



## Clinical and biological assessment of cemented titanium femoral stems: an 11-year experience.

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**Clinical and biological assessment  
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**No benefits or funds were received in support of the study.**

## Abstract

This study prospectively assessed the outcome of 134 cemented titanium stems and serum ion levels. The stems were smooth and collarless with circular cross-sections.

At endpoint, only one stem revision was performed for aseptic loosening, and two were planned due to subsidence superior to 5 millimetres. Non-progressive radiolucencies in zones 1 and 7 were observed in 16 hips at the cement-interface, without osteolysis. Median serum titanium concentrations were below the detection limit (30 nmol/l) except in patients with failed stems.

The overall stem survival rate was 97.7% at a mean follow-up of 9 years, which is comparable to other series of cemented stems. The protective layer of titanium oxide coating the stem and a thick cement mantle may help resist aseptic loosening.

**Key words:** titanium, total hip prosthesis, corrosion, osteolysis, femoral stem

30

31 **Introduction**

32

33 Titanium and its alloys are commonly used for orthopaedic implants such as screws,  
34 plates, and spinal implants. This success is explained by the mechanical and biological  
35 properties of these materials such as resistance to fatigue, low elasticity modulus to reduce  
36 stress shielding, and bio inertness in a physiological environment [1,2]. Despite these  
37 properties, the use of polished cemented titanium stems is still debated [3-5]. Titanium stems  
38 are thought to be highly sensitive to corrosion and micromotion leading to early aseptic  
39 loosening [4,5,6].

40 Like other metallic orthopaedic implants, titanium stems can release metal debris and ions  
41 from their coated surface that may also contribute to titanium stem failure [7-11]. Several  
42 previous studies investigated ion and particle release into the biological fluid from joint  
43 replacement, but to the best of our knowledge no series concerning cemented titanium stems  
44 are available [12-15].

45 In this prospective study, we hypothesized that satisfactory results could be reached with  
46 cemented smooth titanium stems that are oval in section. In addition, the titanium ions  
47 released into the serum from the stems was measured up to the last time-point, in both  
48 unilateral and bilateral hip replacements, to monitor the behaviour of the stems.

## 1 Materials and methods

**Demographic data:** From January 1997 to December 2000, we prospectively followed a consecutive series of 109 patients who underwent primary total hip replacements performed at our institution (134 joint replacements/ 25 bilateral). All patients provided informed consent for the long duration of this prospective clinical and biological study. They received complete information, including the goals and procedures for blood sampling.

The inclusion criteria were strict; patients with orthopaedic titanium implants other than their hip stem, professional or dental exposure to titanium, previous hip conservative surgical procedures, or renal disease were excluded. Additionally, all patients enrolled were under 60 years of age at the time of surgery. In our practice, this represented less than 20% of all primary total hip arthroplasty performed during the study period.

The average follow up was 9 years, with follow up ranging from 7 to 11 years. The age at the time of arthroplasty ranged from 30 to 60 years (mean age: 54 years). Fifty-three females and 56 males were included. Sixty eight right hips were treated, and 66 left hips. Etiologies were essentially symptomatic stage of osteonecrosis or primary arthritis. Patients were evaluated preoperatively and followed-up with clinical and radiological examinations at regular intervals. Hip function results were rated according to the Harris Hip Score grading system in the preoperative period and latest follow up [16].

**Prostheses:** The cemented femoral stem was collarless, oval in cross section, and straight (Alizé<sup>®</sup> Fournitures Hospitalières, Quimper, France). The implant was made of titanium alloy (TiA16V4) with a polished surface coated with titanium oxide (TiO<sub>2</sub>) obtained by anodization [17,18]. The thickness of the titanium oxide layer was 1/10000 micron. Six different sized stems were available.

This modular stem was combined with a 28 millimeter (mm) Metasul® femoral head (Centerpulse-Zimmer, Warsaw, Indiana, U.S.) using a 12 – 14, 5°43 taper.

