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# The contribution of the micropores in bone cement surface to generation of femoral stem wear in total hip replacement

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ABSTRACT

Although cemented total hip replacement has long been recognized as a situation that can lead to wear, the wear generated on the femoral stem has not been well documented, especially with regard to how this wear is initiated and propagated. This present work aimed to further investigate this issue based on a comprehensive study on surface morphology of the femoral stem and the bone cement, which were collected from seven in vitro wear simulations. It was shown that the wear locations on the stem surface compared well with the results of retrieval studies, and the boundaries of the worn areas matched well the edges of the micropores present in the bone cement surface. This indicated that the micropores could potentially contribute to the generation of femoral stem wear. In addition, metallic debris was detected around the micropores from the simulation with increased loading cycles. However, no evidence of macro-cracks was observed across the cement mantle in spite of the presence of micro-cracks initiated at the edge of the micropores. This study demonstrated a possible cause for progression of femoral stem wear and it may have an important bearing on the long term durability of cemented hip prosthesis.



## 1. Introduction

Cemented total hip replacement (THR) is routinely performed worldwide to improve the quality of life of patients suffering from hip disorders. Although improved survivorship of hip prosthesis has been achieved with the use of ‘‘benchmark’’ femoral stems and ‘‘modern cementing techniques’’, aseptic loosening is still a dominant factor in mechanical malfunction of the stem–cement–bone system [1], and it is accepted as the primary reason for revision of cemented THR [2,3]. The stem–cement interface has consistently been cited as a weak link and it contributes to premature failure of cemented THR [4,5]. Acrylic bone cement, as a component of this interface, has incurred a few problems since its introduction. For example, the unreacted methylmethacrylate monomer following polymerization could lead to chemical necrosis of bone tissues [6]. In addition, micropores would be generated and distributed across the cement mantle during the process of cement mixing, delivery, and stem implantation. These micropores may cause a decrease of the interfacial bond strength, and act as potential stress concentrators resulting in the formation of fatigue cracks [7]. Nowadays, it is accepted that debonding at the stem–cement interface is inevitable for almost all stem designs, regardless of stem geometry and surface finish [8,9]. Therefore, low-amplitude micromotion would occur at this interface under physiological loading, and a typical fretting wear mechanism ensues and results in fretting damage of the femoral stem.

Femoral stem wear has been recognized to be an intractable problem involved in cemented THR, releasing cement as well as metallic debris to the surrounding periprosthetic environment [10,11]. This debris could lead to third-body wear and transport along cement mantle deficiencies to bone tissues, where macrophage response could destroy bone stock and result in subsequent aseptic loosening of the hip prosthesis. In spite of its significance as a source of failure of cemented THR, femoral stem wear has received relatively little concern due to the fact that much attention has been paid to the wear generated at the articulating head–cup interface. Additionally, the femoral stem has been previously considered to anchor well in the cement mantle and stem wear is sometimes difficult to recognize with the naked eye.

Recently, with the introduction of cross-linked ultrahigh molecular weight polyethylene (UHMWPE) and hard-on-hard bearing systems, wear at the head–cup interface has been greatly reduced [12,13]. Consequently, wear at the stem–cement interface shows an increasing significance in the overall wear of cemented THR. However, a detailed description of the wear mechanism at this interface has still not received enough attention. It was not until recently an intensive study on 172 explanted femoral stems was performed that a better understanding of this issue has been obtained [14]. It was shown that femoral stem wear was primarily determined by stem surface finish,

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although a similar wear location was defined for both matt and polished femoral stems. However, the contributory factors of generation of femoral stem wear have not been fully investigated in previous studies. Therefore, it is considered necessary to gain an insight into progression of femoral stem wear, through which potential information gleaned can be implemented to strengthen functionality of cemented THR. This present study aimed to investigate initiation and propagation of femoral stem wear by performing a comprehensive study on surface morphologies of the femoral stem and the bone cement, which were collected from seven in vitro wear simulations.

## 2. Materials and methods

Seven in vitro wear simulations were performed, utilizing polished Exeter V40$^{TM}$ femoral stems (stainless steel REX 734, Stryker Howmedica Osteonics, Newbury, UK) and three different bone cements—Simplex P (radio-opaque agents: $BaSO_4$), Palacos R (radio-opaque agents: $ZrO_2$), and CMW 3 (radio-opaque agents: $BaSO_4$), all of which have been widely employed in clinical situations. Details of the wear simulations are summarized in Table 1. The bone cements were all handmixed according to the manufactures' instructions and delivered into a reamed sawbone (3rd generation composite femur, Sawbones, Malmö, Sweden) in a retrograde fashion using a cement delivery system. Whilst it was recognized that vacuum mixing is the usual practice, handmixing was chosen in this case in an attempt to simulate the worst scenario and accentuate the deleterious effects of experimental conditions. The femoral stem was then implanted and the cement cured as instructed to replicate surgical techniques. The stem–cement–sawbone system was stabilized using an acrylite resin (Rubert & Co. Ltd., Cheadle, UK) in a steel tube at a position of 10° in adduction and 9° in flexion. A custom-made fixture was designed to enable wear simulation employing an Instron test machine 1273. The simulations were carried out in part with reference to the specifications for endurance of hip prosthesis instructed by ISO standard 7206-4. The load was applied vertically to the femoral head in compression between 0.3 and 2.3 kN in a sine wave to simulate the hip joint force during walking. All wear simulations were performed at 3 Hz. In addition, a 9 g/l saline solution was used to represent the environmental conditions in the human body. The overall methodology and the potential factors influencing the result, including temperature control, test frequency, cement creep, etc., were discussed elsewhere [15].

