Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales

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Summary

Background Total hip replacement (THR) is extremely common. Some prostheses fail, particularly in younger patients, and need to be revised, most commonly for loosening secondary to wear or dislocation. Surgeons have tried to address these problems by implanting large diameter metal-on-metal bearing surfaces. Our aim was to assess if metal-on-metal bearing surfaces lead to increased implant survival compared with other bearing surfaces in stemmed THR and, additionally, if larger head sizes result in improved implant survival.

Methods We analysed the National Joint Registry of England and Wales for primary hip replacements (402 051, of which 31 171 were stemmed metal-on-metal) undertaken between 2003 and 2011. Our analysis was with a multivariable flexible parametric survival model to estimate the covariate-adjusted cumulative incidence of revision adjusting for the competing risk of death.

Findings Metal-on-metal THR failed at high rates. Failure was related to head size, with larger heads failing earlier (3·2% cumulative incidence of revision [95% CI 2·5–4·1] for 28 mm and 5·1% [4·2–6·2] for 52 mm head at 5 years in men aged 60 years). 5 year revision rates in younger women were 6·1% (5·2–7·2) for 46 mm metal-on-metal compared with 1·6% (1·3–2·1) for 28 mm metal-on-polyethylene. By contrast, for ceramic-on-ceramic articulations larger head sizes were associated with improved survival (5 year revision rate of 3·3% [2·6–4·1] with 28 mm and 2·0% [1·5–2·7] with 40 mm for men aged 60 years).

Interpretation Metal-on-metal stemmed articulations give poor implant survival compared with other options and should not be implanted. All patients with these bearings should be carefully monitored, particularly young women implanted with large diameter heads. Since large diameter ceramic-on-ceramic bearings seem to do well we support their continued use.

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Introduction

Osteoarthritis is an increasingly prevalent disorder. Roughly 5% of people in France aged 70 years have symptomatic osteoarthritis of the hip,[1] and, as populations age and become more obese, it is probable that the prevalence will increase further. Advanced hip osteoarthritis can be so successfully treated with total hip replacement (THR) that it has been described it as "the operation of the 20th century".[2] THR is now extremely common: about 270 000 replacements are done each year in the USA and this is projected to increase by 174% between 2005 and 2030.[3] The National Joint Registry of England and Wales reported 68 907 primary operations in 2010.[4]

The long-term problem with THR is failure, resulting in revision surgery. In England and Wales, about 5% of THRs are revised within 7 years.[4] However, this figure probably underestimates failure, because many hips with poor function and pain are not revised.[5] In England and Wales, the mean age of a patient undergoing THR is 67 years; however, 12% of patients are younger than 55 years.[4] Implant survival is particularly important in younger patients who have longer life expectancy and higher activity levels. The results in these patients are disappointing; the Finnish Arthroplasty Register reports 15 year implant survival of only 60% in patients younger than 55 years.[6]

The leading cause of THR failure is aseptic loosening secondary to polyethylene wear.[7] A second major cause of failure is dislocation affecting about 4% of THRs, most within 6 months.[8] Surgeons and engineers have tried to address these problems by investigating alternative bearing surfaces that have lower wear and allow larger head sizes. This would decrease the risk of dislocation by increasing the primary arc of movement (the movement before the neck impinges and begins to lever out the head) and the jump distance (the distance the head needs to travel to dislocate, which equals the radius of the head). However, there are anatomical limitations to the size of implant and the largest sizes can only be implanted in people with large acetabula. Ceramic bearing surfaces have the advantage of very low wear, but are expensive and there have been reports of ceramic fracture[9] and audible squeaking.[10] Metal-on-metal bearing surfaces have been extensively assessed in simulator tests and noted to be highly resistant to wear even when used in very large head sizes.[11] In simulator tests, larger head sizes paradoxically give lower wear because the lubrication regime changes from less favourable boundary lubrication to more favourable mixed or fluid-film lubrication.[12]

