31], global offset, and length using the method of Ranawat [32]. All these measurements were performed on digital radiographs using Imagika™ software (View Tec, Saint-Maurice, France). The reference value was the known diameter of the implanted cup, to eliminate error due to the amplification effect (Fig. 2).

Table 2 Demographic features in the three implant groups.

Features	Durom™	Magnum™	Conserve™
Number of patients	24	23	20
Males/females, n	10/14	9/14	11/9
Age in years, mean (range)	67 (50—79)	67 (51—81)	65 (45—77)
BMI in Kg/m², *mean (range)*	27 (18—46)	29.6 (29—34)	26.6 (19—39)
Indication for hip replacement			
Osteoarthritis	24	23	18
Femoral head avascular necrosis	0	0	2

BMI: body mass index.

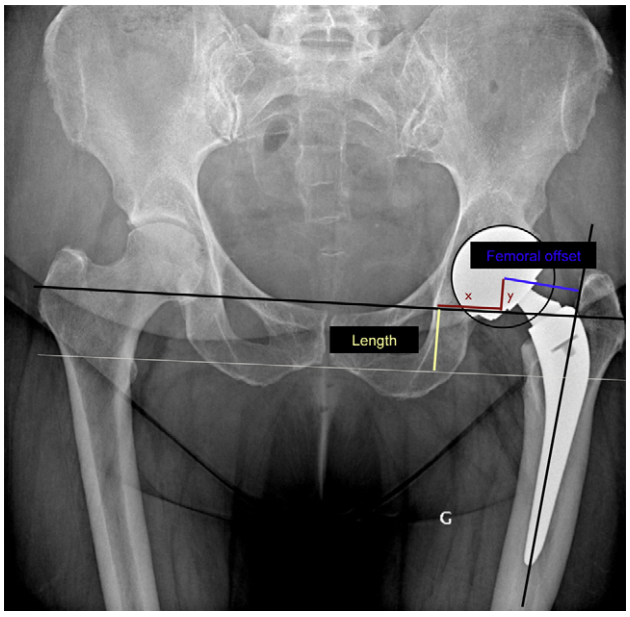

Figure 2 Radiographic measurements performed using Imagika™ software (ViewTeck, Saint-Maur, France).

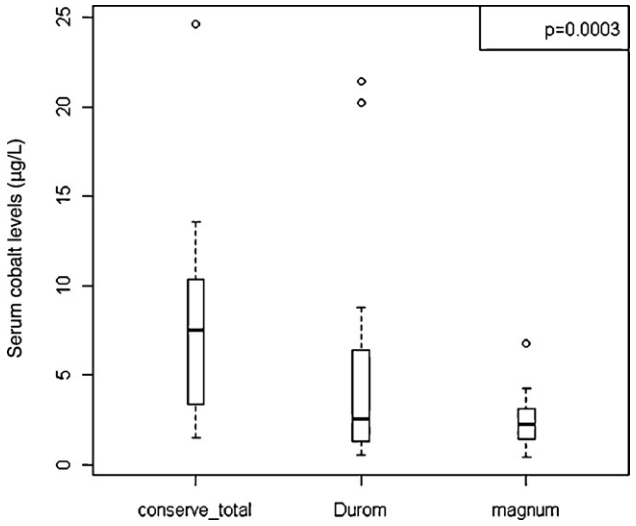

Figure 3 Serum cobalt levels in each of the three implant groups. The data are median (interquartile range) in microgram per litre.

Statistical methods

The statistical analysis was performed at the Biostatistics Department of the Amiens Teaching Hospital, Amiens, France, using SAS 9.2 (SAS, Cary, NC, USA). Quantitative variables were described as mean ± SD and range or as median and qualitative variables as percentage. The Kruskal-Wallis test was used for comparisons of quantitative variables across the three implant groups. Post hoc comparisons were with the Wilcoxon test and Bonferroni correction. Comparisons of qualitative variables across the three implant groups were performed by means of the Fisher exact test. A linear regression model was built to look for correlations between metal ion levels and clinical variables. Logistic regression was performed to assess associations between the study variables and pain. Values of *P* lower than 0.05 were considered significant.

