Blood metal ion concentrations after hip resurfacing arthroplasty

A COMPARATIVE STUDY OF ARTICULAR SURFACE REPLACEMENT AND BIRMINGHAM HIP RESURFACING ARTHROPLASTIES

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doi:10.1302/0301-620X.91B10.22308 $2.00

J Bone Joint Surg [Br] 2009;91-B:1287-95.
Received 15 January 2009; Accepted after revision 2 June 2009

There have been no large comparative studies of the blood levels of metal ions after implantation of commercially available hip resurfacing devices which have taken into account the effects of femoral size and inclination and anteversion of the acetabular component. We present the results in 90 patients with unilateral articular surface replacement (ASR) hip resurfacings (mean time to blood sampling 26 months) and 70 patients with unilateral Birmingham Hip Resurfacing (BHR) implants (mean time 47 months).

The whole blood and serum chromium (Cr) and cobalt (Co) concentrations were inversely related to the size of the femoral component in both groups ($p < 0.05$). Cr and Co were more strongly influenced by the position of the acetabular component in the case of the ASR, with an increase in metal ions observed at inclinations > 45° and anteversion angles of < 10° and > 20°. These levels were only increased in the BHR group when the acetabular component was implanted with an inclination > 55°.

A significant relationship was identified between the anteversion of the BHR acetabular component and the levels of Cr and Co ($p < 0.05$ for Co), with an increase observed at anteversion angles < 10° and > 20°. The median whole blood and serum Cr concentrations of the male ASR patients were significantly lower than those of the BHR men ($p < 0.001$). This indicates that reduced diametral clearance may equate to a reduction in metal ion concentrations in larger joints with satisfactory orientation of the acetabular component.

Hip resurfacing using cementless acetabular components with metal-on-metal bearings for the treatment of second-stage hip osteoarthritis was introduced approximately ten years ago.[1,2] The implants in use currently are popularly referred to as the 'third-generation' and include the Birmingham Hip Resurfacing (BHR) (Smith and Nephew, Warwick, United Kingdom). Independent intermediate clinical results have shown the BHR to be a highly successful procedure when performed to a satisfactory technical standard after appropriate patient selection.[3]

De Smet et al[4] recently demonstrated that serum metal ion concentrations can be used as a surrogate marker of articular wear, owing to the positive correlation with metal ion concentrations in the joint fluid. Increased wear has been implicated in the early failure of metal-on-metal joints secondary to metal sensitivity and the development of pseudotumours.[5,6] With the added theoretical concern of carcinogenicity, low levels of metal ions are desirable in resurfacing arthroplasty.

It has not yet been determined *in vivo* whether the cumulative effects of the macro- and microscopic differences in the design of resurfacing devices from competing manufacturers will lead to an increase or reduction in wear rates or, more importantly, a change in the clinical outcome of the patient receiving the implant. No large-scale independent comparative study of the different types of hip resurfacing has been carried out using the same laboratory for metal ion analysis and taking into account the anteversion and inclination of the acetabular component and the implant size. We sought to determine whether there is a significant difference in the chromium (Cr) and cobalt (Co) concentrations in the blood of patients surfaced with two common types of resurfacing arthroplasty. We also sought to identify the orientations of the component most strongly associated with the lowest blood metal ion levels and, in so doing, test our previous recommendations for the orientation of the acetabular component[7] of the articular surface replacement (ASR) (DePuy, Johnson and Johnson, Leeds, United Kingdom) using a larger group of patients.

Table I. Subtended articular surface angles increase with increasing acetabular component diameter in both devices (source: manufacturers' details and independent testing[21])

	ASR*	BHR†
Subtended articular surface angle (°)	148 to 160	158 to 166
Mean radial clearance (μm)	50	100 to 150
Wall thickness at rim (mm)	3.1	3.6/4.6
Manufacturing method of head	As cast	As cast
Manufacturing method and treatment of acetabular component	HIP/SA‡	As cast
Surface roughness (μm)	0.025	0.029
Deviation of roundness head (μm)	3.4	0.9
Deviation of roundness acetabular component (μm)	3.8	0.9
Carbon content§	High	High

* ASR, articular surface replacement

† BHR, Birmingham hip resurfacing

‡ HIP/SA, cast process and heat treatment by hot isostatic pressure/surface annealed

§ high carbon content defined as ≥ 0.20%

Patients and Methods

Implants. *In vitro* studies[8,9] have suggested that full fluid film lubrication can be promoted by reducing the radial clearance between the articulating surfaces of the resurfacing components. It was on this basis that the 'fourth-generation' ASR was introduced with a radial clearance of 50 μm. This nominal clearance is significantly lower than the 100 μm radial clearance of the BHR.