Tapers were inspected individually before micro threading, using an electro pneumatic system (HIGH PRESSURE ELECTRONIC PNEUMO TRANSDUCER 150015, Solex Metrologie, La Boisse, France) for the taper angle (precision, 1 minute), the diameter at the base, and the diameter at the summit (precision, 1 micron). This inspection was counter-checked by a unit control on a tridimensional machine with 1-micron precision. The micro threading was inspected using a projected side view with a 20x enlargement for the pace, profile, and dimension of the threading (Pexit 14 VS Profile Profector, Pixit Dorsey Gage, Cambridge, UK). Compatibility between cones and heads were controlled and guaranteed by the manufacturers. All of the sockets were “sandwich” cemented Metasul® cups (Weber cups, Centerpulse-Zimmer, Warsaw, Indiana, U.S.). Palacos Genta® cement (Scherring Plough, Brussels, Belgium) was used to cement both components in all cases.

***Surgical technique:*** All procedures were performed following the standard procedure at our institution via an antero-lateral approach on a Judet orthopaedic table [19]. In order to obtain a complete and thick cement mantle, the canal was over-reamed by 2 mm. Then the femoral canal was washed, brushed, and distally occluded by a resorbable femoral plug (Synplug®, Zimmer, Warsaw, Indiana, U.S.). The cement was inserted retrogradely using a gun.

***Radiological evaluation and clinical assessment:*** Anteroposterior (AP) and lateral radiographs of each hip were available before and immediately after surgery, 6 weeks after discharge from the hospital, and at 3 months, 6 months, 1 year, and then yearly thereafter. We defined radiographic loosening of the cup as the presence of radiolucent lines measuring at least two millimeters according to DeLee-Charnley zones, axial cup migration of > 5 mm, or > 5° of change in cup inclination on the AP radiographs of the pelvis [20].

Parameters investigated on the femoral side included presence and progression of radiolucent lines according to Gruen et al, calcar resorption or atrophy, subsidence, periprosthetic osteolysis, and cortical hypertrophy [21]. Loosening of the stem was defined as a migration exceeding 3 mm or a continuous radiolucent line greater than 2 mm. Heterotopic ossifications, if present, were graded according to Brooker et al. [22].

***Titanium serum level determination:*** In order to determine titanium release from the femoral stem, dosages were determined in two patient groups: those with unilateral replacements and those with bilateral replacements. Blood samples were taken just before implantation and at 3 months, 6 months, 1 year, and then yearly thereafter until the last end point was reached.

To avoid metallic contamination, blood samples were drawn using a sampling kit specifically dedicated to trace element determination: a needle for S-Monovette® (ref. 85.1162.400) and 7.5 mL S-Monovette® Lithium Heparin for Trace Metal analysis (ref. 01.1604.400) from Sarstedt (Marnay, France). Two Monovettes were sampled and numbered in sampling order. After centrifugation, aliquots of plasma were placed in metal-free plastic tubes (2 tubes/sample) and frozen at – 20°C. All metal measurements were performed on two samples in order to control for any contamination.

Titanium was measured in blood plasma diluted by Inductively Coupled Optical Emission Spectrometry (ICP-OES) on a JY24 spectrometer® (Jobin Yvon, Longjumeau, France). The detection limit (DL) was 30 nmol/L of plasma. Concentrations under the DL were set at half the DL value (15 nmol/L) to allow for statistical calculation by convention.

Meanwhile, chromium and cobalt were also determined in the serum from the same samples. Cobalt and chromium were determined by Electrothermal Atomic Absorption Spectrometry on a simultaneous SIMAA 5100 spectrometer® UNTIL 2004, and then 6100 (Perkin Elmer,

127 Courtabœuf, France). The detection limits were 3 nmol/L for cobalt and 1 nmol/L for  
128 chromium. Seronorm Levels I and II (Sero, distributed by Ingen, Rungis, France) were  
129 analyzed in each analytical run as internal quality controls. The serum titanium level was  
130 expressed in nmol/L ( $1 \text{ nmol/L} = 47.9 \text{ ng/L} = 0.0479 \text{ } \mu\text{g/L} = 0.0479 \text{ ppb}$ ).



## Statistical analysis

Survival analyses were calculated according to the Kaplan-Meier method. Loosened stems (revised or not) were considered as end points. For each time-point, the median as well as the twenty-fifth and seventy-fifth percentiles of serum titanium concentrations were calculated in the unilateral and the bilateral replacement groups. Continuous data were tested for normal distribution using the Kolmogorov-Smirnov test. Normally distributed data were analysed with t-tests.

