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EDITORIAL

Trunnionosis: A pain in the neck

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Abstract

Metal-on-metal (MoM) hip replacements have proven to be a modern day orthopaedic failure. The early enthusiasm and promise of a hard, durable bearing was quickly quashed following the unanticipated wear rates. The release of metal ions into the blood stream has been shown to lead to surrounding soft tissue complications and early failure. The devastating destruction caused has led to a large number of revision procedures and implant extractions. The resulting research into this field has led to a new area of interest; that of the wear at the trunnion of the prosthesis. It had been previously thought that the metal debris was generated solely from the weight bearing articulation, however with the evolution of modularity to aid surgical options, wear at the trunnion is becoming more apparent. The phenomenon of "trunnionosis" is a rapidly developing area of interest that may contribute to the overall effect of metallosis in MoM replacements but may also lead to the release of metal ions in non MoM hip designs. The aim of this paper is to introduce, explain and summarise the evidence so far in the field of trunnionosis. The evidence for this phenomenon, the type of debris particles generated and a contrast between MoM, non MoM and resurfacing procedures are also presented.

Key words: Wear; Trunnion; Ions; Arthroplasty; Hip

Core tip: Metal ions, derived from Metal-on-Metal (MoM) hip replacements have been a subject of interest since the catastrophic failure of this bearing surface. However, debris generation is not solely limited to the articulating surface, but can arise from the interface between the head and neck at the trunnion. Furthermore, it appears that the phenomenon of 'trunnionosis' is not limited to only MoM prosthesis, but to all modular designs and may therefore contribute to the problem of metallosis.

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INTRODUCTION

The devastating effects of metal on metal hip arthroplasty are well recognized and described in the literature[1,2]. The term adverse reaction to metal debris (ARMD) is an umbrella term that has been used to describe the effects of metal ion deposition within soft tissues in the body. Patients who become symptomatic and develop ARMD frequently need revision of their prostheses[3], whilst those who are asymptomatic but suffer with high serum metal ion levels represent a more controversial group to treat[4].

Historically, early hip replacements consisted of a non modular femoral head with a single neck option, the so called "monobloc". This meant that restoring leg length and offset was difficult, and may have resulted in instability and abductor dysfunction. As a result, modularity was introduced into the design of hip prostheses and has become increasingly common in the last two decades. Modularity can be exhibited at the junction between the head and the neck with the junction being made at the trunnion or the neck and the body. The neck head junction typically consists of a trunnion which typically has a machined taper allowing for an interference fit. The taper interface is where the femoral head (female taper surface) attaches to the trunnion (male taper) of the femoral stem. The attraction of this degree of modularity to the operating surgeon is clear. Armed with these options, alterations to the offset, version and length of the final implanted device can be achieved independent of the femoral stem fixation, thus restoring the hip centre[5].

A recent area of interest involves the head and neck interface. The evidence is still unclear but there are concerns that this extra junction between the head and the trunnion may be exacerbating the problem of metal on metal replacements and may be a source of metal wear debris. This potential wear process has been given the term "trunnionosis".

Metal on metal (MOM) hip replacements and hip resurfacing offer a useful model for the study of trunnionosis. Since metal-on-metal revision procedures are now frequently performed, the retrieved prostheses are being sent for analysis at regional centres. This enables a thorough and detailed analysis of the prostheses, including the trunnion/taper sites, to be performed. Given that hip resurfacing and MOM hip replacements use the same bearing, but hip resurfacing has no trunnion or modularity, differences in metal wear debris can be compared between the two. The study of trunnionosis has a potential impact on all modular hip replacement prostheses regardless of the bearing surface used.

The aim of this paper is to present the early and growing body of evidence to support the presence of wear debris generated from the taper junction and relate it to the clinical outcome.

WHAT IS THE EVIDENCE?