Failure analyses and metal ion studies have shown that edge loading is an important factor leading to increased wear secondary to increased angles of acetabular component inclination.[10-12] The ASR acetabular component is sub-hemispherical in design, as opposed to the near full hemisphere of the BHR implant. De Haan et al[13] recently showed that reduced component cover can render a joint more susceptible to the negative effects of edge loading at lower angles of inclination than expected.

Although all manufacturers use high-carbon-containing cobalt-chromium alloy, the processing of the alloy differs. Cast components may undergo post-casting heat treatments such as hot isostatic pressing and/or solution heat treatment. The significance of these treatments has been debated over the last decade. Annealing results in depletion of the surface carbides, but hip simulator studies do not demonstrate significant differences between the wear behaviour of as-cast arthroplasty and heat-treated alloys.[14] Table I summarises the important similarities and differences of the ASR and the BHR.

Patients. From April 2004 a prospective trial of the ASR was undertaken. The clinical results of the first 200 patients involved in this independent trial have already been published.[15] Metal ion analysis has been carried out at our unit on a routine basis since June 2007 for patients under the care of the senior author (AVFN). This paper presents data from patients attending for routine follow-up during the period from June 2007 to June 2008. The results of the first 76 of the 90 ASR patients included in this study have been published previously.[7]

Owing to the disparity in patient numbers between the ASR and the BHR groups, 12 BHR patients attending review clinics at a second local centre who met the inclusion criteria gave consent to recruitment into this study. Each operating surgeon at this centre is a lower limb arthroplasty specialist. The posterior approach was used in each case. At this centre, all blood samples were obtained by the same orthopaedic registrar involved in the main centre study, using identical equipment and the same laboratory for analysis. For both groups of patients, the only exclusion criteria were the presence of another joint replacement and the resurfacing having been performed within 12 months of blood sampling. Patient demographics are shown in Table II.

Methods. Blood samples are obtained via Venflon, with the first 5 ml being discarded before the definitive sample is drawn. All samples are frozen and sent to the same laboratory for blinded whole blood and serum Cr and Co analysis using inductively coupled plasma mass spectrometry.

The same technique of EBRA (Einzel-Bild-Roentgen-Analyse)[7,16] (University of Innsbruck, Innsbruck, Austria) analysis of standing radiographs was used to assess the BHR group and the larger ASR patient group. As well as the orientation of the acetabular component, we measured the femoral stem/shaft angle relative to the anatomical axis of the femur as previously described.[7] The orientation of the components was assessed and recorded prior to the metal ion results becoming available. For all measured parameters, all technically satisfactory weight-bearing radiographs available for each patient were analysed and the mean values calculated and used in the final analysis. An overview of joint sizes and orientations of the acetabular component is shown in Table II.

Statistical analysis. Spearman's rank correlation was used to identify any significant relationships between the independent variables (as above, as well as the Harris Hip Score[17] and the University of California, Los Angeles activity score[18] at the time of blood sampling, the time from surgery and age) and the dependent variables (whole blood and serum values

Table II. Patient demographics, including joint sizes and acetabular component orientations

	ASR*	BHR†	Significance
Demographics			
Number	90	70	
Age in yrs (range)	55 (28 to 77)	51 (32 to 67)	0.501
M:F (% female)	42:38 (*42*)	44:26 (*37*)	
Post-operative time in mths (range)	26 (12 to 44)	47 (14 to 75)	0.001
American society of anethesiologists score	1.6 (1 to 3)	1.39 (1 to 2)	0.630
Femoral size in mm (range)	49.0 (41 to 59)	48.6 (38 to 58)	0.437
Inclination angle in ° (range)	49.9 (32 to 65)	47.5 (32 to 65)	0.150
Anteversion angle in ° (range)	20.6 (4 to 39)	17.4 (-5 to 39)	0.041
Outcome scores (range)			
Harris Hip Score	94 (35 to 100)	97 (51 to 100)	0.076
UCLA‡ activity score	7.3 (3 to 10)	7.5 (3 to 10)	0.633
Serum metal ion levels (range)			
Cr (μg/L)§	3.99 (0.58 to 115.0)	3.55 (0.65 to 190)	0.723
Co (μg/L)§	2.30 (0.38 to 228.0)	1.65 (1.8 to 76)	0.082
Whole blood metal ion levels (range)			
Cr (μg/L)§	3.60 (1.5 to 69.8)	3.95 (2.37 to 39.8)	0.213
Co (μg/L)§	2.08 (0.38 to 271.0)	1.43 (0.63 to 147)	0.037

* ASR, articular surface replacement
† BHR, Birmingham hip resurfacing
‡ UCLA, University of California, Los Angeles
§ median values. All other values are means. Cr, chromium; Co, cobalt

