CASE REPORT

Stem-Sleeve Junction Failure of a Modular Femoral Hip System: a Retrieval Analysis

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Introduction

The use of a modular femoral hip system in total hip arthroplasty has increased in the last two decades.

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Modularity gives the surgeon the flexibility to adjust for excess femoral anteversion, offset and leg length and to restore the biomechanics of the hip joint independent of femoral fixation [3, 6, 20, 24, 36].

Proximal femoral modularity includes neck-stem junctions and stem-sleeve junctions [37]. Previous reports have expressed concerns of fretting and corrosion damage at modular interfaces [3, 4, 6, 10, 26, 39, 40]. Modular component dissociation can occur in well-fixed components with disengagement of the trunnion during closed reduction of dislocated modular prostheses and also with subsidence of the femoral stem [1, 8, 28, 33, 35, 43]. Although uncommon, several reports have been published describing cases of fracture of the femoral stem at the neck-stem junction following total hip arthroplasty [12, 31, 32, 41, 44]. These mechanical failures occurred secondary to crevice corrosion, which created a microenvironment predisposing to fatigue fracture. While a few reports have been published documenting stem fracture within the stem-sleeve junctions [18, 25, 26], these reports lacked examination of patient- or implant-related factors that contributed to stem failure. In the present study, we report a case of an S-ROM® fracture (S-ROM®, DePuy Synthes, Warsaw, IN) within the modular sleeve in an adult female patient following a primary total hip arthroplasty. Systematic investigation and retrieval analysis were carried out to determine the underlying circumstances that contributed to the failure.

Case Report

A 64-year-old female nurse's aide presented with right hip osteoarthritis secondary to a mild developmental dysplasia of the hip (Crowe 1; 70 kg, 158 cm, body mass index 28.0 kg/m²). She underwent total hip arthroplasty via a direct lateral approach in April 2007. A 48-mm modular acetabular component (PINNACLE® DePuy Synthes) with a 28-mm ceramic liner was implanted. On the femoral side, a 9-mm femoral S-ROM® cementless stem (DePuy Synthes)

with a 36-mm offset neck and a 14B sleeve were used. A 28-mm ceramic head was implanted (Fig. 1a). Seven years postoperatively, she felt a sudden onset of right hip pain causing her to fall. She continued with her daily activities using crutches for support expecting that she would improve. Two weeks later, she presented to the emergency room where radiographs revealed a fracture of the femoral component (Fig. 1b). Infection was ruled out with a normal ESR and CRP. The patient was scheduled for revision of the femoral component. During revision, the synovial fluid was stained black and there was metal staining of the synovial tissues. There was no evidence of wear at the bearing surface, nor any evidence of impingement on the rim of the cup. The femoral prosthesis was found to be broken at the stem-sleeve junction. Both the femoral stem and sleeve were well fixed to the bone with no evidence of loosening. An extended trochanteric osteotomy was utilized to extract the fractured femoral component. A revision of the femoral component was carried out using an extensively porous coated 12 mm×8 in. stem (DePuy Synthes) and a new 28-mm ceramic head.

The extracted stem and fragments were sent for retrieval analysis. The retrieved S-ROM® hip stem (Fig. 2) was sterilized in a 10% formalin solution for 48 h and carefully cleaned with a soft-bristled brush, avoiding removal of particulates from the location of the fracture. The proximal sleeve could not be separated from the remaining stem through mechanical force upwards of 10 kN (Instron E10000, Norwood, MA), and thus, the sleeve was cut with a Dremel® cutting blade on the anterior and posterior aspects to facilitate dissociation. Macroscopic observational analyses were performed using a Nikon light microscope (SMZ1000, Nikon, Tokyo, Japan) with photographs obtained using a Canon D20 Digital SLR camera with a macroscopic lens (Canon Inc., Tokyo, Japan). The distal face of the fracture is shown in Fig. 3, and the sleeve taper junction is shown in Fig. 4. Scanning electron microscope (SEM) images were obtained of the fractured faces, the corroded areas of the distal stem taper and the sleeve (JSM 6610LV, JEOL, MA, USA).

Macroscopic analyses revealed that a laterally initiated fatigue fracture was the cause of failure of this stem [29]. Crescent-shaped progression marks indicating the advancing front of the fatigue crack [29] can be seen emanating from the fracture origin (#1 in Fig. 3) at the lateral edge of the stem (#2 in Fig. 3). The fractured surfaces of the stem showed evidence of articulation between the fragments post-fracture (#3 in Fig. 3). An area of final failure can be easily seen on both fragments (#4 in Fig. 3). Substantial corrosion damage was seen on the entirety of the taper junction on both the stem and the sleeve of the implant (Fig. 4).