Results

In each of the three groups, tCr and tCo were significantly increased compared to the upper limit of normal. In the overall study population, tCo was 2.9 µg/L (1.6—6.8) or 50.9 nmol/L (28.1—122.9) and tCr was 2.2 µg/L (1.2—4.5) or 42.1 nmol/L (23—87). Median tCo was 2.8 µg/L (1.3—6.6) with Durom™, 2.2 µg/L (1.4—3.1) with M2a Magnum™, and 7.5 µg/L (3.6—10.2) with Conserve Total™. Median tCr was 1.6 µg/L (1—2.4) with Durom™, 2.5 µg/L with M2a Magnum™ (1.9—3.8), and 4.4 (1.4—6.3) with Conserve Total™ (Figs. 3 and 4 and Table 3). The tCo values varied significantly across the three implant groups ($P = 0.0003$), with significantly higher levels in the Conserve Total™ group than in the Durom™ and Magnum™ groups. The difference between the Magnum™ and Durom™ groups was not statistically significant. The tCr values varied significantly across the three implant groups ($P = 0.038$). The values were significantly lower in the Durom™ group than in the Conserve Total™ group. No statistically significant differences in tCr were found between the Durom™ and Magnum™ groups or between the Magnum™ and Conserve Total™ groups (Table 3).

Table 4 reports the clinical outcomes in the three implant groups. The three groups were comparable in terms of sample size, age, sex distribution, body mass index (BMI), and reason for THR. After 1 year, the mean PMA score was 17.3 ± 1.2 (10—18) and the mean OHS was 19.2 ± 9.6 (12—42). The clinical scores in the M2a Magnum™ group

Table 3 Serum levels of cobalt and chromium in the three implant groups.

Serum levels	Durom™	M2a Magnum™	Conserve Total™
	Median (interquartile range)		
Cobalt			
μg/L	2.76 (1.31—6.57)	2.24 (1.42—3.13)	7.5 (3.6—10.2)[a]
nmol/L	47.5 (22.5—137.5)	38.5 (24.5—53.9)	129.6 (68.1—186.4)[a]
Chromium			
μg/L	1.6 (1.01—2.42)[b]	2.51 (1.86—3.79)	4.4 (1.4—6.3)
nmol/L	30.5 (19.5—46.5)[b]	52.2 (36.6—72.7)	85 (26.7—120.4)

[a] Serum cobalt levels were significantly higher with Conserve Total™ than with Durom™ and M2a Magnum™ (no significant difference between these last two cups).
[b] Serum chromium levels were significantly lower with Durom™ than with Conserve Total™. No significant differences were found between Durom™ and M2a Magnum™ or between Conserve Total™ and M2a Magnum™.

Table 4 Clinical outcomes in the three outcome groups.

Clinical scores	Durom™	M2a Magnum™	Conserve Total™
PMA score	17.5 ± 0.7 (16—18)	17.7 ± 0.5 (16—18)	16.7 ± 1.8 (10 —18)
Oxford Hip Score	18.2 ± 8.5 (12—42)	15.2 ± 6.4 (12—30)	22.9 ± 10.1 (12—42)

The data are mean (range). A significant difference was found across the three groups ($P = 0.02$, Kruskal-Wallis test). Post-hoc analyses showed a significant difference between M2a Magnum™ and Conserve Total™ ($P = 0.008$, Wilcoxon test) with no significant difference between Durom™ and M2a Magnum™ ($P = 0.22$) or between Durom™ and Conserve Total™ ($P = 0.11$). PMA: Postel-Merle d'Aubigné.

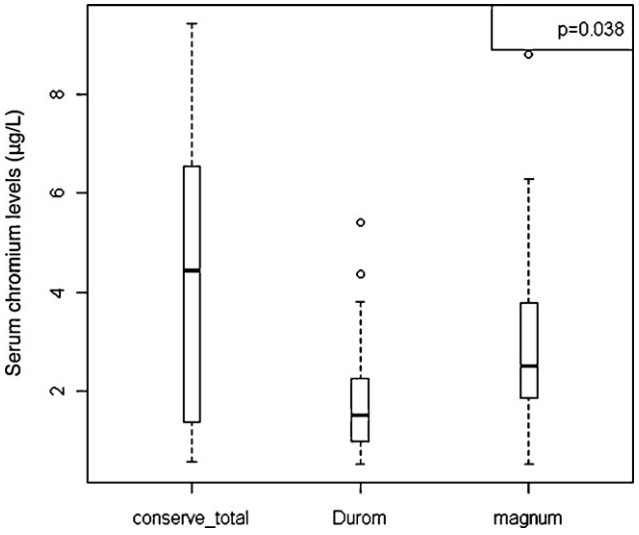

Figure 4 Serum chromium levels in each of the three implant groups. The data are median (interquartile range) in microgram per litre.

