UNUSUAL FATIGUE FAILURE OF A COBALT-CHROMIUM ALLOY CEMENTLESS FEMORAL STEM: *IMPLANT RETRIEVAL AND BIOMECHANICAL ANALYSIS*

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ABSTRACT

Recent premature failures of metal total hip replacements have raised concerns about their load bearing capacity, safety, reliability and survival rates. Specifically, femoral stem fracture is one of the most acute complications and results in greater morbidity and higher cost of revision hip surgery. In this contribution, we report an unusual case of fatigue failure of a cobalt-chromium alloy cementless femoral stem which functioned well for 24 years. Failure occurred at the neck-stem junction remote from any modular interface with only a minor traumatic event. Fractography, compositional and microstructural investigations revealed no intrinsic defect of the failed component. This late failure illustrates the importance of proper long-term testing of implants in regards to cyclic loading, as patients undergoing total joint replacement are increasingly younger and more active, putting implants at greater risk of long-term fatigue failure.

INTRODUCTION

Total hip replacements (THR) achieve high levels of survivorship and are now being implanted in younger and more active patients [1]. Cementless femoral fixation is favoured for implant longevity due to its biological fixation and the avoidance of potential cement fatigue failure. For the majority of these stems the incidence of aseptic loosening is relatively low. However, other potential modes of failure, including fracture may be more prominent. Femoral stem fracture is a rare complication of THR with a varying incidence from 0.23% to 10.7% depending on geometric design and prosthetic materials [2,3]. We report a rare case of a late fatigue failure at the stem neck junction in a well-functioning cementless Lord THR. This stem is a fully porous coated implant with 1mm beaded surface spaced by 0.5mm for osteointegration [4]. The patient provided informed consent.

CASE REPORT

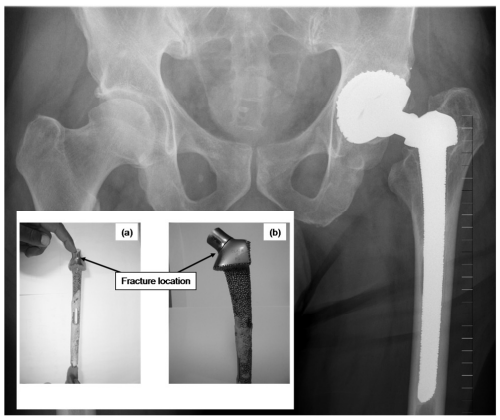

Figure 1: Anteroposterior radiograph showing prosthetic fracture at neck/stem junction. Insets (a) and (b) show the retrieved Lord femoral stem with a complete fracture at the neck/stem junction.

In 1985, a 51 year-old healthy male underwent a left THR for idiopathic osteoarthritis with a cementless Lord stem and threaded acetabular cup. The Lord stem was introduced in the 1970s and is FDA-approved. In 2000, the patient required revision surgery (isolated head and liner exchange) for polyethylene wear. Intra-operatively, the femoral and acetabular components were found to be stable and direct visualization showed the femoral prosthesis trunnion to be in excellent condition. A new polyethylene insert was cemented into the existing well fixed acetabular component. The patient returned to his previous level of activity. In 2009, the patient presented to the emergency department with a sudden onset of acute left hip pain after stepping down from a boat onto a dock from a height of about 2 feet. Anteroposterior radiographs showed a fracture at the base of the femoral neck-stem junction

(Figure 1). The remaining femoral stem and acetabular cup appeared well-fixed. This was confirmed at surgery. The patient underwent femoral component revision with an extended trochanteric osteotomy and insertion of a distally fixated modular revision femoral component. At 3 months post-op, the femoral component subsided leading to a subsequent revision at 6 months once the fracture had united. Onlay allografts provided additional fixation for intraoperative distal stem tip fracture. At one year follow-up the stem is radiographically stable and functioning well (Figure 2).

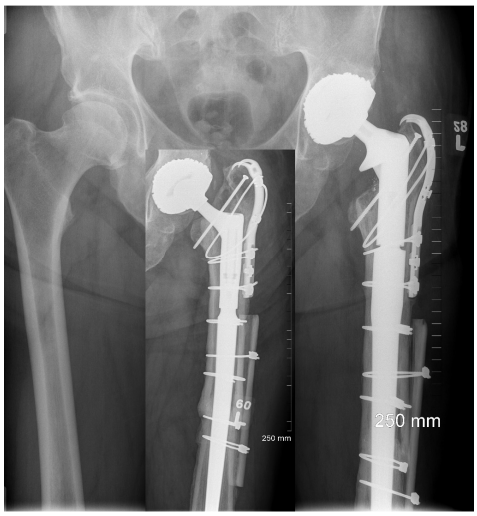

Figure 2: Anteroposterior radiograph with stable uncemented modular revision femoral stem at one year post second revision surgery. Insets show loose of modular revision stem prior to second revision.

MICROSCOPY INVESTIGATIONS

Fractography investigations were performed on both fracture surfaces using a ZEISS EVO MA10 scanning electron microscope (SEM). The SEM was equipped with an INCAX-act energy dispersive spectrometer (EDS) to investigate the chemical composition and potential inclusions or precipitates that could have initiated/facilitated implant failure. The implant was also sectioned for optical microscopy (OM) using a XJP-3A stereo microscope and SEM study. The section was mounted in epoxy resin using hot mounting, ground and polished, and etched using a solution of 40 ml Lactic Acid + 30 ml HCl + 5 ml HNO_3 for 5 minutes to expose the grain boundaries. For comparison, SEM, EDS and OM investigations were also performed on an unused identical implant.