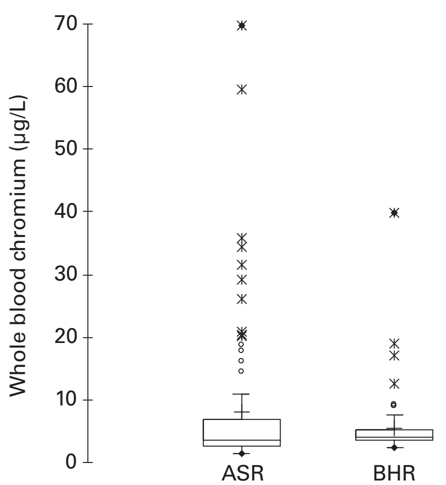

Fig. 1

Scatter plot showing the ranges of whole blood chromium data for the articular surface replacement (ASR) and Birmingham hip resurfacing (BHR) implants. The inferior, middle and superior horizontal lines of the boxes represent the first quartile, median and third quartiles. The ends of the 'whiskers' correspond to the limits of the data, beyond which values are considered anomalous. The mean is displayed with a +, outliers with a °, extreme outliers with a '*' and upper and upper and lower values with '•'

of Cr and Co) of the ASR and BHR patient groups. Each variable was also plotted individually against the metal ion values in order to identify non-linear relationships.

In order to determine the joint orientations most strongly associated with the lowest blood metal ion levels, the angles of inclination and anteversion were divided into subgroups. Mann-Whitney U tests were then used to identify significant differences ($p < 0.05$) between these subgroups. Two-sample *t*-tests were used to compare values from groups with normal distributions. The same methods were used to determine significant differences in independent and dependent variables between the ASR and BHR groups. Windows SPSS version 16.0 (SPSS Inc., Chicago, Illinois) was used for statistical analysis.

Results

An overview of the Cr ion data in whole blood can be seen in the box and whisker plots in Figure 1. There was a highly significant positive correlation between whole blood/serum Cr and Co concentrations (Tables III and IV), and we therefore feel it appropriate to use Cr and Co interchangeably for graphical representation.

ASR analysis. The results from this larger group of patients showed a significant inverse relationship between femoral size and Cr and Co concentrations (Fig. 2 and Tables II and III). In order to investigate the effect of the interaction between size and orientation of the acetabular component on the ion levels, the ASR patients were split into groups according to individual femoral sizes. A multiple regression model was then constructed for each group size, with Co as the dependent variable and acetabular component inclination and anteversion as the explanatory variables. As illustrated in Figure 3, as the size of the ASR implants

Table III. Spearman's rank correlation of whole blood chromium levels to various clinical parameters for all patients

	ASR* (n = 90)		BHR† (n = 70)	
	Correlation	Significance level	Correlation	Significance level
Age	-0.165	0.129	-0.138	0.324
Post-operative time	0.010	0.929	-0.009	0.954
Head size	-0.283	0.010	-0.265	0.038
Acetabular component inclination	0.312	0.005	-0.048	0.731
Acetabular component anteversion	0.250	0.026	0.115	0.406
Stem-shaft angle	-0.058	0.595	0.136	0.449
UCLA‡ score	-0.325	0.104	0.109	0.585
Whole blood Co§	0.859	< 0.001	0.713	< 0.001
Serum Co	0.851	< 0.001	0.693	< 0.001
Serum chromium	0.914	< 0.001	0.708	< 0.001

* ASR, articular surface replacement
† BHR, Birmingham hip resurfacing
‡ UCLA, University of California, Los Angeles
§ Co, cobalt

Table IV. Spearman's rank correlation of whole blood cobalt levels to various clinical parameters for all patients

	ASR* (n = 90)		BHR† (n = 70)	
	Correlation coefficient	Significance level	Correlation coefficient	Significance level
Age	-0.075	0.489	0.230	0.419
Post-operative time	0.088	0.420	-0.009	0.954
Head size	-0.248	0.024	-0.173	0.178
Acetabular component inclination	0.417	< 0.001	-0.009	0.949
Acetabular component anteversion	0.308	0.006	0.285	0.037
Stem shaft angle	-0.047	0.665	0.014	0.938
UCLA‡	-0.368	0.001	0.234	0.239
Whole blood Cr§ level	0.897	< 0.001	0.713	< 0.001
Serum cobalt level	0.966	< 0.001	0.815	< 0.001
Serum Cr	0.906	< 0.001	0.679	< 0.001

* ASR, articular surface replacement
† BHR, Birmingham hip resurfacing
‡ UCLA, University of California, Los Angeles
§ Cr, chromium

increased the corresponding R^2 value decreased (i.e. acetabular component orientation had less influence on Co as the femoral size increased). The relationship between acetabular component inclination/anteversion and metal ions was negligible in ASRs with femoral components > 51 mm. For the purposes of this study, ASRs with femoral components > 51 mm are referred to as large ASRs. Below this size there was a significant increase in metal ions when acetabular components were positioned at > 45° of inclination and/or > 20° of anteversion. In this larger series of patients it also became apparent that acetabular component anteversion < 10° was also associated with an increase in metal ion concentrations (Fig. 4). ASRs with femoral components ≤ 51 mm are henceforth referred to as small.