Therefore, implantation of large diameter metal-on-metal bearing surfaces on stemmed prostheses has become popular, because they should result in lower failure rates. However, there are several potential dangers of exposure to metals such as chrome and cobalt, including genotoxicity and direct damage to end organs such as kidneys.[13] Furthermore, major problems have been reported with the ASR, a brand of metal-on-metal prosthesis, which seems to fail early.[14]

We aimed to use the National Joint Registry of England and Wales to assess if metal-on-metal bearing surfaces lead to increased implant survival compared with other bearing surfaces in stemmed THRs. Because larger head sizes should result in lower dislocation rates, our second hypothesis is that larger head sizes will result in improved implant survival.

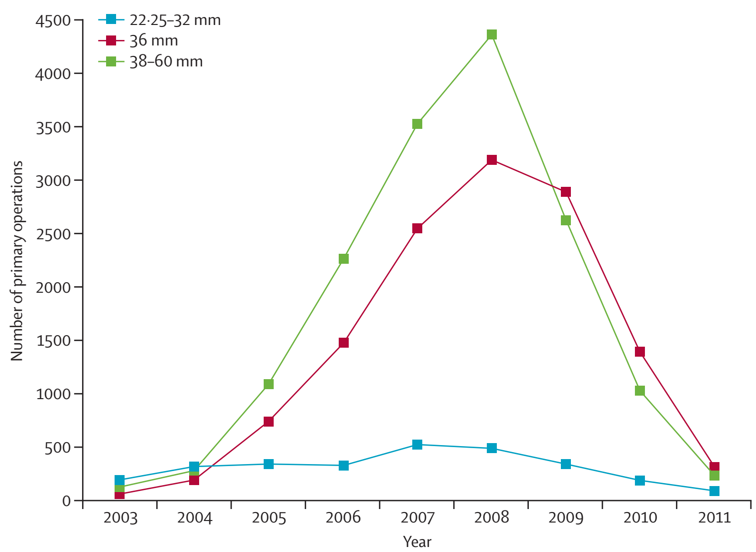
See Online for appendix

Methods

Data source

We assessed data from the National Joint Registry of England and Wales—established in 2003 and the largest arthroplasty database in the world. It records all primary and revision hip and knee replacements done in England and Wales. By April, 2011, 1 082 465 procedures had been recorded.

Our analysis is based on 402 051 (82%) of 491 505 primary stemmed THR procedures between April, 2003, and September, 2011, recorded in the National Joint Registry, which include patient identifiers that allow revisions to be linked to primary operations. These operations were done in 447 units under the care of 2578 consultant surgeons.



	2003	2004	2005	2006	2007	2008	2009	2010	2011
22·25–32 mm	200	336	351	341	534	501	352	203	101
36 mm	68	204	754	1487	2562	3199	2896	1407	327
38–60 mm	136	285	1096	2277	3534	4372	2637	1033	245

Figure 1: **Number of stemmed metal-on-metal implants by head size, National Joint Registry 2003–11**
Data for 2003 and 2011 are estimated (9 months data extrapolated to 12 months). Because of lower compliance in the early days of the registry, data for 2003 and 2004 might underestimate the number of operations by about 35%.

Procedures

Our analysis estimates all-cause revision rates. Our unit of analysis is implant (rather than patient) so we include 2266 bilateral procedures. We estimated revision rates for stemmed metal-on-metal prostheses for different head sizes. Furthermore, we have compared revision rates for three types of bearing surface: metal-on-metal, ceramic-on-ceramic, and metal-on-polyethylene. We compared various commonly used head sizes for the metal-on-metal and ceramic-on-ceramic groups, whereas the most commonly used head size of 28 mm has been chosen for the metal-on-polyethylene group (appendix). A confounding variable is the fixation of the implant, which we have addressed by reporting the three bearings in uncemented implants. However, since metal-on-polyethylene is so commonly used, we also show results for cemented and hybrid fixation.