Following each wear simulation, the stem–cement–sawbone system was secured gently with a vice in order to not break the components. The femoral stem was cautiously extracted from the cement mantle and then cleaned using alcohol prior to further observation. The sawbone was removed from the acrylite resin and sawn longitudinally into two equal parts; the internal surface was also cleaned using alcohol to enable the investigation of the bone cement surface. Four different methods were employed to study the femoral stem and the bone cement surfaces in terms of evidence of wear. Firstly, visual assessment was completed to establish the overall locations of the worn areas. Secondly, the worn areas on the stem surface and the corresponding zones on the cement surface were evaluated using an optical stereomicroscope (MZ6, Leica Microsystems Ltd., Wetzlar, Germany). Furthermore, surface topographies of the worn areas were obtained through measurement utilizing an optical interferometer (Talysurf CCI 3000, Taylor Hobson Ltd., Leicester, UK). The measurements were then processed using Surfstand software V3.3 to extract the surface features. Finally, the bone cement was sectioned and carbon coated to facilitate a scanning electron microscope (SEM, JEOL JSM-6060 LV, JEOL Ltd., UK) study of the areas of interest, and an energy dispersive X-ray (EDX) analysis was performed to evaluate the element composition of the wear debris on the cement surface.

**Table 1**
In vitro wear simulations to reproduce fretting wear on the femoral stem surface.

| Simulations | Femoral stem | Bone cement | Cycles (million) |
|---|---|---|---|
| I | Polished Exeter V40$^{TM}$ | Simplex P | 5 |
| II | Polished Exeter V40$^{TM}$ | Simplex P | 5 |
| III | Polished Exeter V40$^{TM}$ | Simplex P | 10 |
| IV | Polished Exeter V40$^{TM}$ | Palacos R | 5 |
| V | Polished Exeter V40$^{TM}$ | Palacos R | 5 |
| VI | Polished Exeter V40$^{TM}$ | CMW 3 | 5 |
| VII | Polished Exeter V40$^{TM}$ | CMW 3 | 5 |

## 3. Results

### 3.1. Visual examination

All the femoral stems demonstrated evidence of wear, and the wear locations mainly concentrated on the anterolateral, posteromedial, and under-neck areas of the stem surface, which compared well with the results of retrieval studies [14]. It was reported that these areas experienced the largest stresses under physiological loading [16]. Therefore, a relative micromotion between the stem and the cement would be likely to occur at these locations, which acts as the prerequisite for generation of fretting wear. The other areas on the stem were relatively smooth and appeared undamaged. Fig. 1 displays typical wear reproduced at the posteromedial area of the stem surface. From the figure it was shown that many "undamaged islands" were located within the worn areas. These "undamaged islands" were irregular in shape and size. The bone cements demonstrated a certain amount of micropores in the surface as well as throughout the cement mantle. However, no macro-cracks were observed in the cement mantle. Additionally, the bone cement surface appeared very rough in the zones contacting the worn areas on the stem surface, while the other zones appeared smooth.

### 3.2. Optical stereomicroscope and optical interferometer evaluation

The "undamaged islands" located in the worn areas on the femoral stem surface were clearly delineated in the optical micrograph (Fig. 2). The other areas were severely damaged and indicative of fretting wear. The optical micrograph of the corresponding zones on the cement surface confirmed the presence of the micropores (Fig. 3), indicating that the edges of these micropores matched well the boundaries of the stem worn areas. This was considered to be of potential significance and more worn areas with different wear severities were investigated using the optical stereomicroscope. Fig. 4 shows another worn area on the stem surface with the corresponding zone on the cement surface, where only slight wear was apparent and the fretting zones seemed to be just initiated. It was demonstrated from this optical micrograph that the edges of the micropores could be associated with the initiation of fretting damage on the stem surface. Fig. 5 provides further evidence with higher magnification, in which the initial damage on the femoral stem surface appeared to propagate and form a larger worn area. Therefore, this area was measured using the optical interferometer. The interferometric micrograph displayed propagation of femoral stem wear more clearly (note that the interference fringes around the "undamaged islands" on the stem surface indicate height deviations in these areas). This measurement was further processed using a Surfstand software V3.3, and its 2D surface topography showed that those smooth areas with little variation in amplitude were the "undamaged