BHR analysis. There was a significant inverse relationship between femoral size and metal ion concentrations in the BHR patients (Spearman's rank correlation (r) = -0.265, p = 0.038, Cr) (Fig. 2). The same multiple regression model described above was used to examine the interaction between femoral size and orientation of the acetabular component on metal ion levels. As with the ASR, increasing femoral size reduced the effect of orientation of the acetabular component on metal ion concentrations (Fig. 3). Acetabular component orientation had no significant effect on BHRs with femoral components in the fourth quartile of the size range (≥ 54 mm). For the rest of the paper, the implants in the fourth quartile of the size range are referred to as large and the remaining implants are referred to as small. Table V shows the significant differences in Cr and Co concentrations between the large and small BHR groups.

Small BHR implants

Inclination of the acetabular component. We identified no linear correlation between the inclination of the acetabular

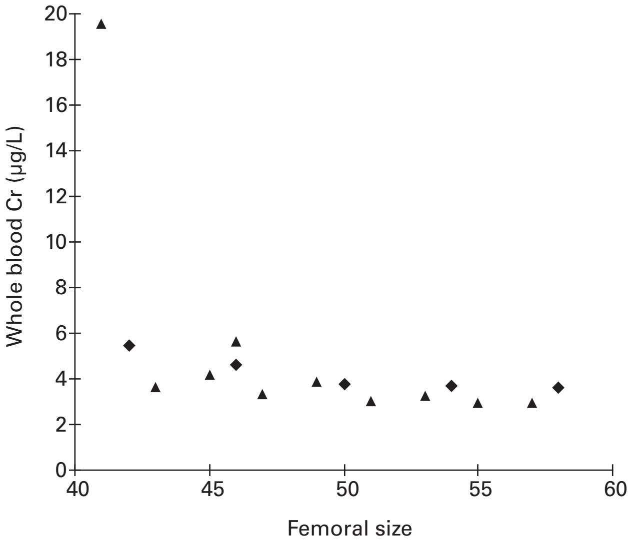

Fig. 2

Graph showing median chromic (Cr) levels for all patients in the study split into groups according to femoral size and device (▲, articular surface replacement patients, ◆, Birmingham hip resurfacing patients)

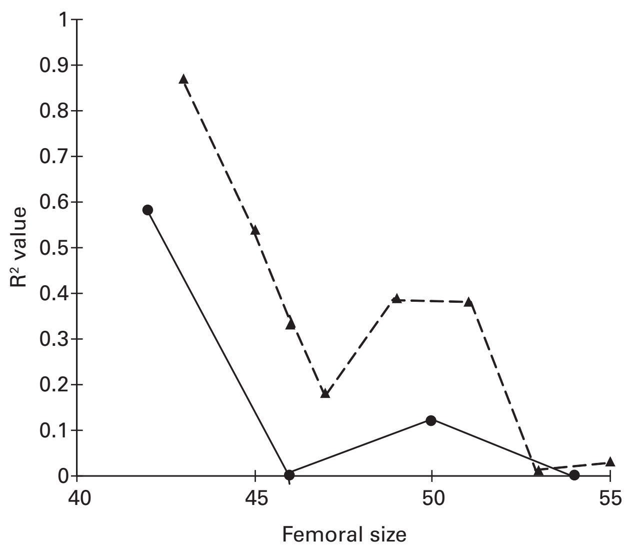

Fig. 3

Graph showing the calculated R^2 (coefficient of determination) values from multiple regression models involving acetabular component inclination and anteversion as explanatory variables and cobalt as the dependent variable. Regression analysis was carried out for both devices (articular surface replacement represented by broken line; Birmingham hip resurfacing represented by solid line) and each femoral size.

component and the concentration of Cr or Co ions. However, the largest three Co and Cr readings were found in the blood of patients with acetabular components implanted with > 55° of inclination. For acetabular components placed below 55° (32.5° to 54.9°), a non-significant inverse relationship to Cr and Co was observed (p = 0.08 and 0.120, respectively) (*see* Fig. 5).