were significantly better than in the Conserve Total™ group ($P = 0.02$) and non-significantly better than in the Durom™ group. Clinical outcomes in the Durom™ group were non-significantly better than in the Conserve Total™ group and non-significantly worse than in the M2a Magnum™ group (Table 4).

Three patients experienced postoperative complications. Anterior dislocation occurred on the day of surgery in a patient in the M2a Magnum™ group. After external reduction, there was no recurrence and the clinical result was excellent (PMA, 18; and OHS, 12). In a patient in the Conserve Total™ group who had persistent pain, posterior dislocation occurred after about 1 year (at follow-up the PMA score was 16 and the OHS score was 32). Finally, another patient in the Conserve Total™ group experienced common fibular nerve palsy that resolved incompletely, leading to a poor clinical outcome (PMA at 10; and OHS at 42). At a distance from the primary procedure, persistent pain required revision surgery in two patients in the Durom™ group, after 23 and 22 months, respectively.

Of the 67 patients, 24 (35.8%) reported persistent groin pain after THR. The pain was mild and consistent with normal activities in 17 (25.4%) patients (PMA pain score, 5/6), moderate in six (8.9%) patients (PMA pain score, 4/6), and severe in a single (1.5%) patient (PMA pain score, < 4/6). Mean PMA score in patients reporting no pain was 17.9 ± 0.3 (16—18), compared to 16.3—1.5 (10—18) in patients reporting persistent pain ($P = 3.5 \cdot 10^{-8}$). Mean OHS was 15.8 ± 5.5 (12—33) and 24.4 ± 11.1 (12—42) in these two groups, respectively ($P = 0.005$). Table 5 lists the types of pain recorded in each implant group. The Conserve™ group had a higher number of patients reporting pain than did the Magnum™ group ($P = 0.009$) and the Durom™ group ($P = 0.08$, non-significant). No significant difference in pain prevalence was found between the Durom™ and M2a Magnum™ groups ($P = 0.38$, non-significant). No patient had radiolucent periacetabular lines or implant migration. No significant differences were found across the three implants regarding verticalisation or mean implant diameter (Table 6).

Table 7 reports the metal ion concentrations in the patients with persistent pain. Compared to patients reporting no pain, those reporting pain of even the mildest intensity had a non-significantly higher median

Table 5 Prevalence and intensity of persistent pain in each of the three implant groups.

Pain intensity	Overall population ($n=67$)	Durom™ ($n=24$)	Magnum™ ($n=23$)	Conserve™ ($n=20$)
Mild	17 (25.4%)	6 (25%)	4 (17.4%)	7 (35%)
Moderate	6 (8.9%)	2 (8.3%)	0	4 (20%)
Severe	1 (1.5%)	0	0	1 (5%)
Total	24 (35.8%)	8 (33.3%)	4 (17.4%)	12 (60%)[a]

Pain was assessed using the Postel-Merle d'Aubigné pain score. A significant difference was found for the overall prevalence of persistent pain ($P=0.0071$, Fisher's exact test).

[a] Persistent pain was significantly more common with Conserve Total™ than with Durom™ or M2a Magnum™. The difference between Durom™ and M2a Magnum™ was not statistically significant.

Table 6 Radiographic outcomes in the three implant groups. The data are mean (range).