INVESTIGATION RESULTS

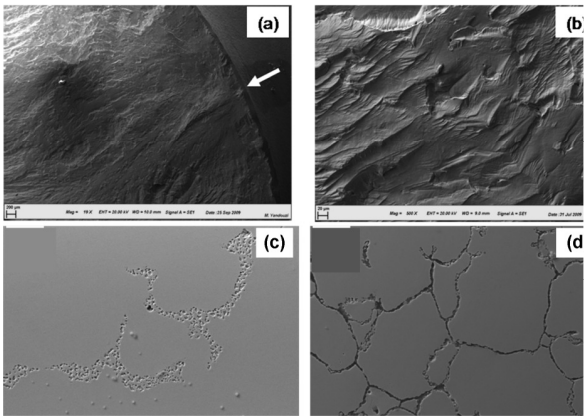

Figure 3: SEM fractography images: (a) crack initiation site (arrow) at the implant surface; (b) strong relief in the crack propagation phase; (c) precipitates along grain boundaries; and (d) overall grain structure.

Implant failure occurred in the filler radius between stem and neck. SEM showed the crack initiated at the topside surface at plastic deformation steps near machining feed marks due to slight stress concentration. The crack then propagated primarily transgranularly (Figure 3a). Strong relief and plastic deformation were seen across the fracture surface (Figure 3b). The crack propagated through roughly half of the neck cross-section before final fracture occurred. There was no evidence that inclusions or precipitates substantially promoted either crack initiation or propagation. The grain size (Figures 3c-d) was 6 to 70 μm, within standard specifications for low carbon wrought CoCrMo, ASTM F1537.

EDS analysis suggests that the grain boundary precipitates are richer in Chromium and Molybdenum as compared to the alloy matrix which hints to metal carbides. Primarily Chromium-carbides of the types $M_{26}C_6$ and M_7C_3 are often reported [5]. The chemical composition of the grain interior (Table 1) confirms the material to be ASTM F1537. The

Chemical composition and manufacturing process are identical for both broken and new implants resulting in practically identical microstructure in both implants. This seems to exclude material defects as primary cause of failure and highlights the role of fatigue overload as the main cause of prosthesis fracture in this case.

DISCUSSION

Table 1: ASTM F1537 specification and chemical composition of the failed implant, SEM-EDS

	C	Cr	Fe	Mn	Mo	N	Ni	Si	Co
Specification for ASTM F1537	0.149	26.0 - 30.0	0.75	1.0	5.0 - 7.0	0.25	1.0	1.0	bal.
Matrix / Grain interior	-	27.02 - 28.97	0.30 - 0.69	0.83 - 1.07	5.51 - 8.55	0.04 - 0.57	1.91 - 2.10	0.87 - 1.14	bal.
Precipitates / Grain boundaries	-	32.29 - 34.27	0.20 - 0.30	0.48 - 0.96	10.51 - 34.78	0.15 - 3.61	0.93 - 1.77	0.96 - 2.25	bal.

We present a case of late fracture of a cementless Lord femoral stem. A survey of American Association of Hip and Knee Surgeons reported a metal femoral stem fracture rate of 0.27% [6]. Femoral prosthetic failure has been classified into broad categories such as implant design, implant defect, and prosthetic fatigue. Using detailed analysis and comparison to an identical non-implanted component, this report suggests a pure mechanical fatigue failure of the stem with no evidence of material defect or faulty design. As opposed to previous reports [4], our stem failed after 24 years of stable, pain-free activity, without major trauma or acute activity level preceding fracture.

The Lord femoral prosthesis has had good success with 94% survivorship at 13 years [7]. Two other studies reporting on its survivorship [4,8] also noted two fatigue stem fractures within the shaft [9]. These were attributed to the stems being made from cast material, whereas forged femoral components have decreased grain size and less inclusions leading to a substantially increased fatigue strength when compared to cast or annealed implants [10]. However, inconsistencies in metallurgy or surface damage of even forged implants can lead to significant stress risers [11], which were not identified in our case. Another potential cause of this late fracture is faulty implant design. Vatani et al. reported 9 prosthetic failures attributed to an inadequate implant neck radius which led to abnormal force transmission and prosthesis fracture [12]. The use of a skirted modular femoral head has been linked to prosthetic failure within the femoral trunnion of a cobalt-chromium uncemented stem [13,14]. Lam et al. showed the skirted modular construct caused local oxygen depletion, leading to intergrannular and crevice corrosion [15]. This mechanism can also be at play in stem designs with modular necks [16].

Fractography in this work showed that the crack initiated at the implant surface and propagated primarily transgranularly. As such, no evidence exists that inclusions or precipitates substantially promoted crack initiation or propagation. SEM suggests that the crack was initiated at the tensile top side in the filler radius. This further supports the hypothesis of overload fatigue as main failure cause. ASTM standard specifications for hip femoral prosthesis (ASTM F 2068-03) are based upon mechanical testing where the stem is fatigue tested for 10 million heel-strike cycles [17]. Actual average patient activity has been estimated to be 1.9 million cycles annually [18]. Particularly younger patients may have even higher activity levels exceeding current standards for current longevity testing.

CONCLUSIONS

A rare case of late Lord prosthesis implant failure is described. Detailed OM, SEM and EDS analysis provided novel information to support fatigue overload as the primary cause of implant failure. Therefore, continual monitoring of arthroplasty patients and improved testing standards seem required to

better understand and predict the long-term behaviour of implanted femoral prostheses.

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