The use of large diameter heads in total hip replacements is thought to improve stability of the articulating surfaces[6,7]. However in the context of metal-on-metal, it has been associated with an increased wear and subsequent failure rate[8]. Elkins *et al*[9] developed a finite element model to evaluate the relationship between implant stability and trunnion wear. The head/neck interface consisted of the tapered trunnion and head bore. When assembled on the trunnion, a moment arm exists between the center of rotation of the head and the trunnion contact pressure centroid. Stability, measured in terms of femoral head subluxation, improved with increased diameter, although diminishing benefit was seen for size increases beyond 40 mm. By contrast, at the trunnion interface, unabated increase in stress was observed for femoral heads exceeding 40 mm, with the greatest effect seen for larger values of head diameter. Linear wear at the trunnion interface demonstrated a similar dependence upon head size, accelerated wear observed for femoral head diameters exceeding 40 mm for both gait and sit-to-stand motions. This seemed to suggest that *ex-vivo*, large-diameter heads for MoM THA have a tendency to undergo deleterious wear generation at the head/trunnion interface, albeit with an associated improvement in construct stability. It also appeared that trunnionosis-inducing wear increased substantially for head diameters greater than about 40 mm.

Considering *in-vivo* evidence, there is a growing body of evidence to suggest the presence of trunnionosis. A study from Japan undertaken by Yoshikawa *et al*[10], sought to investigate the likely source of the metal ions that led to adverse reaction to metal debris (ARMD) in ten out of thirty eight revised MoM THRs. All ARMD cases showed metal debris-like deposits on head-neck junction on the trunnion and massive periprosthetic tissue scarring at time of revision. Histological analysis and metal ion measurements confirmed that the periprosthetic tissue necrosis occurred due to toxicity due to excess accumulation of cobalt and chromium ion levels. Most interestingly, the energy dispersive X-ray spectrometry findings suggested that the deposits resulted from a tribochemical reaction on trunnion rather than any other area of the prosthesis.

Garbuz *et al*[11] performed a randomized clinical trial to compare outcomes and serum metal ion levels in two groups of patients, one receiving the Durom femoral resurfacing component and the other group a large-head MoM THA (M/L Taper stem made of titanium, with a large Metasu head *via* a Cr-Co alloy metal sleeve adapter and Morse taper in order to match the 12/14 taper of the stem. One of the hypotheses was that since the articulating portion of these implants is identical, there should be no difference in serum metal ions between the two groups. They found that although both groups had raised metal ion levels, the levels were much higher in large-head metal-on-metal hip replacement group. One reasonable conclusion drawn was that the markedly elevated serum cobalt and chromium levels related to the two areas of modularity for the attachment of the femoral head to the stem.

Furthermore, Beaulé *et al*[12] performed a similar comparative study involving cohorts of 26 patients matched according to gender femoral head size and BMI. One group received a modular stem THA while the other group received a MoM hip resurfacing prosthesis. Once again, the acetabular components and bearing surfaces used in both groups were identical. Cobalt ion levels were significantly higher in the cohort of patients who received a THA at 6, 12 and 24 mo.

Similar conclusions were drawn by Langton *et al*[13]. Their group analysed the 206 ASR hip resurfacing and 51 ASR THA systems, each used with an identical acetabular component. The THA head attaches to the stem *via* a cobalt-chromium taper junction in two sizes 11/13 and 12/14. As the bearing diameter increased in the resurfacing group, there was a significant decreasing trend of ion concentration. For the THA group, there was a non significant increase as bearing diameter increased. They speculated that the generation of metal debris from taper junctions explained the poor performance of the larger sized THA joints and also the increased failure rates of the smaller sizes relative to the pure resurfacings. The patterns of material loss suggested to them that the tapers were splayed open by mechanical forces.

In a bid to quantify wear, corrosion and to determine the main mechanism of material loss at the taper, a retrospective study of 78 large metal-on-metal hip replacements retrieved after revision was conducted by Matthies *et al*[14]. Corrosion was assessed using light microscopy and scanning electron microscopy (SEM). Evidence of at least mild taper corrosion was seen in 90% cases, with 46% severely corroded. SEM confirmed the presence of corrosion debris, pits and fretting damage. However, volumetric wear of the taper surfaces was significantly lower than that of the bearing surfaces (P = 0.015). They concluded that corrosion appeared to be the predominant mechanism of material loss at the taper junction.