Variables		Durom™	M2a Magnum™	Conserve Total™
Cup				
Diameter (mm)	ns	53.4 (48;60)	51 (44;58)	53.8 (46;62)
Abduction (°)	ns	50.9 (38;58)	47.7 (25;59)	48.8 (34;60)
Centre of rotation x (mm)	ns	30.6 (26;38)	31.5 (23;40)	28.9 (23;37)
Centre of rotation y (mm)	$P=0.005$	14.3 (9;24)	14.1 (7.7;37)	15.6 (10;20)
Teardrop cup rim distance (mm)	ns	5.4 (−3.8; +11.1)	0.7 (−10.8;8.3)	3.1 (−2.8;8.1)
Femur				
Femoral offset (mm)	ns	36.6 (17;46)	42.8 (33.6;56.7)	39.7 (25;50)
Length (mm)	ns	32.8 (11;43)	31.9 (13;45)	32 (18;50)
Variation in femoral offset (mm)	ns	+2.9 (−11; +19)	+4.5 (−13; +19)	+2.0 (−5; +11)
Variation in global offset (mm)	ns	+3.2 (−11; +23)	+1.5 (−16; +15)	+0.2 (−11; +13)
Variation in length (mm)	ns	+0.8 (−14; +15)	−0.7 (−17; +19)	+0.03 (−8.5; +8.4)

tCo value (6.4 μg/L versus 2.6 μg/L). When only patients with moderate-to-severe pain were considered, the difference was statistically significant (8 μg/L versus 2.6 μg/L, $P=0.002$). The median tCr level was 2.1 μg/L in the patients reporting no pain, 2.55 μg/L in those reporting pain of any intensity ($P=0.07$, non-significant), and 7.1 μg/L in those reporting moderate-to-severe pain ($P=0.0004$). The tCo and tCr values did not correlate significantly with age, sex, body weight, implant size, femoral offset, length, global offset, or use of a modular femoral component. The strongest correlations with tCo and tCr levels, in order of decreasing strength, were with the PMA score (negative correlation), persistent pain, BMI (negative correlation), patient height, and cup abduction. Figs. 5 and 6 show tCo and tCr values by cup abduction and cup size.

Table 7 Serum metal ion levels in patients with and without persistent pain. The data are median (range) in microgram per litre.

Pain category	Overall population
No pain	
n of patients	43
Cobalt	2.6 (1.4–3.8)
Chromium	2.1 (1.1–3.5)
Pain of any intensity	
n of patients	24
Cobalt	6.45 (1.9–9.5)
Chromium	2.55 (1.4–5.9)
Moderate-to-severe pain	
n of patients	7
Cobalt	8.3 (7.21–10.4) $P=0.002$
Chromium	7.1 (5.7–8.2) $P=0.0004$

In patients with mild pain, no investigations were performed to determine the source of pain, as the clinical outcomes were nevertheless excellent in this subgroup. In the Durom™ group, the first patient to report moderate pain had a tCo value of 6.9 μg/L, a tCr value of 5.4 μg/L, a BMI of 26.2 Kg/m^2, and 52.4° of cup abduction. Her C-reactive

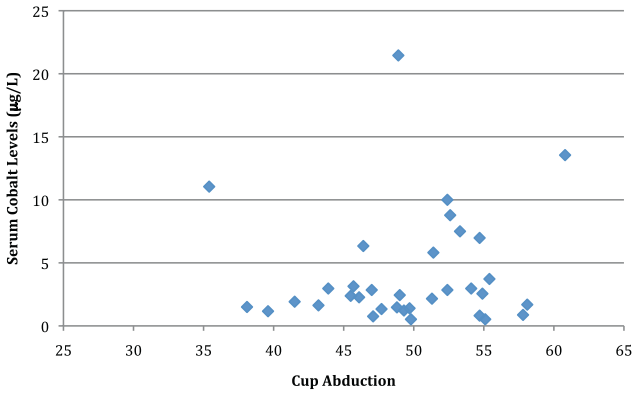

Figure 5 Serum cobalt levels (μg/L) by cup abduction (°): positive correlation.

Table 8 Patients with persistent pain in the Conserve Total™ group.

Features	Patient #1	Patient #2	Patient #3	Patient #4	Patient #5
Sex	M	F	F	M	F
BMI	29.3	21.6	39.5	18.7	35.2
Cup abduction	58.8°	53.3°	51.4°	52.4°	51.6°
Cup size	62	54	54	54	54
Serum Co (μg/L)	10.7	7.5	5.8	10.1	2.8
Serum Cr (μg/L)	7.1	5.9	0.6	9.1	0.8
Suggested diagnosis	Psoas tendinitis	Delayed posterior dislocation	Collection in the psoas muscle	None, watchful waiting	Common fibular nerve palsy

BMI: body mass index.