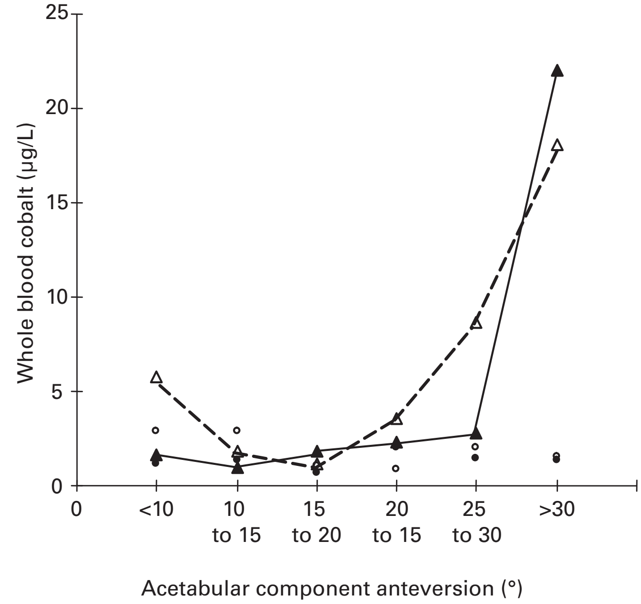

Fig. 4

Graph showing the effect of acetabular component anteversion angle on whole blood cobalt concentrations. Data plots correspond to medial ion levels of small articular surface resurfacings (ASRs) (△ joined by broken lines), large ASRs (°), large Birmingham hip replacements (BHRs) (•) and small BHRs (▲joined by solid line).

Anteversion of the acetabular component. There was a significant positive correlation between anteversion of the acetabular component and Co (r = 0.309, p = 0.047). A similar, but slightly weaker relationship was identified between Cr and anteversion (r = 0.274, p = 0.079). The lowest median values of whole blood Cr and Co were associated with acetabular components positioned in 10° to 20° of anteversion (3.46 and 1.44 µg/l, respectively). Acetabular components placed in versions above or beyond these boundaries were associated with higher Co and Cr concentrations (p = 0.004 and 0.063, respectively) (Fig. 4).

Comparison of devices by acetabular component orientation. Each implant group was divided into sub-groups according to angles of acetabular component inclination and anteversion. Median ion values for each sub group were then calculated and plotted (Figs 4 and 5). Table VI shows the overall relative effects of suboptimal acetabular component position on the two resurfacing systems using patients from the small ASR and BHR implant groups.

Comparison of devices by gender. Men were implanted with significantly larger components than the women and acetabular components with significantly larger angles of anteversion in both the ASR and BHR groups (p < 0.001 for both variables).

Men. There were 52 men with ASR and 44 men with BHR. Whole blood Cr was found to be significantly lower in the ASR men than in the BHR patients (p = 0.012), although Co concentrations were comparable (Table VII).

Table V. Comparison of the mean, median and ranges of whole blood metal ion levels associated with the Birmingham hip resurfacing patient group split by size

	Large implants (n = 16) mean/median (range)	Small implants (n = 54) mean/median (range)	Significance
Chromium (μg/l)	3.69/3.59 (2.37 to 6.56)	5.92/4.04 (2.41 to 39.8)	0.017*
Cobalt (μg/l)	1.28/1.32 (0.63 to 2.03)	5.31/1.68 (0.77 to 147)	0.023*
Inclination (°)	49.51	47.0	0.227†
Anteversion (°)	15.02	18.23	0.317†

* Mann-Whitney U test for non-parametric data, two-sample *t*-test

† quoted acetabular component angles are mean values

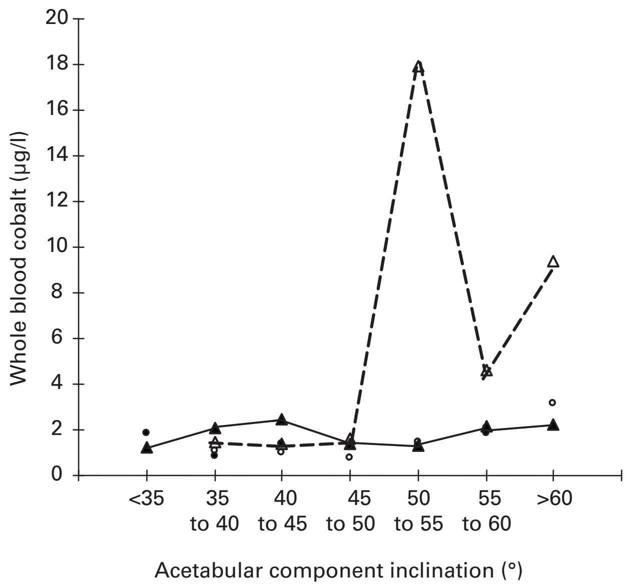

Fig. 5

Graph showing the effect of cup inclination angle on whole blood cobalt concentrations. Data plots correspond to medial ion levels of small articular surface replacements (ASRs) (Δ joined by broken line), large ASRs (°), large Birmingham hip resurfacings (BHRs) (•) and small BHRs (▲ joined by solid line).