Langton *et al*[15] prospectively investigated the failure of 111 failed and explanted DePuy MoM THA. One hundred and four of these (94%) had been revised secondary to adverse reactions to metal debris. On visual inspection, 38 of the tapers (34%) showed no identifiable surface change. Volumetric and linear wear analysis showed little or no distinction between these tapers and the unused, sterile tapers used as a control. However the remaining 73 tapers were found to have clear visual surface changes, the patterns of which were markedly similar. The investigating group noted an area of significant damage in a localised circumferential band that corresponded to the insertion of the base of the trunnion. The damage was so severe that in some cases it was palpable. Proximal to this band, the trunnion had left an imprint of its machining grooves. Scanning electron microscopy images confirmed the above findings. Furthermore, the ridges formed by the trunnion grooves appeared flattened with multiple pits. These pits were localised, approximately ten microns in diameter and appeared to be partially filled with inclusion bodies. Further analysis showed that the pits were rich in chromium and the presence of small amounts of chlorides and oxides suggested that there was evidence of local corrosion. The surface around these pits was identical to the manufactured alloy.

Nassif *et al*[16] assessed the trunnion taper junction of fifty large metal-on-metal retrieved implants to determine damage modes and severity of wear. All had heads of greater than 40 mm. The female tapers were examined visually for gross wear and deformation and discoloration associated with oxidative wear was also recorded. Trunnion counterparts were further analyzed using a laser profilometry system to determine location and severity of wear and to measure linear and then correlated to taper geometry and head size. They found that all taper types demonstrated discoloration consistent with corrosive damage, while gross mechanical damage was found in 16% of examined tapers. Corrosive damage of the trunnion interface was present on 58% of implants demonstrating circumferential discoloration of varying severity. Implants that employed "11/13" taper geometries had a significantly higher evidence of mechanical wear and toggling compared to "12/14". Implants from all manufacturers demonstrated consistently high incidence of oxidative wear. Patients with more severe tissue destruction (abductor damage and bone loss) had an 80% incidence of corrosive wear at the trunnion junction. Less severe soft tissue damage was associated more with mechanical wear, but had only a 50% incidence of corrosive wear. They concluded that taper-trunnion micromotion and corrosion in large head MOM THA did not correlate with head size however were significantly affected by trunnion taper geometries with "11/13" taper designs being more susceptible. Nonetheless, corrosive damage is present across all taper designs.

Meyer *et al*[17] also failed to find a correlation between head size and metal ion release. In a retrieval analysis of 114 patients who had revisions of large-diameter head MoM articulations, electrochemical reactions between the stem and adapter were performed. All patients presented with early clinical symptoms; 59 patients had radiographic signs of loosening. However ninety-four percent of patients had instability at the cone/taper interface. Intra operatively, one hundred four patients had metal ion induced foreign body reactions and necrosis. The largest amounts of metal released were titanium or iron. However, their analysis showed a risk for galvanic corrosion and loosening at the cone/taper interface.

A further retrieval study by Hexter *et al*[18], quantified taper corrosion in 161 failed MoM components (head components n = 128; femoral stem n = 33) from nine hip types with the use of a qualitative subjective scoring system. They unexpectedly noted a region on the female taper surface that contained ridges that directly corresponded with the ridged microthread on the trunnion. The ridges were not present on unimplanted (control) female taper surfaces. Historically the ridged microthread was introduced to trunnions to minimise the risk of burst fracture of ceramic heads. They called this phenomenon "imprinting". The corrosion and imprinting scores were strongly correlated (r = 0.694, P = 0.001). Corrosion was largely confined to the area of the female taper interface where imprinting had occurred, at the region that had been in contact with the trunnion microthread. Scanning electron microscopy showed evidence of fretting corrosion and substantial mechanical wear within the ridged region on the female taper surface. Their group proposed a process of "mechanicallyassisted crevice corrosion," starting with joint fluid entering the taper junction as a result of pumping of fluid along the machined microthread of the trunnion. This results in galvanic corrosion of the anodic surface (the cobalt-chromium femoral head or taper sleeve). The pattern of corrosion of the head taper is determined by the surface profile of the screw thread of the trunnion, thus leaving an imprinted appearance. Thus they speculated that these ridges exacerbate the mechanical wear at this junction in metal-on-metal hip bearings.

IS THIS A PROBLEM EXCLUSIVE TO MOM REPLACEMENT?