There were substantial differences between the bearing groups (appendix). To reduce the effects of confounding, we selected an analysis sample that represented typical patients. For all bearing groups, this sample was those patients with an American Society of Anesthesiologists grade of 1 or 2 at time of primary surgery and those whose surgery was undertaken for osteoarthritis only. Furthermore, we excluded ASR implants from our metal-on-metal analysis because ASR revision rates are much higher than other brands and the ASR has now been withdrawn by the manufacturers.[14]

Furthermore, we used multivariable analysis to adjust for the age of patients and to measure the effect of head size. Separate models were estimated for men and women because of the very different head-size profile of each. We also specified separate models for the different bearing groups: metal-on-metal, ceramic-on-ceramic, and the three metal-on-polyethylene groups (uncemented, cemented, and hybrid fixation).

Statistical analysis

Our multivariable models were flexible parametric survival models[15] that estimate the cumulative incidence of revision in the presence of the competing risk of death.[16] Standard survival analysis treats death simply as censored information, but this overestimates revision rates, particularly in an elderly population.[4] The appendix provides more details of these models. In all models, we selected head size and age as predictors of revision and age as a predictor of death for the competing risk. We allowed the effect of age to differ for the main and competing risks. These models produce hazard ratios (HRs), which are a measure of relative risk (averaged over time). However, to illustrate the absolute effect of these factors, we have used the models to predict revision

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rates for a typical patient by estimating the covariate-adjusted cumulative incidence function in the presence of competing risks (appendix).

We also assessed reasons for revision across all groups by dividing the number of revisions for each reason by the total person-time at risk of revision (per 1000 patient-years). This is equivalent to a person-time incidence rate and we have estimated 95% CIs by assuming a Poisson distribution (appendix).

Role of the funding source

The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and AWB had final responsibility for the decision to submit for publication.

Results

Overall, about 8% of stemmed THR procedures recorded in the National Joint Registry of England and Wales involve a metal-on-metal prosthesis (n=31 171). Stemmed metal-on-metal procedures involve either a modular cup (a metal cup with a metal liner) or a large diameter monobloc cup (as used in hip resurfacing). In England and Wales, the use of stemmed metal-on-metal implants escalated strongly after 2004 to a peak of more than 9000 operations in 2008, but then declined sharply (figure 1). The increase in stemmed metal-on-metal from 2004 was almost entirely due to the use of larger heads.

Metal-on-metal procedures were evenly split between monobloc (14 930; 48%) and modular cups (16 241; 52%). Most modular cups (12 782; 79%) were 36 mm and another 2469 (15%) were 28 mm. From 2007, 617 larger modular cups (>36 mm) have also been used (4%). Monobloc cups were larger: 6526 (79%) of 8212 men had a cup size between 46 mm and 52 mm and 5626 (84%) of 6708 women had a cup size in the range of 42–48 mm.

With an overall 5 year revision rate of 6·2% (95% CI 5·8–6·6), metal-on-metal articulations failed more quickly than other types of bearing surface (figure 2).

The multivariable models for metal-on-metal articulations confirmed that head size was an independent predictor of revision for both men (HR 1·020, 95% CI 1·004–1·037; p=0·013) and women (1·019, 1·001–1·038; p<0·0005) suggesting that larger head sizes were more likely to be revised. These HRs can be broadly interpreted as each 1 mm increase in head size being associated with a 2% increase in the hazard (the risk at a particular point in time) of revision. Age was a significant predictor of revision for women (HR 0·981, 95% CI 0·970–0·991; p<0·0005) suggesting that younger women were more likely to have their implants revised. In the appendix we provide our predicted revision rates from these models.

The risk of revision after implantation of stemmed metal-on-metal replacements was lower with smaller head sizes in both men and women (figure 3). For example, for a man aged 60 years, the 5 year revision rate with a 28 mm head was 3·2% compared with 5·1% for a 52 mm head (appendix).