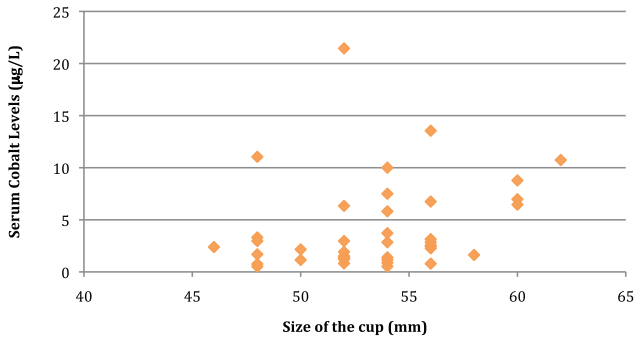

Figure 6 Serum cobalt levels (μg/L) by cup size diameter (mm): no correlation.

protein level was normal and aspiration of the hip recovered sterile radiopaque fluid. Her skin prick tests for metal allergy were positive. Computed tomography (CT) of the hip was unremarkable. Revision surgery was performed to implant a ceramic-on-ceramic prosthesis and to collect pathological specimens. Histology showed a predominantly lymphoplasmacytic inflammatory infiltrate in a perivascular distribution and a few metal particles. In the second Durom™ patient reporting moderate pain, tCo was 97.7 μg/L, tCr 45.6 μg/L, BMI 22.2 Kg/m^2, and cup abduction 56.8°. As with the previous patient, investigations for infection were negative and the CT-scan unremarkable. Revision surgery to change the bearing couple was performed at a different institution. Abnormal mobility was found between the adapter sleeve

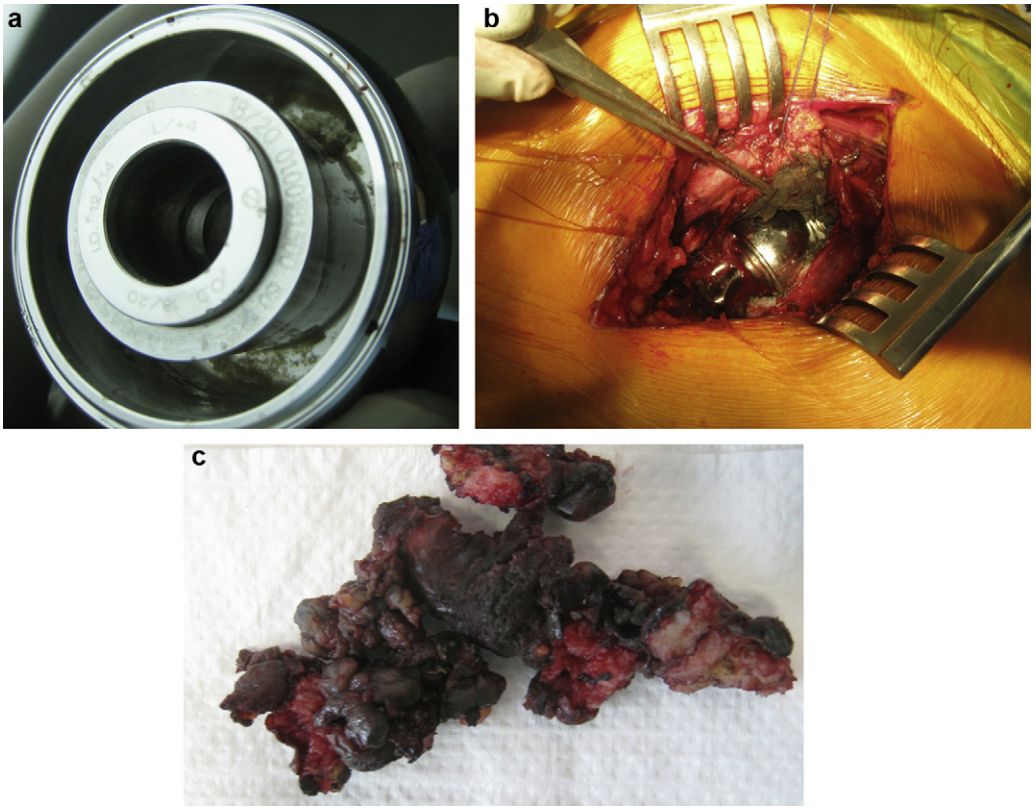

Figure 7 Intraoperative evidence of metallosis upon revision surgery in the second Durom™ patient reporting clinically significant persistent pain (courtesy of Henri Migaud, Lille Teaching Hospital, Lille, France).