Wear at the neck/stem interface is not exclusive to MoM replacements, however due to the recent interest in this area, more attention has been given to this process. The effect of trunnion wear is also evident with non metal-on-metal bearing surfaces. Several studies have shown that even when using polyethylene inserts, there are still detectable levels of metal ions within the blood, albeit at a much lower rate compared to that of metal on metal bearing recipients. Using identical femoral and acetabular components, MacDonald *et al*[19] randomised two groups of patient to receive either a metal or a polyethylene acetabular insert. At a minimum of 2 years, patients who had metal-on-metal inserts had on average a 7.9-fold increase in erythrocyte cobalt, a 2.3-fold increase in erythrocyte chromium, a 1.7-fold increase in erythrocyte titanium, a 35.1-fold increase in urine cobalt, a 17.4-fold increase in urine chromium and a 2.6-fold increase in urine titanium. Patients receiving a polyethylene insert had no change in erythrocyte titanium, urine cobalt, or urine chromium and a 1.5-fold increase in erythrocyte cobalt, a 2.2-fold increase in erythrocyte chromium, and a 4.2-fold increase in urine titanium.

Isaac *et al*[20]measured whole blood metal ion levels for a series of ceramic-on-metal total hip replacements and compared them metal-on-metal prostheses. The median increase in chromium and cobalt levels at 12 mo was 0.08 μg/L and 0.22 μg/L respectively for the CoM bearings, compared to 0.48 μg/L and 0.32 μg/L for the MoM implants. These findings may suggest that even in patients with well functioning metal or ceramic-on-polyethylene total hip replacements, metal ion release at the modular femoral head-neck junctions remains a source of serum cobalt and chromium particle debris release.

HOW SIGNIFICANT IS THE WEAR DEBRIS DERIVED FROM THE TRUNNION?

It is beginning to become evident that material loss does appear to occur at the region of the trunnion interface. The question still remains about the significance of this debris produced. Hart *et al*[21] retrieved 53 large head metal-on-metal hip replacements and attempted to determine the relative contributions of the bearing and taper surfaces to the total wear volume. Volumetric wear of the bearing surfaces was measured using a coordinate measuring machine and of the taper surfaces using a roundness measuring machine. They found that the mean taper wear volume was lower than the combined bearing surface wear volume ($P = 0.015$). On average the taper contributed 32.9% of the total wear volume, and in only 28% cases was the taper wear volume greater than the bearing surface wear volume.

IS IT THE SAME PARTICLES AS THAT DERIVED FROM THE WEIGHT BEARING SURFACE?

There is no clear evidence pointing to whether the wear particles generated at the taper are dissimilar to those generated at the weight bearing surfaces. However there does appear to be evidence to support the notion that taper derived particles may be more biologically active and destructive to soft tissues.

Langton *et al*[15] have reported data involving 369 explanted metal-on-metal devices from various manufacturers from patients who all suffered with adverse reaction to metallic debris. Volumetric wear analysis of the bearing surfaces and taper junctions was carried out using a coordinate measuring machine. The relationships between total metallic loss and metal ion concentrations and the macroscopic and histological tissue appearance of THA patients were compared to those in resurfacing patients. Resurfacing explants retrieved from patients who had suffered ARMD were found to have significantly higher median rates of volumetric wear than the THAs [10.16 *vs* 2.25 mm^3/year ($P < 0.001$)]. Total volumetric material loss from taper junctions ranged from 0.01 to 21.55 mm^3. When volumetric taper wear was combined with bearing surface wear in the THR patients this total rate of material loss was still significantly less than in the resurfacing patients 2.52 mm^3/year *vs* 10.16 mm^3/year ($P < 0.001$). Despite this, macroscopic tissue destruction and extent of ALVAL (aseptic lymphocyte-dominated vasculitis-associated lesion) infiltration was found to be significantly greater in the THA patients. This may suggest that taper debris may be more able to more readily stimulate a destructive immune cascade than debris from primary bearing surfaces.

Several of the studies mentioned in this paper have also speculated that the material released at the taper may be more biologically active than that derived from the weight bearing surfaces[14,21].

HAS THE DESIGN OF MODERN PROSTHESES CHANGED AND DOES THIS HAVE ANY SIGNIFICANCE?