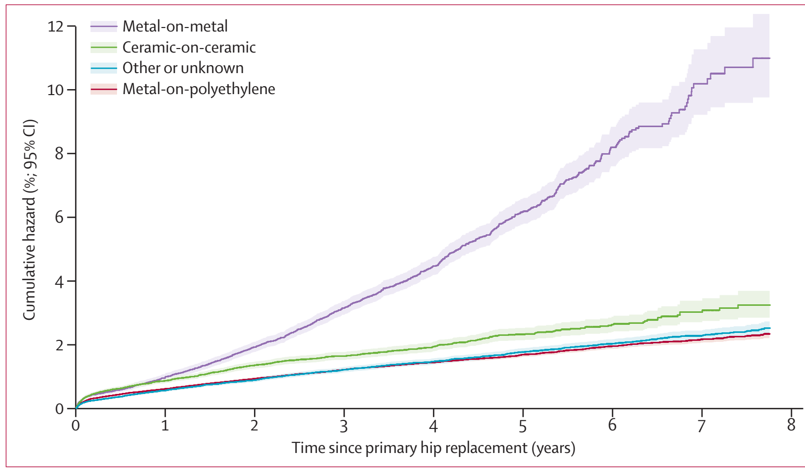

Figure 2: **Risk of revision by bearing surface**

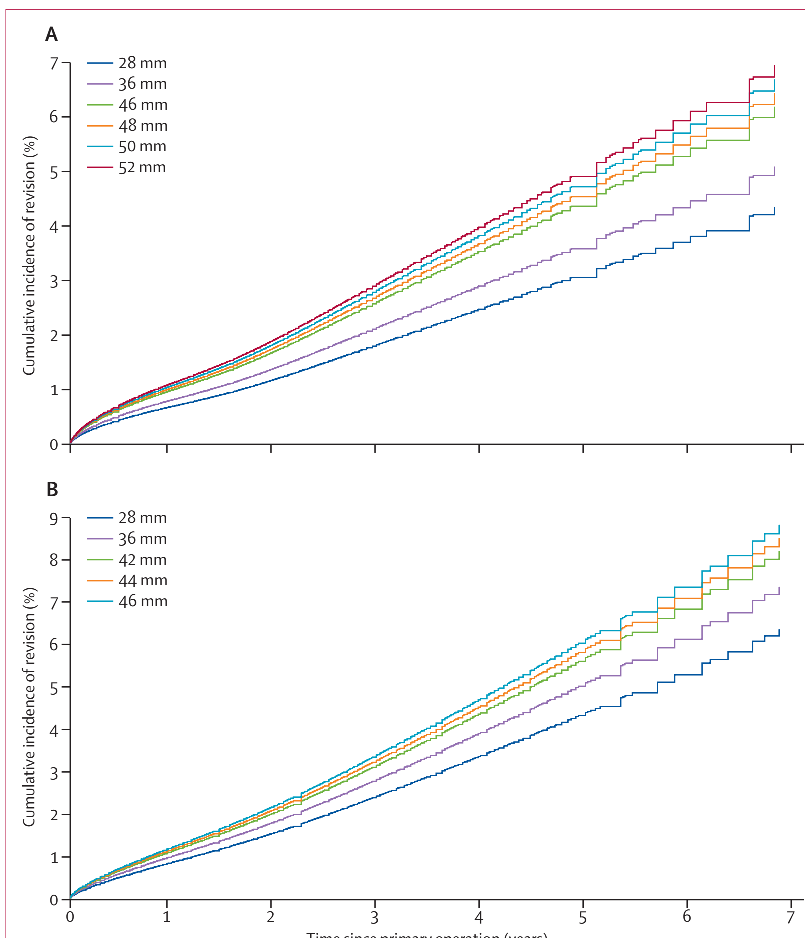

Figure 3: **Estimated cumulative incidence of revision by head size for metal-on-metal articulations**
Data are for men (A) and women (B) aged 60 years.

Metal-on-metal revision rates for women were higher than for men, even with the same head size (appendix). With a head size of 36 mm, women aged 60 years had a 5 year revision rate of 5·1% compared with 3·7% for men aged 60 years. Age at time of primary operation affected revision rates for women: women aged 55 years with a 28 mm head size had a 5 year revision rate of 4·8% compared with 3·6% for women aged 70 years. There was little difference by age for men.