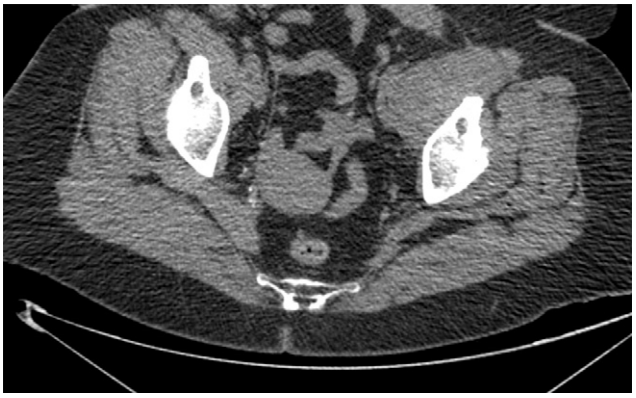

Figure 8 Computed tomography showing a hematoma in the psoas muscle of patient #3.

and head, as well as marked metallosis (Fig. 7). None of the patients in the M2a Magnum™ group reported substantial pain, and none required revision surgery. In the Conserve Total™ group, five patients reported moderate-to-severe pain. Their main features are reported in Table 8. The poor clinical outcome in patient #5 was directly ascribable to fibular nerve palsy. The other four patients had excessive cup verticalization and high tCo and tCr values. In none of these four patients was the source of pain clearly identified. Patient #3 had lower-limb venous compression related to a collection within the psoas muscle in contact with the hip (Fig. 8). To date, none of these patients has requested revision surgery. In the overall study population, the existence of persistent pain did not correlate with age, sex, body weight, or lower-limb lengthening. In contrast, persistent pain correlated with patient height, implant size, tCo, tCr, femoral offset (negative correlation), global offset (negative correlation), and cup abduction.

Discussion

Cobalt and chromium release into the bloodstream varied across the three types of cup evaluated in our study. Release was significantly lower with M2a Magnum™ than with Durom™ and Conserve Total™. The clinical outcomes were consistent with the metal ion data: the M2a Magnum™ group had significantly better PMA score and OHS values and significantly fewer patients with persistent pain after THR. The tCo values correlated with the PMA score, persistent pain, BMI, patient height, and cup abduction. Persistent pain was significantly associated with higher tCo values, and the data suggested that tCo values in excess of 8 μg/L might be associated with an increased risk of persistent pain.

One source of bias in our study was the small number of patients in each group. However, we had more than 20 patients per group, which allowed us to perform appropriate statistical tests. Second, we did not obtain data on changes in metal ion values over time in a given patient. Finally, differences occurred across the three groups regarding the distribution of femoral stems and the use of the stems by the three different surgeons. The Durom™ and Conserve Total™ cups were used with modular necks, whereas the M2a Magnum™ cup was not. However, neck modularity occurred at a titanium-on-titanium interface, where potential wear would have had little impact on our assay results. Thus, our data chiefly reflect wear at the bearing couple, and the influence of the head-neck interface should not have influenced our results.

In patients without implants or with ceramic-on-ceramic implants, tCo and tCr are undetectable [13]. With MOM implants measuring 28 mm in diameter, the serum levels are near, or slightly lower than, 1 μg/L [13,33]. No significant differences have been reported between 28-mm MOM THR and resurfacing [34]. Resurfacing with Durom™ was associated with cobalt levels of 0.67 μg/L in a study by Vendittoli et al. [35] and 0.95 μg/L in a study by Pattyn et al. [36]. A comparison by Garbuz et al. [37] of levels with Durom™ resurfacing and Durom™ THR showed a larger increase with THR (46-fold versus 10-fold the normal value) related to the existence of modular components in the THR prosthesis. Lavigne et al. [38] compared serum metal ion levels with four types of large-diameter MOM implants. They reported increases similar to those found in our study, again with lower values in the M2a Magnum™ group. Interestingly, the increases were not larger than those seen after total knee replacement, a procedure that is not generating as much concern regarding the use of cobalt-chromium alloys [39]. Luetzner et al. [39] measured cobalt and chromium levels in 18 patients with cemented unilateral THR after a mean follow-up of 66 months and in 23 patients with bilateral THR after a mean follow-up of 50 months. The cobalt level was 3.28 μg/L in the unilateral THR group and 4.28 μg/L in the bilateral THR group. These values were higher than those found in most patients after large-diameter MOM THR [36—39].