A direct correlation between design changes to prostheses and trunnionosis is still unclear however several of the studies already mentioned are noticing some correlations that may be of significant importance. Langton *et al*[15] have highlighted, in their opinion, several changes to the design of large head metal-on-metal hips that may contribute to the phenomenon of trunnionosis. Modern prosthetic designs tend to have a shorter and slimmer trunnions. This is thought to increase the impingement free range of movement by reducing the trunnion skirt. This does however mean that the base of the trunnion now sits very close to the taper which may lead to an increase in edge loading at the trunnion base. In addition, the slimmer and smaller diameter taper means that the surface area of contact between the taper and the trunnion is less. This may reduce the chance of a successful interference fit and thus increase the potential for micromotion as also concluded by Nassif *et al*[16]. Another change in modern trunnion design in that most tend to have a ridge surface machined into the material to accommodate ceramic heads. As shown by Langton *et al*[4] and Hexter *et al*[18], these grooves leave imprints on the majority of tapers and thus increase wear rate and material loss. This could also lead to increased corrosion.

CONCLUSION

Despite contributing less to the total material loss than the bearing surfaces, the head-stem taper junction appears to represent an important source of implant-derived wear debris. Analysis of metal ion levels in THA appear to be higher than hip resurfacings with comparable acetabular designs, Evidence is growing following analysis if the retrieved prostheses show clear patterns of material loss at the taper/trunnion junction, which is likely to involve corrosion. It has been speculated that the material released may be more biologically active than that from the bearing surface. What is certain is that as further analysis is undertaken, the significance or not surrounding the process of trunnionosis will become clearer.

REFERENCES

1 **Mann BS**, Whittingham-Jones PM, Shaerf DA, Nawaz ZS, Harvie P, Hart AJ, Skinner JA. Metal-on-metal bearings, inflammatory pseudotumours and their neurological manifestations. *Hip Int* 2012; **22**: 129-136 [PMID: 22476931 DOI: 10.5301/HIP.2012.9185]

2 **Haddad FS**, Thakrar RR, Hart AJ, Skinner JA, Nargol AV, Nolan JF, Gill HS, Murray DW, Blom AW, Case CP. Metal-on-metal bearings: the evidence so far. *J Bone Joint Surg Br* 2011; **93**: 572-579 [PMID: 21511920 DOI: 10.1302/0301-620X.93B4.26429]

3 **Lombardi AV**, Barrack RL, Berend KR, Cuckler JM, Jacobs JJ, Mont MA, Schmalzried TP. The Hip Society: algorithmic approach to diagnosis and management of metal-on-metal arthroplasty. *J Bone Joint Surg Br* 2012; **94**: 14-18 [PMID: 23118373 DOI: 10.1302/0301-620X.94B11.30680]

4 **Langton DJ**, Sidaginamale RP, Joyce TJ, Natu S, Blain P, Jefferson RD, Rushton S, Nargol AV. The clinical implications of elevated blood metal ion concentrations in asymptomatic patients with MoM hip resurfacings: a cohort study. *BMJ Open* 2013; **3**: pii: e001541 [PMID: 23482990 DOI: 10.1136/bmjopen-2012-001541]

5 **Archibeck MJ**, Cummins T, Carothers J, Junick DW, White RE. A comparison of two implant systems in restoration of hip geometry in arthroplasty. *Clin Orthop Relat Res* 2011; **469**: 443-446 [PMID: 21082363 DOI: 10.1007/s11999-010-1678-9]

6 **Sikes CV**, Lai LP, Schreiber M, Mont MA, Jinnah RH, Seyler TM. Instability after total hip arthroplasty: treatment with large femoral heads vs constrained liners. *J Arthroplasty* 2008; **23**: 59-63 [PMID: 18922375 DOI: 10.1016/]

7 **Lombardi AV**, Skeels MD, Berend KR, Adams JB, Franchi OJ. Do large heads enhance stability and restore native anatomy in primary total hip arthroplasty? *Clin Orthop Relat Res* 2011; **469**: 1547-1553 [PMID: 20953855 DOI: 10.1007/s11999-010-1605-0]

8 **Smith AJ**, Dieppe P, Vernon K, Porter M, Blom AW. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet* 2012; **379**: 1199-1204 [PMID: 22417410 DOI: 10.1016/SO124-6736(12)60353-5]