In order to test for any difference between small stems and larger ones regarding subsidences or radiolucencies, we selected two subgroups of stems within the unilateral hip replacement group. The first subgroup was composed of stems with a size of 1 to 3. In the second subgroup, the sizes of the stems ranged from 4 to 6. A non-parametric Wilcoxon test was performed to detect any difference in these 2 subgroups. Statistical significance was set at  $p < 0.05$ .

All statistical analyses were carried out with PRISM 3 (GraphPad Software, Inc, San Diego, U.S.).

## Results

**Survival rate** (Fig 1): Overall stem survival (loosened, revised or not) was 97.7% at a mean follow-up of 9 years (95% CI, 95.4%–99.5%).

**Complications:** Two recurrent dislocations required revisions due to impingement between the titanium femoral neck and the edge of the chromium-cobalt insert of the cup, 1 month and 6 months, respectively, after the implantation. At the time of revision, the components were not loosened; black staining of the joint space was observed due to titanium release from femoral neck notches. In both cases, the patient's serum titanium levels were high due to the release of titanium from the femoral neck lesions. All of the components were revised with the same polished cemented stem and a cemented polyethylene cup.

Eight revisions were performed for loosened Metasul® cemented cups with radiolucencies superior to 2 millimeters and osteolysis.

In the first 3 cases, hips were revised using new metal-on-metal or polyethylene cups with respect to the femur.

Considering the high cobalt-chromium serum levels and the local conditions in 2 revision cases, the bearing surfaces were converted to alumina-on-alumina using a new cementless stem. In last three cases, the hips were revised using alumina-on-alumina with sleeved femoral heads (Ceramtec, Plochingen, Germany) as the taper and the stem fixation was intact.

One case of progressive subsidence due to poor cement technique required a unipolar femoral revision using a cementless stem, 5 years after implantation.

One prosthesis was revised due to persistent and unexplained pain. At the time of the revision, we found no abnormalities apart from a massive and macroscopic metallosis of the joint. The cobalt serum level was increased more than 20-fold compared with the detection

limit. The implants were changed, and new metal-on-metal bearing surfaces were again implanted, but did not resolve the symptoms.

**Clinical results:** The mean Harris Hip Score improved significantly ( $p < 0.05$ ) from 39 (range 15-68) preoperatively to 91 (range 83-97) at the ultimate follow-up.

**Radiological results:** We observed 4 cases with osteolysis and 16 cases with evolutive radiolucencies at the cement-bone interface on the acetabular side.

Three stem subsidences due to poor cement technique were identified on the early postoperative radiographs. Two were inferior to 10 mm and slowly evolutive with time requiring potential revision in the future (Fig 2). The third was of more concern (subsidence superior to 10 mm) and was revised, as mentioned previously. It was associated with osteolysis in zone 6 of Delee and Charnley [20].

Non-progressive femoral radiolucent lines were present in zone 1 at the cement-prosthesis interface in 10 hips, and had spread into zone 7 in six more hips. We did not observe femoral hypertrophic reaction around the distal stem or calcar resorption.

No statistically significant difference ( $p > 0.05$ ) was observed between small and large titanium stems regarding subsidences ( $p = 0.74$ ) and radiolucency frequencies ( $p = 0.96$ ).

Periarticular ossification, according to the method of Broocker et al. [22], was observed in 30% of the hips. Eight percent were type III and IV.

**Serum titanium concentration:** In both the unilateral and bilateral replacement groups, the median titanium concentration was constant and within range, and always below the detection limit of 15 nmol/l (Tables 1 and 2).

196 Failed stems, as shown in Table 3, caused the highest titanium serum levels at their end-point  
197 in the series, and titanium levels were much higher than the detection limit ranging from 196  
198 to 1274 nmol/l.  
199 Titanium serum levels remained below the detection limit in cases with loosened cups.