In the first study seeking to identify safe serum cobalt and chromium levels, MacDonald [40] reviewed occupational exposure data. They found that the safe limit in the event of occasional exposure was 15 μg/L [41] but recognized the need for clinical studies of patients with metal implants. In a more recent study of 26 patients undergoing revision surgery 2.9 years on average after resurfacing, De Smet et al. [42] found strong correlations linking serum and joint metal ion levels, head wear, and evidence of metallosis at revision. Cobalt levels greater than 19 μg/L were associated with the development of metallosis [42]. In our study, cobalt levels above the far lower threshold of 8 μg/L were associated with persistent pain. The impact of excessive cup verticalization demonstrated in our study is consistent with data from De Haan et al. [43].

Several hypotheses may explain the differences across cup types. First, the M2a Magnum™ adapter sleeve is made of titanium and therefore limits the chrome-cobalt surface area on which passive corrosion can occur, thereby diminishing the release of chromium and cobalt ions at this interface. This factor has been suggested by Lavigne et al. [38] as a cause of differences across cups. In addition, the larger diameter of the Magnum™ adapter sleeve probably decreases rotational friction of the head on the adapter sleeve. The Durom™ cup has the thinnest wall, of only 4 mm, (3.7 mm of alloy + 0.3 mm of titanium). This feature may be associated with increased susceptibility to deformities generated during cup impaction and, therefore, to greater friction at the interface.

In addition to metal ion release, persistent pain is of concern after large-diameter MOM THR and can require

revision to change the bearing couple. Persistent pain may be related to a variety of mechanisms. Aseptic lymphocytic vasculitis-associated lesion [20,44] occurred in 1 to 2% of patients in a study by Thomas et al. [45]. Fluid-filled or solid pseudotumours may develop [46], requiring surgical revision for tissue excision and a change in the bearing couple [47]. Pseudotumour development is the most dreaded complication after MOM hip arthroplasty. One study supports a link between pseudotumours and increased serum cobalt levels after resurfacing [47]. Similarly, an association between persistent pain and excessive cup verticalization was demonstrated by Berton et al. [48] after Durom™ cup implantation for THR. In our study, persistent pain correlated positively with patient height, implant size, and serum cobalt and chromium levels and negatively with femoral offset, global offset, and cup abduction.

None of the patients in our M2a Magnum™ group had clinically significant pain. In contrast, of the five patients reporting moderate-to-severe pain in the Conserve Total™ group, four (80%) had abnormalities suggesting an adverse reaction to metallic debris at the 1-year evaluation. Revision surgery was performed in 2 (8.4%) patients in the Durom™ group. Similarly, Illgen et al. [49] found that 11.1% of patients required a change in the bearing couple after 1 year because of persistent pain, in agreement with results by Berton et al. [48]. Langton et al. [50,51] studied failure of resurfacing or MOM THR in 660 patients. After a mean follow-up of 41 months, 3.4% of patients had required revision surgery for persistent pain.

Conclusion

This comparison of three large-diameter MOM hip prostheses identified differences in serum cobalt and chromium levels. The levels were lowest with the M2a Magnum™ cup. However, serum cobalt and chromium levels with all three cups were higher than those reported with Metasul 28 mm (about 1 μg/L). The advantages of MOM implants for THR should be weighed against our findings of clinically significant persistent pain in 10.4% of patients and of significantly increased serum levels of cobalt ($P = 0.002$) and chromium ($P = 0.0004$) 1 year after surgery. The source of persistent pain remains unclear but may involve adverse reactions to metal debris released at foci of surface wear or at modular junctions. We believe that implantation of MOM hip prostheses is a demanding procedure that must meet strict criteria for acetabular cup positioning.

Disclosure of interest

J.-F. Lardanchet, J. Taviaux, D. Arnalsteen, A. Gabrion, declare that they have no conflicts of interest concerning this article.

P. Mertl, co-designer of the Durom™ cup

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