Compared with other bearing surfaces, stemmed metal-on-metal implants with larger head sizes had higher failure rates in men (appendix). By contrast, a larger head size with a ceramic-on-ceramic bearing surface was associated with lower revision rates (3·3% for a 28 mm head at 5 years compared with 2·0% for a 40 mm head for a man aged 60 years). Overall, the lowest revision rates for men aged 60 years were associated with a cemented 28 mm metal-on-polyethylene combination (1·8% at 5 years), although rates for hybrid and uncemented metal-on-polyethylene and larger head ceramic-on-ceramic implants were similar. The highest revision rates were associated with stemmed metal-on-metal implants with the large monobloc cups (5·1% at 5 years).

Women with stemmed metal-on-metal prostheses had poorer outcomes than with other surgical options (appendix). Revision rates for stemmed metal-on-metal implants in women were up to four-times higher than those of other bearing surfaces. For women aged 60 years, the 5 year revision rate for a 46 mm metal-on-metal prosthesis was 6·1% compared with 1·6% for a hybrid 28 mm metal-on-polyethylene articulation. In figure 4 we summarise selected results.

The most common reasons for revision of stemmed metal-on-metal procedures in both men and women were aseptic loosening and pain and these were significantly higher in patients who received metal-on-metal implants than for other surgical options (appendix). Revisions for dislocation in men with metal-on-metal replacements were slightly lower, showing some benefit to larger head sizes in this regard. The categories for infection and other complications also show slightly higher incidences of revision for stemmed metal-on-metal implants. It is probable that these relate to some cases of local adverse reaction to metal.

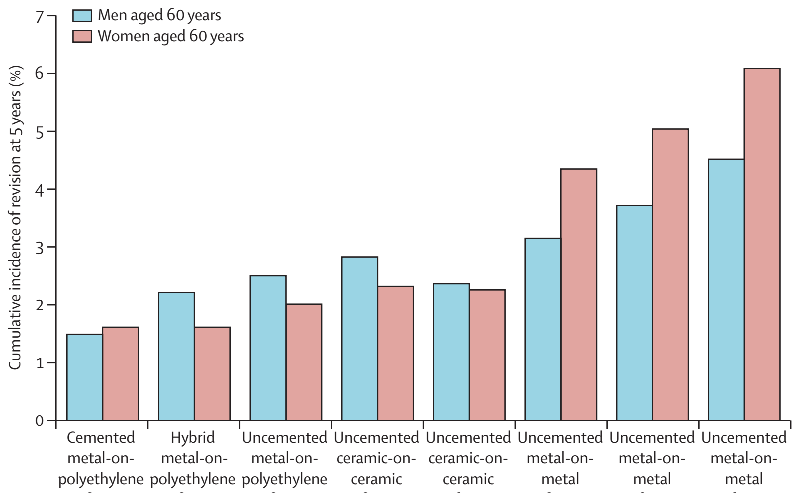

Figure 4: **Estimated 5 year revision by articulation, fixation, and sex**

Discussion

Our hypothesis that large-diameter metal-on-metal stemmed prostheses would have good implant survival rates has been refuted by use of the largest arthroplasty database in the world. Stemmed metal-on-metal THR has poorer implant survival in the medium term than other bearing surfaces, and larger head sizes are associated with higher, rather than lower, revision rates. Implant survival is particularly poor in women. By contrast, ceramic-on-ceramic articulations have better implant survival with larger head sizes.