## Discussion

Use of cemented titanium alloy stems remains extremely controversial and has caused some surgeons to renounce them [3-5]. Some series showed a large rate of early aseptic loosening, usually when the stem was rough and cemented [4-6,23-25]. Jergesen reported an 11.5% aseptic loosening rate in a series of 118 total hip replacements at a mean follow-up of 66 months [6]. In the Scholl E series, the revision rate was 88% at a mean of 6.6 years due to loosened stems, and 30% of cases showed a significant osteolysis of the proximal femur [26]. Two factors are suggested that explain the early stem failure for the cemented titanium solutions. Firstly, the high elasticity of titanium and the excessive stresses in the mantle of the cement could lead to micromotion and debonding of the stem [4]. Micro-movements at the cement-stem interface may be responsible for cement mantle breakage and titanium-debris generation inducing necrosis and osteolysis [23]. The failure risk could be higher for smaller stems due to their greater elasticity, and in males who are physically active [26], while larger diameter titanium stems may be more successful [6]. In our series, we did not observe this relationship.

The second factor in early stem failure for the cemented titanium implants could be corrosion affecting the cemented, titanium alloy, stem surface. The implant could be deeply damaged by micromotion at the cement-stem interface leading to a progressive abrasion, which later induces a surface corrosion. Retrieval studies on loosened titanium alloy cemented stems report severe corrosion with associated typical crevices [5,27]. Scholl found such abrasions in corroded areas in all stem revisions with radiographic osteolysis at the same location [26]. Tissues were stained black with granuloma, including titanium wear particles. These findings suggest that corrosion could initiate an inflammatory foreign-body reaction that is responsible for the osteolysis of the adjacent bone, and aseptic loosening as seen with polyethylene wear particles.

The results of this prospective series are not in accordance with these observations. The overall survival rate of the stems was 97.7% at a mean of 9 years, which makes the failure rate consistent with the survival rate at 10 years of other cemented stems as reported in the Swedish Hip registry [28]. In the past, satisfactory results have been reported in the literature with cemented titanium stems. Known as the “French paradox”, the stems were rectangular in cross section, filling the medullary canal of the femur as much as possible with the largest implant associated with a thin cement mantle [29]. Survivorship at ten years ranged from 97% to 99% in these series [30,18].

The present study demonstrated that good results could be achieved with a different design and a different concept. In this cohort, the alloyed femoral stems were smooth, anodized, collarless, oval in section proximally, and circular for the distal 2/3 to reduce stress contact areas around the implants. Collarless implants have been associated with an increase in the frequency and width of radiolucent areas in zones 2 and 7 [31]. Nevertheless, we did not find such radiographic results and the rate of radiolucent lines was low in our study (14/119) at a mean follow-up of 9 years. Moreover, Meding et al. performed a prospective randomized study of collared versus collarless femoral prosthesis and reported that there was no difference in stem subsidence or functional scores [32]. Irrespective of their design or surface coating, all stems have been shown to move inside of their cement mantle in the first years after implantation [33]. Obviously, a polished surface limits the abrasion due to micromotion and ipso facto reduces production of active biological debris. On the contrary, it is established that the roughness of the stem directly influences the amount of debris produced and the rate of femoral loosening [23,34,35]. Better results have been obtained after implantation of titanium alloy stems with a polished surface compared with a rough surface with regard to the aseptic loosening rate [36]. Resistance to abrasion and corrosion of titanium implants depends on a thin and highly protective surface of oxide film [37]. The

protective, passive, titanium oxide film (TiO<sub>2</sub>) is obtained by anodization during the manufacturing process. This titanium oxide surface protects against exposure to air or other oxidizing elements. If scratches occur, this passive layer is supposed to heal and restore itself. In our series, we experienced 3 femoral subsidences that could be clearly explained by a poor cementing technique. The cementing technique did not follow the “French paradox” guidelines; our cement mantle had to be complete and superior to 2 millimeters thickness using a pressurized cementing technique. Studies focused on stress at the interfaces demonstrated minimal micromotion of the stem when the cement mantle was 3 to 4 millimeter thick around either a titanium or a more rigid, cobalt-chromium implant [38,39]. Moreover, in these studies, high micromovement occurred when the cement was thinner than 2 mm and there was no difference in micromotion or debonding between a titanium and a cobalt-chromium stem [38,39]. A finite-element analysis study identified factors influencing cement strains of the femoral component [40]. The authors of this study found that mantle thickness had the greatest effect on cement strains and suggested that a cement mantle thickness of 2.5 to 5.0 mm was optimal.