Women. There were 38 women with ASR and 26 with BHR implants. The mean femoral component size was larger in the ASR group, as were the mean angles of inclination and anteversion of the acetabular component. The median Co concentration in the women with ASR was three times that of the median Co in the women with BHR (p = 0.010) (Table VII).

Discussion

Our results substantiate our previous conclusions[7] that generation of metal ions following ASR resurfacing is linked to both the size of the implant and the three-dimensional orientation of the acetabular component. The present, larger group of results provides further evidence of the importance of the anteversion of the acetabular component with increased metal ion loads observed in components with both excessive (> 20°) and insufficient (< 10°) radiological anteversion.

As with the ASR, there was a significant inverse relationship between the size of the femoral component and whole blood Cr in the BHR patients. In the fourth quartile of ASR and BHR implant sizes, the blood metal ion concentrations were significantly lower than those found in the patients with smaller implants. Larger ASR and BHR acetabular components appear more resistant to suboptimal positioning in terms of metal ion generation. This is probably due to the thicker fluid film achieved by the larger implants[8] as well as the greater arc of cover. Both of these factors protect against the increased rates of wear associated with edge loading.

A further variable that has been shown to affect lubrication *in vitro* is clearance. Rieker et al[9] showed that wear rates can be reduced by reducing clearance as much as manufacturing processes will allow. The improved lubricating film that the reduced clearance of the ASR theoretically provides may be the reason for the significantly lower whole blood Cr values in the male ASR patients. These clearance values are, however, nominal. When the components are implanted they are vulnerable to the effects of distortion,[19] the extent of which is impossible to measure *in vivo* routinely. By definition, a low-clearance device is at greater risk of accelerated wear should the combined distortion of the components be greater than expected. Whereas the median Cr value of the male ASR patients is lower than that of the male BHR group, the range of the male ASR Cr and Co concentrations is much broader, with several extremely high values.

In order to conserve bone and increase impingement-free range of movement, the ASR acetabular component is subhemispherical in design. For the smallest ASR acetabular component, the arc of cover (the subtended angle to the articular surface) is 148°, increasing to 160° for the largest. This is in sharp contrast to the cover provided by the BHR acetabular component with 158° for the smallest, increasing to 166° for the largest acetabular component. The reduced cover provides a potential explanation for the increased vulnerability of the ASR device to angles of inclination greater than only 45°. This also accounts for the increased sensitivity to suboptimal position of small BHRs compared to their larger counterparts. This is consistent with the results of De Haan et al,[13] who found a highly significant relationship between the arc of cover of the acetab-

Table VI. The differences in blood chromium and cobalt concentrations associated with optimally and suboptimally placed small implants. Optimal position refers to small acetabular components positioned with inclination angles ≥ 35° and ≤ 55° and anteversion angles 10° to 20°. Suboptimal refers to acetabular components placed with inclination and anteversion angles beyond these boundaries. Mann-Whitney U test for non-parametric data used to establish significant differences. Metal ion concentrations in bold are median values with ranges in parentheses

	Suboptimal	Optimal	Significance
BHR*			
Chromium (μg/l)	6.56 (2.6 to 39.8)	3.46 (2.37 to 6.32)	0.001
Cobalt (μg/l)	5.26 (1.2 to 147)	1.27 (0.63 to 5.74)	0.028
ASR†			
Chromium (μg/l)	17.51 (3.2 to 69.8)	3.06	< 0.001
Cobalt (μg/l)	27.90 (1.6 to 271)	1.19	< 0.001

* ASR, articular surface replacement
† BHR, Birmingham hip resurfacing

Table VII. Comparison of metal ion concentrations between the groups split according to gender

	Men			Women		
	ASR*	BHR†	p	ASR	BHR	p
Femoral size	51.3	50.5	0.173	45.5	44.6	0.09
Acetabular component inclination (°)	49	48.2	0.309	50.5	46.2	0.08
Acetabular component anteversion (°)	18.9	17	0.173	23.4	19.9	0.19
Whole blood chromium (μg/l)	3.07	3.78	0.012	4.92	4.34	0.74
Whole blood cobalt (μg/l)	1.58	1.41	0.618	4.68	1.66	0.01

* ASR, articular surface replacement
† BHR, Birmingham hip resurfacing

ular component and serum metal ions. The fact that the larger acetabular component of the BHR is associated with lower ion levels suggests that the mechanism of metal ion release is more commonly due to the effects of edge loading rather than impingement.