Unfortunately there are few randomised controlled trials on this subject[17] and information on the relative merits of the many different types of prostheses is largely dependent on observational data, principally derived from surgical registries (panel). Registries have limitations, particularly relating to the data collected, and most, including the National Joint Registry, have little information on patient-related outcomes such as pain and possible confounders such as patients' activity levels. National Joint Registry data on body-mass index, another possible confounder, is incomplete but there is no reason to suspect that these possible confounders would differ greatly between patients with metal and ceramic articulations. Causality is difficult to infer from observational data since patients are not randomly allocated between treatment groups. However, the high number of participants assessed in the National Joint Registry gives us confidence in the reported outcomes, and the consistency of the data relating to revision rates and head sizes suggests a causal relation. Furthermore, registries have the advantage of reporting on the entire population receiving the treatment rather than a selected sample in a trial, thus reducing sampling bias; the large sample size and the diversity of surgeons, patients, and implants included means the results have good generalisability and external validity. It is possible that a combination of differences in the mixture of cases and confounding by indication mean the results cannot be generalised beyond the UK, but we believe this to be unlikely. Registry data from other countries confirm that patient demographics and disease profile are similar, as are the implants used.[24] Our crucial new finding is that larger head sizes increase implant failure rates for metal-on-metal prostheses, but reduce them for ceramic-on-ceramic ones, and these two implant types are used in similar patients throughout the world.

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We have shown a difference in failure rates between bearing surfaces despite our decision to remove the worst performing prosthesis (the ASR) from our analysis. We removed this implant because it has been recalled, and thus is no longer of clinical relevance, and so that a single outlier did not distort our overall assessment. Some in the orthopaedic community perceive that failing metal-on-metal prostheses is an implant-specific ASR characteristic. Our analysis clearly shows that it is not.

Although the use of metal-on-metal bearing surfaces has declined in England and Wales, the latest published data suggest they are still extensively used in the USA with 35% of hips having metal-on-metal bearings in 2009.[21] It is encouraging that surgeons in England and Wales have responded to poor outcomes by changing practice, suggesting that evidence-based medicine is practised by the orthopaedic community, but worldwide there remain many people who have metal-on-metal hip implants.

Our knowledge of tribology (the study of interacting surfaces in relative motion) suggests that larger diameter heads should increase the chance of fluid-film lubrication, thereby reducing wear, and should decrease dislocation rates. It thus makes sense that larger diameter ceramic heads produce better implant survival than smaller ones. There are several possible explanations for the surprising finding that large diameter metal heads fail earlier than smaller heads including failure to achieve optimum lubrication or trunion (the post that inserts into the head) wear[14] resulting in metal debris leading to local soft-tissue reactions[25] or early loosening due to increased transmitted torque from the larger head. There are other factors that need to be considered when implanting metal-on-metal bearing surfaces. Metals have been shown to be toxic to many organs including the lungs, kidneys, and brain[13] and can disseminate throughout the body after THR.[26] Furthermore, there is now strong evidence that cobalt and chrome are genotoxic[27] and can signal across biological barriers at concentrations produced after THR.[28]

In conclusion, analysis of National Joint Registry data provides unequivocal evidence that metal-on-metal stemmed prostheses are associated with higher failure rates than other types, and that use of large head sizes, and use of these prostheses in younger women, is associated with a particularly high rate of early revision surgery. By contrast, ceramic-on-ceramic bearings do better with larger head sizes.

We therefore recommend that metal-on-metal bearing surfaces are not used in stemmed THRs. We recommend that all patients with metal-on-metal THR undergo at least annual review with both clinical and radiological examination for the duration of the longevity of the implant. It is particularly important that younger women and those with large implanted heads are reviewed regularly. In the UK, the Medicines and Healthcare products Regulatory Agency advises annual follow-up to at least 5 years.[29] We fail to see any reason for less frequent follow-up after 5 years since exposure to metals continues and risk of revision does not decrease with time. We recommend that future research is focused on understanding the biological consequences of exposure to orthopaedic metals. And we recommend that larger head sizes are used with ceramic bearing surfaces where appropriate.