In addition to the clinical assessment, we measured the serum titanium levels at each patient follow-up. The only source of titanium particles and ions in this study was the femoral stem. The aim was to monitor the behaviour of the implant as previously performed with chromium or cobalt [8,41]. Regarding titanium, several previous reports have shown significantly increased levels in case of failure in arthroplasty [13,42,43]. Buly reported a series of failed cemented all-titanium alloy femoral stems with high titanium levels in either dry tissues or synovial fluid [13]. Leopold and von Schroeder reported a failed patellar component in total knee arthroplasty, with elevated serum titanium at least 20 times higher than normal values [43,44].

Although a few studies have analysed titanium release from femoral stems previously, it is difficult to compare their results with ours because of differences in the type of stems (design, coating, etc), mean follow-up, and units [12-15]. In the present study, medians were constant in range up to a mean follow-up of 9 years in both unilateral and bilateral hip replacement groups, and were always under the detection limit. The low serum concentrations observed are reassuring with regard to some concerns about potential titanium toxicity [44]. Although titanium is considered safe except for its potential osteolytic activity, it circulates throughout the body and particles have been found in hair, lungs, brain, urine, and serum [44,45].

The highest titanium serum concentrations were found in cases of mechanical complications such as stem fixation (subsidiences) or neck impingement. These findings are in accordance with previous studies that monitored metal release. They could also emphasize the ability of polished and titanium oxide coated surfaces to resist against corrosion and micromotion.

Another potential source of titanium particle release could be the junction between the cobalt-chromium femoral head and the softer femoral taper due to fretting and corrosion. In all of our revision cases, we carefully studied the femoral taper. In the 2 revisions with an exchange of the femoral stem, both the head and taper were under the specifications and we did not observe significant lesions in the contact areas. Our interpretation of higher serum titanium levels in a few patients is the unusual fretting and corrosion of the stem against the cement mantle. In the revision cases without femoral stem exchange, an inspection of the taper did not show significant alteration of the implant, allowing us to use sleeved revision femoral heads according to the recommendations.

In conclusion, this series shows that satisfactory results can be achieved using cemented, smooth, and oval in section titanium alloy stems. In addition, these results are consistent with series using other cemented implants [28]. A thick cement mantle combined



with a polished, anodized surface may play a major role in minimizing the debris source and the stress at the interfaces.

The high rate of acetabular loosening in this series of cemented cups questions the potential role of titanium debris. We could not find an argument for this hypothesis. We did not observe relationships between acetabular loosening and high titanium serum levels; head-neck modularity did not seem responsible. Moreover, all the tapers were intact at the time of the revision. In addition, titanium serum levels found in this study showed satisfactory monitoring of the stems.

## References

1. Head WC, Bauk DJ, Emerson RH, Jr. Titanium as the material of choice for cementless femoral components in total hip arthroplasty. *Clin Orthop Relat Res* 1995;311:85.
2. Krupa D, Baszkiewicz J, Kozubowski JA, Mizera J, Barcz A, Sobczak JW, Bilinski A, Rajchel B. Corrosion resistance and bioactivity of titanium after surface treatment by three different methods: ion implantation, alkaline treatment and anodic oxidation. *Anal Bioanal Chem* 2005;381:617.
3. Barrack RL. Early failure of modern cemented stems. *J Arthroplasty* 2000;15:1036.
4. Emerson RH, Jr., Head WC, Emerson CB, Rosenfeldt W, Higgins LL. A comparison of cemented and cementless titanium femoral components used for primary total hip arthroplasty: a radiographic and survivorship study. *J Arthroplasty* 2002;17:584.
5. Thomas SR, Shukla D, Latham PD. Corrosion of cemented titanium femoral stems. *J Bone Joint Surg Br* 2004;86:974.
6. Jergesen HE, Karlen JW. Clinical outcome in total hip arthroplasty using a cemented titanium femoral prosthesis. *J Arthroplasty* 2002;17:592.
7. Coleman RF, Herrington J, Scales JT. Concentration of wear products in hair, blood, and urine after total hip replacement. *Br Med J* 1973;1:527.
8. Brodner W, Bitzan P, Meisinger V, Kaider A, Gottsauner-Wolf F, Kotz R. Serum cobalt levels after metal-on-metal total hip arthroplasty. *J Bone Joint Surg Am* 2003;85:2168.
9. 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.
10. Savarino L, Granchi D, Ciapetti G, Cenni E, Nardi Pantoli A, Rotini R, Veronesi CA, Baldini N, Giunti A. Ion release in patients with metal-on-metal hip bearings in total joint

replacement: a comparison with metal-on-polyethylene bearings. *J Biomed Mater Res* 2002;63:467.