Anteversion may cause an increase in metal ion levels owing to a combination of factors. First, increased anteversion will reduce component cover, potentially impairing the generation of a sufficient fluid film and causing wear to occur nearer to the rim of the acetabular component. Excessive anteversion may cause femoral neck impingement on the posteroinferior portion of the acetabular component when the hip is extended and externally rotated. The reverse process, with reduced anteversion causing anterior impingement during deep flexion, could explain the slight increase in metal ions observed in near-neutral ASR and BHR acetabular components. However, we believe that this effect is more likely to be explained by posterior edge loading in deep flexion and stair climbing,[20] as near-neutral ASR acetabular components are associated with a greater increase in metal ions than the hemispherical acetabular component of the BHR.

Taking the value of 10 μg/l (which is double the United Kingdom workplace exposure limit[21]) as an arbitrary unacceptable threshold for whole blood Co concentrations, Fisher's exact test showed a significant difference between the ASR and BHR data groups, with a p-value of 0.014. There were only two BHR patients with Co levels above 10 μg/l compared to 14 in the ASR group. The mean inclination and anteversion angles of these two BHR joints were higher than those of the 14 ASR joints (BHR inclination/anteversion = 59.9°/33.4°; ASR inclination/anteversion = 54.8°/26.9°). The BHR joints were also smaller, with a mean femoral size of 44.0 mm compared to 47.8 mm for the ASRs. This is compatible with the idea of the BHR acetabular component being more forgiving of suboptimal positioning.

A theoretical model to explain the variation in ion levels associated with the two resurfacing systems. Bergmann et al[20] showed that, in the standing position, the average hip joint contact force is directed 14° medially from the longitudinal axis in the anteroposterior plane and 16° anteriorly in the transverse plane. Using these data and the orientations of the acetabular components of the patients in this study, we calculated the distance from the centre of the theoretical contact patch to the superior anterior edge of the articular surface of the acetabular component (or its rim) for each patient in the standing position. We assumed the contact patch to be centred over the hip contact force vector. The resultant distance between the contact patch and the acetabular component rim (CPR distance) is therefore dependent on the diameter and the arc of cover provided by the acetabular component, and also the radiological angles of inclination and anteversion. We found a highly significant inverse correlation between the CPR distance and blood and serum Cr and Co

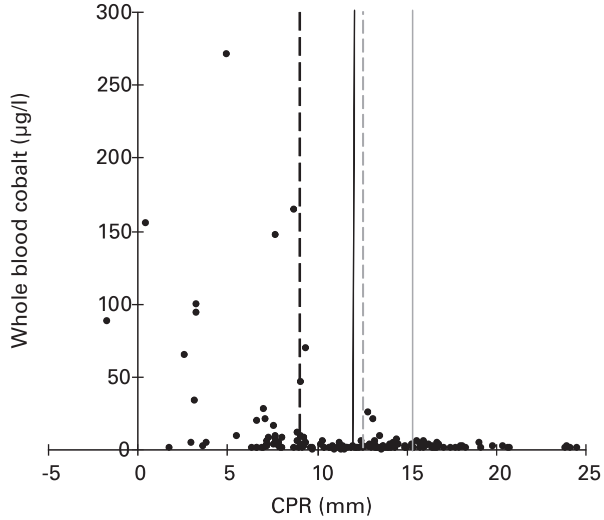

Fig. 6

Graph showing all articular surface replacement (ASR) and Birmingham hip resurfacing (BHR) patients in the study (Spearman rank correlation -0.49, p < 0.001) Mean ASR male patient acetabular component rim (CPR) distances represented by solid vertical black lines and the mean ASR female patients represented by the broken black line. The mean male BHR patient CPR distance is represented by the solid grey vertical line and the female BHR distance by the broken grey line. CPR values are calculated using the mean acetabular component sizes and inclination/anteversions for each patient group in the study.

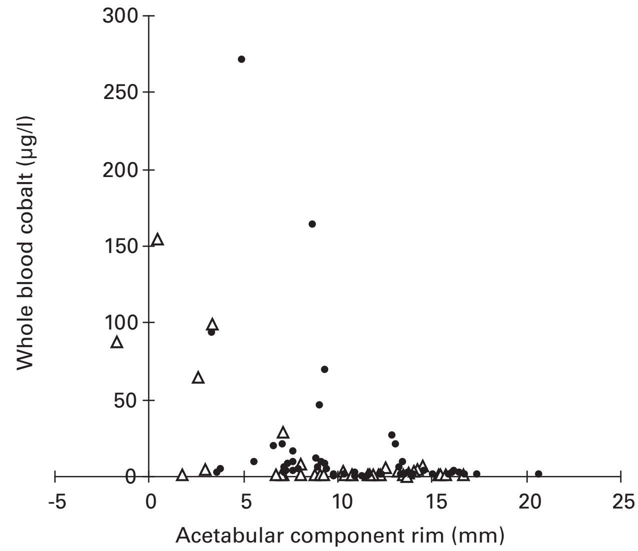

Fig. 7

Articular surface replacement patients only. Whole blood cobalt values versus distance from the centre of the calculated contact patch to the edge of the articular surface of the cup. 'Δ' represents samples drawn between 12 and 18 months post resurfacing. '•' represents blood samples drawn at 18 months and beyond.