Panel: Research in context

Systematic review

We searched the Cochrane Library, Medline, and Embase with no date restriction for studies that compared the implant survival of total hip replacement by bearing surface. Our search terms related to hip arthroplasty or replacement, metal-on-metal, and systematic review or appraisal. The quality of reviews was judged by two researchers with the Database of Abstracts of Reviews of Effects criteria. We identified three relevant systematic reviews published in 2011[17–19] and four recent appraisals.[20–23] We also reviewed other national joint registries. The systematic reviews identified more observational data than trials, and commented on the low quality of many of the studies. The most recent and comprehensive review summarised data from 3404 hips involved in comparative studies, and 830 000 operations from many different registries.[17] It concluded that there was limited evidence on the comparative effectiveness of the various hip-implant bearings. The other reviews concluded that although uncertainty remains, metal-on-metal hips might have a place in the management of the young active patient. The largest additional study reported data from 36 423 hip replacements in the US Medicare data, but only had implant survival data for 2 years.[21] There was a non-significant trend towards poor survival of metal-on-metal implants when compared with ceramic-on-ceramic hips, but no data on head size were available.

Interpretation

Our findings substantially add to existing published work. The National Joint Registry of England and Wales has the biggest database on hip replacements in the world, allowing us to analyse more than 400 000 procedures up to 7 years after surgery, and avoiding problems that can arise from selection bias or loss to follow-up in other types of study. In addition to showing that all types of metal-on-metal prostheses are prone to early failure, analysis by head size has definitively shown that failure rates increase directly with head size.

Contributors

AJS was involved in the statistical analysis, preparation of the figures, data interpretation, study design, and writing the report. PD was involved in the study design, data interpretation, and writing the report. KV was involved in the data analysis. MP was involved in the study design and writing the report. AWB was involved in the review of published work, data interpretation, study design, and writing the report.

Conflicts of interest

MP receives royalties from DePuy for a cemented total hip prosthesis. The other authors declare that they have no conflicts of interest.

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References

1 Guillemin F, Rat AC, Mazieres B, et al. Prevalence of symptomatic hip and knee osteoarthritis: a two-phase population-based survey. *Osteoarthritis Cartilage* 2011; **19:** 1314–22.

2 Learmonth ID, Young C, Rorabeck C. The operation of the century: total hip replacement. *Lancet* 2007; **370:** 1508–19.

3 Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States of America from 2005 to 2030. *J Bone Joint Surg Am* 2007; **89:** 780–85.

4 National Joint Registry for England and Wales. 8th annual report 2011. http://www.njrcentre.org.uk/NjrCentre/Portals/0/Documents/NJR%208th%20Annual%20Report%202011.pdf (accessed Jan 31, 2012).

5 Wylde V, Blom AW. The failure of survivorship. *J Bone Joint Surg Br* 2011; **93:** 569–70.

6 Mäkelä KT, Eskelinen A, Pulkkinen P, Paavolainen P, Remes V. Results of 3,668 primary total hip replacements for primary osteoarthritis in patients under the age of 55 years. *Acta Orthop* 2011; **82:** 521–29.

7 Howard JL, Kremers HM, Loechler YA, et al. Comparative survival of uncemented acetabular components following primary total hip arthroplasty. *J Bone Joint Surg Am* 2011; **93:** 1597–604.

8 Blom AW, Rogers M, Taylor AH, Pattison G, Whitehouse S, Bannister GC. Dislocation following total hip replacement: the Avon Orthopaedic Centre experience. *Ann R Coll Surg Engl* 2008; **90:** 658–62.

9 Aldrian S, Nau T, Gillesberger F, Petras N, Ehall R. Medium-term analysis of modern ceramic-on-ceramic bearing in THA. *Hip Int* 2009; **19:** 36–40.

10 Choi IY, Kim YS, Wang KT, Kim YH. Incidence and factors associated with squeaking in alumina-on-alumina THA. *Clin Orthop Relat Res* 2010; **468:** 3234–39.

11 Smith SL, Dowson D, Goldsmith AA. The effect of femoral head diameter upon lubrication and wear of metal-on-metal total hip replacements. *Proc Inst Mech Eng H* 2001; **215:** 161–70.

12 Dowson D, Hardaker C, Flett M, Isaac GH. A hip joint simulator study of the performance of metal-on-metal joints—part II: design. *J Arthroplasty* 2004; **19** (8 suppl 3): 124–30.