11. Gleizes V, Poupon J, Lazennec JY, Chamberlin B, Saillant G. [Value and limits of determining serum cobalt levels in patients with metal on metal articulating prostheses]. *Rev Chir Orthop Reparatrice Appar Mot* 1999;85:217.

12. Jacobs JJ, Skipor AK, Patterson LM, Hallab NJ, Paprosky WG, Black J, Galante JO. Metal release in patients who have had a primary total hip arthroplasty. A prospective, controlled, longitudinal study. *J Bone Joint Surg Am* 1998;80:1447.

13. Buly RL, Huo MH, Salvati E, Brien W, Bansal M. Titanium wear debris in failed cemented total hip arthroplasty. An analysis of 71 cases. *J Arthroplasty* 1992;7:315.

14. Jacobs JJ, Skipor AK, Black J, Urban R, Galante JO. Release and excretion of metal in patients who have a total hip-replacement component made of titanium-base alloy. *J Bone Joint Surg Am* 1991;73:1475.

15. Dorr LD, Bloebaum R, Emmanuel J, Meldrum R. Histologic, biochemical, and ion analysis of tissue and fluids retrieved during total hip arthroplasty. *Clin Orthop Relat Res* 1990;82.

16. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 1969;51:737.

17. Lappalainen R, Santavirta SS. Potential of coatings in total hip replacement. *Clin Orthop Relat Res* 2005;430:72.

18. Le Mouel S, Allain J, Goutallier D. [10-year actuarial analysis of a cohort of 156 total hip prostheses of a cemented polished aluminum/polyethylene alloy]. *Rev Chir Orthop Reparatrice Appar Mot* 1998;84:338.

19. Siguier T, Siguier M, Brumpt B. Mini-incision anterior approach does not increase  
dislocation rate: a study of 1037 total hip replacements. Clin Orthop Relat Res 2004;164.
20. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip  
replacement. Clin Orthop Relat Res 1976;20.
21. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type  
femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res  
1979;141:17.
22. Brooker AF, Bowerman JW, Robinson RA, Riley LH, Jr. Ectopic ossification following  
total hip replacement. Incidence and a method of classification. J Bone Joint Surg Am  
1973;55:1629.
23. McGrath LR, Shardlow DL, Ingham E, Andrews M, Ivory J, Stone MH, Fisher J. A  
retrieval study of capital hip prostheses with titanium alloy femoral stems. J Bone Joint Surg  
Br 2001;83:1195.
24. Tompkins GS, Lachiewicz PF, DeMasi R. A prospective study of a titanium femoral  
component for cemented total hip arthroplasty. J Arthroplasty 1994;9:623.
25. Ebramzadeh E, Normand PL, Sangiorgio SN, Llinas A, Gruen TA, McKellop HA,  
Sarmiento A. Long-term radiographic changes in cemented total hip arthroplasty with six  
designs of femoral components. Biomaterials 2003;24:3351.
26. Scholl E, Eggli S, Ganz R. Osteolysis in cemented titanium alloy hip prosthesis. J  
Arthroplasty 2000;15:570.
27. Willert HG, Broback LG, Buchhorn GH, Jensen PH, Koster G, Lang I, Ochsner P,  
Schenk R. Crevice corrosion of cemented titanium alloy stems in total hip replacements. Clin  
Orthop Relat Res 1996;333:51.
28. Malchau H, Herberts P, Eisler T, Garellick G, Soderman P. The Swedish Total Hip  
Replacement Register. J Bone Joint Surg Am 2002;84:2.