levels in both implant groups, with no large values observed when the contact patch was calculated to be > 10 mm from the rim (Fig. 6). This is consistent with retrieval studies which have demonstrated increased wear secondary to edge-loaded implants. The 'wear scar' on retrieved components is commonly located at 10° to 15° from the vertical, consistent with Bergmann's *in vivo* joint contact area measurements.[22,23] In this series a number of patients had acceptable levels of CrCo even with a calculated CPR distance < 10 mm. However, as the time from surgery to blood sampling increased, so did the probability that patients with a CPR distance < 10 mm were found to have grossly increased blood metal ion concentrations (Fig. 7). This observation may represent the temporary tolerance of the hard metal-on-metal surfaces to a suboptimal position until the joint reaches a state of accelerated wear.[22]

We believe that the calculated CPR distance is a reliable indicator of the vulnerability of a joint to the effects of anterior edge loading and anterior subluxation. If subluxation does occur we speculate that the effects of the sharp ASR rim are likely to be particularly damaging to the femoral component. CPR distance does not, however, guage the vulnerability of the resurfaced joint to the risk of anterior impingement and posterior edge loading/subluxation. The surgeon must strike a balance between attempting to reduce the negative effects of edge loading by implanting an acetabular component with reduced inclination and anteversion, and attempting to maintain a satisfactory range of movement of the hip. From the data available to us, we feel it reasonable to recommend that the ASR acetabular component to be placed in 40° (SD 5) of inclination and 15° (± 5) of weight-bearing radiological anteversion in order to reduce levels of metal ions in the blood. We have a smaller amount of ion data for the BHR device. However, the metal ion increase in our series only appears above 55°. When considering the optimal inclination for the BHR, the lowest ion values are associated with acetabular components positioned between 45° and 55°, rather than around the lower limits (< 40°). We believe that low inclination angles of near-hemispherical acetabular components with reduced anteversion, coupled with the reduced head to neck ratio inherent to surface arthroplasty, may lead to anterior impingement and posterior edge loading/subluxation during common activities such as stair climbing and rising from a chair.[20,24,25] Reduced inclination angles combined with high anteversion may increase the risk of anterior edge wear with or without posterior impingement.[26,27] For this reason, we feel that the BHR acetabular component should be placed with a target inclination of 45° in mind, allowing a 5° margin of error on either side and remaining within the limits conducive to a satisfactory outcome in terms of function and metal ion levels. With regard to standing radiological anteversion, we recommend 10° to 20°, with the same justification and allowance for a margin of error. In the senior author's patient group, the minimum Harris Hip Score of the 14 patients with acetabular components in this target area was 97 (mean score 99.0, mean femoral size 48.0 mm (42 to 54)).

There are two main limitations to this study, the first being the difference in time post-operatively at which blood samples were collected in the two groups. We do, however, believe that this factor is relatively insignificant compared to implant size and orientation. We believe that comparison between groups is justified as the mean time to sample collection in both groups was well beyond the bedding-in phase, where accelerated wear is said to occur.[28,29] Our data suggest that suboptimally placed acetabular components will produce increasing amounts of metal debris with time, and therefore if the difference in follow-up between the ASR and BHR groups were truly significant we would expect the BHR metal ion levels to be higher. Furthermore, the Birmingham group themselves have published convincing evidence that in well-positioned joints, metal ion levels tend to decrease over time.[30] This supports the idea that the reduced clearance of the ASR is indeed beneficial, given that Cr levels are lower in the male ASR patients despite the shorter follow-up period.

The second limitation is that we did not collect preoperative blood samples for metal ion analysis, a variable which Vendittoli et al[11] showed to correlate with post-operative ion levels. We believe this weakness is offset by the large number of patients and the fact that all those involved in the study came from the same geographical region.

Increased blood Cr amd Co concentrations following the Birmingham Hip Resurfacing procedure are associated with smaller components, acetabular component anteversion > 20° and < 10° and inclination > 55°. The female ASR patients in this series had a median Co level three times that of the female BHR group. The male ASR group had a slight but significantly reduced Cr level compared to the BHR group. The overall results suggest that the reduced clearance of the ASR promotes an improved joint lubrication regimen but this positive effect may be overridden by the increased vulnerability of the ASR acetabular component to suboptimal positioning. The BHR acetabular component is tolerant of a wider range of orientations. We have found no evidence in this study to support the idea that inclination angles < 40° equate to a reduction in metal ion concentrations.

Supplementary material

ë Further information relating to these findings and the measurement of the contact force and contact patch distance is available with the electronic version of this article on our website at www.jbjs.org.uk

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