9 **Elkins J**, Callaghan JJ, Brown TD. Are large heads an unqualified benefit for metal-on-metal Total Hip Replacement? Stability vs. "Trunnionosis" Wear. Unpublished but presented at AAOS 2013, p001-p110 adult reconstruction hip posters. Available form: URL: http://www.abstractsonline.com/plan/ViewAbstract.aspx?mID=2984&sKey=2dc80fb2-e218-400a-8025-ea3b12f68962&cKey=9e9aba09-6ba9-4fa2-8443-45c07ea0e5fb&mKey=%7B342D5FB6-3E41-46BB-82B4-861286ECFB41%7D

10 **Yoshikawa T**, Yamakawa T. Morikawa J, Matsumoto M, Nakazora S, Hosoi S, Sudo A. Adverse reaction to metal debris from head-neck junction of metal on metal total hip athroplasty. Unpublished but presented at SICOT 2013. Available form: URL: http://www.sicot.org/resources/File/Dubai/Dubai%20Abstract%20Book%20-%20-ral%20presentations.pdf

11 **Garbuz DS**, Tanzer M, Greidanus NV, Masri BA, Duncan CP. The John Charnley Award: Metal-on-metal hip resurfacing versus large-diameter head metal-on-metal total hip arthroplasty: a randomized clinical trial. *Clin Orthop Relat Res* 2010; **468**: 318-325 [PMID: 19697090 DOI: 10.1007/s11999-009-01029-x]

12 **Beaulé PE**, Kim PR, Hamdi A, Fazekas A. A prospective metal ion study of large-head metal-on-metal bearing: a matched-pair analysis of hip resurfacing versus total hip replacement. *Orthop Clin North Am* 2011; **42**: 251-27, ix [PMID: 21435499 DOI: 10.1016/j.ocl.2011.01.005]

13 **Langton DJ**, Sidaginamale R, Lord JK, Nargol AV, Joyce TJ. Taper junction failure in large-diameter metal-on-metal bearings. *Bone Joint Res* 2012; **1**: 56-63 [PMID: 23610672 DOI: 10.1302/2046-3758.14.200004]

14 **Matthies AK**, Racasan R, Bills P, Panagiotidou A, Blunt L, Skinner J, Blunn g, Hart AJ. Material loss at the taper junction of large head metal on metal hip replacements. *Bone Joint J* 2013; **95-B** Supp 13 13

15 **Langton D**, Sidaginamale R, Lord J, Joyce T, Natu S, Nargol A. Metal debris release from taper junctions appears to have a greater clinical impact than debris released from metal on metal bearing surfaces. *Bone Joint J* 2012; **95-B** Supp 1 1

16 **Nassif NA**, Nawabi DH, Stoner K, Elpers M, Wright T, Padgett DE. Taper Design Affects Failure of Large-head Metal-on-metal Total Hip Replacements. *Clin Orthop Relat Res* 2013; Epub ahead of print [PMID: 23801060]

17 **Meyer H**, Mueller T, Goldau G, Chamaon K, Ruetschi M, Lohmann CH. Corrosion at the cone/taper interface leads to failure of large-diameter metal-on-metal total hip arthroplasties. *Clin Orthop Relat Res* 2012; **470**: 3101-3108 [PMID: 22864616 DOI: 10.1007/s11999-012-2502-5]

18 **Hexter A**, Panayiotidou A, Singh J, Skinner J, Hart A. Mechanism of corrosion in large diameter head metal-on-metal

total hip arthroplasty: a retrieval analysis of 161 components. *Bone Joint J* 2013; **95-B** Supp 12, 4
19 **MacDonald SJ**, McCalden RW, Chess DG, Bourne RB, Rorabeck CH, Cleland D, Leung F. Metal-on-metal versus polyethylene in hip arthroplasty: a randomized clinical trial. *Clin Orthop Relat Res* 2003; (**406**): 282-296 [PMID: 12579029]
20 **Isaac GH**, Brockett C, Breckon A, van der Jagt D, Williams S, Hardaker C, Fisher J, Schepers A. Ceramic-on-metal bearings in total hip replacement: whole blood metal ion levels and analysis of retrieved components. *J Bone Joint Surg Br* 2009; **91**: 1134-1141 [PMID: 19721036 DOI: 10.1302/0301-620X.91B9.22306]
21 **Hart AJ**, Matthies AK, Racasan R, Bills P, Panagiotidou A, Blunt L, Blunn G, Skinner J. Taper wear contributes only a third of the total volumetric material loss in large head metal on metal hip replacement. *Bone Joint J* 2013; **95-B** Supp 13 14

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