- 384 29. Langlais F, Kerboul M, Sedel L, Ling RS. The 'French paradox.' J Bone Joint Surg Br  
385 2003;85:17.
- 386 30. Nizard RS, Sedel L, Christel P, Meunier A, Soudry M, Witvoet J. Ten-year survivorship  
387 of cemented ceramic-ceramic total hip prosthesis. Clin Orthop Relat Res 1992;282:53.
- 388 31. Kelley SS, Fitzgerald RH, Jr., Rand JA, Ilstrup DM. A prospective randomized study of a  
389 collar versus a collarless femoral prosthesis. Clin Orthop Relat Res 1993;294:114.
- 390 32. Meding JB, Ritter MA, Keating EM, Faris PM, Edmondson K. A comparison of collared  
391 and collarless femoral components in primary cemented total hip arthroplasty: a randomized  
392 clinical trial. J Arthroplasty 1999;14:123.
- 393 33. Alfaro-Adrian J, Gill HS, Marks BE, Murray DW. Mid-term migration of a cemented  
394 total hip replacement assessed by radiostereometric analysis. Int Orthop 1999;23:140.
- 395 34. Anthony PP, Gie GA, Howie CR, Ling RS. Localised endosteal bone lysis in relation to  
396 the femoral components of cemented total hip arthroplasties. J Bone Joint Surg Br  
397 1990;72:971.
- 398 35. Mohler CG, Callaghan JJ, Collis DK, Johnston RC. Early loosening of the femoral  
399 component at the cement-prosthesis interface after total hip replacement. J Bone Joint Surg  
400 Am 1995;77:1315.
- 401 36. Hinrichs F, Kuhl M, Boudriot U, Griss P. A comparative clinical outcome evaluation of  
402 smooth (10-13 year results) versus rough surface finish (5-8 year results) in an otherwise  
403 identically designed cemented titanium alloy stem. Arch Orthop Trauma Surg 2003;123:268.
- 404 37. Fini M, Cigada A, Rondelli G, Chiesa R, Giardino R, Giavaresi G, Nicoli Aldini N,  
405 Torricelli P, Vicentini B. In vitro and in vivo behaviour of Ca- and P-enriched anodized  
406 titanium. Biomaterials 1999;20:1587.

38. Ramaniraka NA, Rakotomanana LR, Leyvraz PF. The fixation of the cemented femoral component. Effects of stem stiffness, cement thickness and roughness of the cement-bone surface. *J Bone Joint Surg Br* 2000;82:297.
39. Kawate K, Maloney WJ, Bragdon CR, Biggs SA, Jasty M, Harris WH. Importance of a thin cement mantle. Autopsy studies of eight hips. *Clin Orthop Relat Res* 1998;355:70.
40. Estok DM, 2nd, Orr TE, Harris WH. Factors affecting cement strains near the tip of a cemented femoral component. *J Arthroplasty* 1997;12:40.
41. Jacobs JJ, Skipor AK, Campbell PA, Hallab NJ, Urban RM, Amstutz HC. Can metal levels be used to monitor metal-on-metal hip arthroplasties? *J Arthroplasty* 2004;19 ( 8 Suppl 3):59.
42. Dunstan E, Sanghrajka AP, Tilley S, Unwin P, Blunn G, Cannon SR, Briggs TW. Metal ion levels after metal-on-metal proximal femoral replacements: a 30-year follow-up. *J Bone Joint Surg Br* 2005;87:628.
43. Leopold SS, Berger RA, Patterson L, Skipor AK, Urban RM, Jacobs JJ. Serum titanium level for diagnosis of a failed, metal-backed patellar component. *J Arthroplasty* 2000;15:938.
44. Kasai Y, Iida R, Uchida A. Metal concentrations in the serum and hair of patients with titanium alloy spinal implants. *Spine* 2003;28:1320.
45. Haynes DR, Rogers SD, Hay S, Percy MJ, Howie DW. The differences in toxicity and release of bone-resorbing mediators induced by titanium and cobalt-chromium-alloy wear particles. *J Bone Joint Surg Am* 1993;75:825.

## Figures

Fig 1: Survivorship of loosened stems as the end point

Fig 2: After 10 years of follow-up, typical evolution of the stem could be seen in this series showing controlled subsidence

Table 1 : Serum titanium levels in the unilateral hip replacement group

Table 2 : Serum titanium levels in the bilateral hip replacement group

Table 3 : Serum titanium levels in the group with failed stems