13 Keegan GM, Learmonth ID, Case CP. A systematic comparison of the actual, potential and theoretical health effects of cobalt and chrome exposures from industry and surgical implants. *Crit Rev Toxicol* 2008; **38:** 645–74.

14 Langton DJ, Jameson SS, Joyce TJ, et al. Accelerating failure of the ASR total hip replacement. *J Bone Joint Surg Br* 2011; **93:** 1011–16.

15 Royston P, Parmar MKB. Flexible proportional-hazards and proportional-odds models for censored survival data, with application to prognostic modelling and estimation of treatment effects. *Stat Med* 2002; **21:** 2175–97.

16 Coviello E. STCOMPADJ: Stata module to estimate the covariate-adjusted cumulative incidence function in the presence of competing risks. http://econpapers.repec.org/RePEc:boc:bocode:s457063 (accessed Jan 31, 2012).

17 Sedrakyan A, Normand SL, Dabic S, Jacobs S, Graves S, Marinac-Dabic D. Comparative assessment of implantable hip devices with different bearing surfaces: systematic appraisal of evidence. *BMJ* 2011; **343:** d7434.

18 Zywiel MG, Sayeed SA, Johnson AJ, Schmalzried TP, Mont MA. Survival of hard-on-hard bearings in total hip arthroplasty: a systematic review. *Clin Orthop Relat Res* 2011; **469:** 1536–46.

19 Shetty V, Shitole B, Shetty G, Thakur H, Bhandari M. Optimal bearing surfaces for total hip replacement in the young patient: a meta-analysis. *Int Orthop* 2011; **35:** 1281–87.

20 Haddad FS, Thakrar RR, Hart AJ, et al. Metal-on-metal bearings: the evidence so far. *J Bone Joint Surg Br* 2011; **93:** 572–79.

21 Bozic KJ, Ong K, Lau E, et al. Risk of complication and revision total hip arthroplasty among Medicare patients with different bearing surfaces. *Clin Orthop Relat Res* 2010; **468:** 2357–62.

22 Bolland BJRF, Culliford DJ, Langton DJ, Millington JPS, Arden NK, Latham JM. High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: clinical, radiological and retrieval analysis. *J Bone Joint Surg Br* 2011; **93:** 608–15.

23 Neuerburg C, Impellizzeri F, Goldhahn J, et al. Survivorship of second-generation metal-on-metal primary total hip replacement. *Arch Orthop Trauma Surg* 2011; published online Nov 18. DOI:10.1007/s00402-011-1427-x.

24 Australian Orthopaedic Association. Australian Orthopaedic Association National Joint Replacement Registry—Annual Report 2010. Adelaide: Australian Orthopaedic Association, 2010.

25 Davies AP, Willert HG, Campbell PA, Learmonth ID, Case CP. An unusual lymphocytic perivascular infiltration in tissues around contemporary metal-on-metal joint replacements. *J Bone Joint Surg Am* 2005; **87:** 18–27.

26 Case CP, Langkamer VG, James C, et al. Widespread dissemination of metal debris from implants. *J Bone Joint Surg Br* 1994; **76:** 701–12.

27 Ladon D, Doherty A, Newson R, Turner J, Bhamra M, Case CP. Changes in metal levels and chromosome aberrations in the peripheral blood of patients after metal-on-metal arthroplasty. *J Arthroplasty* 2004; **19** (8 suppl 3): 78–83.

28 Parry MC, Bhabra G, Sood A, et al. Thresholds for indirect DNA damage across cellular barriers for orthopaedic biomaterials. *Biomaterials* 2010; **31:** 4477–83.

29 Medicines and Healthcare products Regulatory Agency. Medical Device Alert: All metal-on-metal (MoM) hip replacements (MDA/2010/033). http://www.mhra.gov.uk/Publications/Safetywarnings/MedicalDeviceAlerts/CON079157 (accessed Jan 31, 2012).