SEM imaging provided a more detailed look at the damage features seen in the macroscopic analysis. Two fracture planes were evident (Fig. 5) at the lateral aspect of the stem fragments. A large corrosion pit was observed at the intersection of the fracture planes on the lateral aspect of the distal stem fragment (Fig. 5). River marks, which indicate the direction of fracture propagation [29], were

identified on both fractured faces of the stem. SEM examination of the sleeve showed significant corrosion over the majority of the inner surface (Fig. 4) with an abrupt transition at the point of contact of the taper junction (Fig. 6).

Discussion

Although modular hip systems have gained popularity, many concerns have been raised with metal on metal modular junctions and the potential for fretting and corrosion. Fracture of the femoral prosthesis is however a rare complication [44]. The present case describes the corrosion and catastrophic failure of a conical Morse taper junction between the femoral stem and proximal sleeve. One of the challenging aspects of this case was the difficulty encountered in dissociating the stem from the well-fixed sleeve. Despite the fact that the stem is smooth, its distal fixation flutes promoted extensive bony ongrowth that precluded stem extraction. Due to the possibility of extensive stem ongrowth, surgeons revising this type of modular stem must be ready to perform an extended trochanteric osteotomy.

The presence of progression marks indicates that this hip stem fractured via a bending fatigue mechanism in which the fracture originated on the lateral side of the stem. The slight varus position of the stem may have contributed to initiating or propagating the fracture mechanism. Based on the direction of the progression marks and location of the final failure area, torsional stress must also be considered. Torsion is believed to be in the direction of external rotation of the lower limb, with respect to the hip joint. Further, the size of the final failure area compared to the size of the fatigue progression area suggests a low-stress failure with areas of stress concentration on the lateral aspect of the stem (the fracture origin). Additionally, the small diameter of this femoral stem is likely to have contributed to fatigue fracture as the bending forces placed on the stem would have been better resisted by a larger cross-sectional area.

We hypothesize that initiation of the stem fracture was the result of localized regions of high stress due to surface inclusions created by mechanically assisted crevice corrosion [17]. Prior studies have indicated that mixed-metal taper junctions have higher corrosion rates than uniform metal tapers because of electro-potential differences in the metals causing galvanic corrosion [10, 11, 15, 16, 23]. However, both the stem and the sleeve of the S-ROM® hip stem are manufactured from the same material, a titanium alloy, Ti-6Al-4V [18, 21]. Pairing similar alloys in modular THR connections removes the possibility of galvanic acceleration of corrosion, a common issue with cobalt alloy head and titanium alloy neck pairings [9]. On the other hand, titanium alloy taper junctions are known to exhibit increased micromotion compared to cobalt-chromium alloy junctions [19, 22], thereby intensifying a process termed mechanically assisted crevice corrosion. This process involves small relative movements between the surfaces which continually strip each of their protective passivation layer [14]. Continual re-oxidation of the titanium alloy surfaces alters the local ionic environment within the crevice of the junction

Fig. 1. **a** Pre-failure anteroposterior (AP) radiograph of the right hip showing a well-fixed femoral component in slight varus. **b** AP radiograph of the patient's prosthesis at presentation showing a stem fracture at the stem-sleeve junction.

reducing the ability of the materials to self-passivate, exposing them to corrosive influx [14].

Fig. 2. The S-ROM® hip stem after cleaning and separating the sleeve from the stem.

Further complications of mechanically assisted corrosion include the production of metal debris and corrosion products [38]. Corrosion products can also lead to an aseptic, lymphocyte-dominated vasculitis-associated lesion (ALVAL) [5]. These products can provoke a lymphocytic inflammatory tissue response leading to the production of pseudotumours and increased osteolysis. The metal-stained tissues encountered intra-operatively clearly demonstrate that corrosion products were produced at the stem-sleeve junction.

Upon retrieval, the modular sleeve was found to be extremely well bonded to the stem. The difficulty encountered in dissociating the sleeve from the stem is reportedly a

Fig. 3. Fractured face of the distal stem fragment.

Fig. 4. Corroded taper surface of the medial inner sleeve.

common issue with titanium alloy taper junctions because of cold welding [13, 21]. Therefore, at some point in time, micromotion between the stem and sleeve ceased. Crevice corrosion alone may have continued to deteriorate the tapered surfaces beyond this point.

We hypothesize that surface inclusions caused by mechanically assisted crevice corrosion were a primary cause of fracture initiation as the intersecting fracture planes were located immediately proximal to a large corrosion pit on the exterior surface of the distal stem (Fig. 5). This corrosion pit may have caused a stress riser at this location on the stem leading to initiation of fracture. The link between implant

Fig. 5. Distal stem side view showing the lateral fracture origin resulting from a corrosion pit (circle). Image was obtained in back-scatter electron (BEC) mode due to charging of corrosion products within the corrosion pit under secondary electron (SEI) mode.

Fig. 6. Transition between corroded (top) and non-corroded (bottom) areas on the medial aspect of the inner sleeve surface.

fracture and various forms of surface corrosion has been well reported [2, 18, 27, 34]. Furthermore, this particular implant was installed in slight varus that would have increased the moment arm and, therefore, the lateral bending stresses on the hip stem increasing the likelihood of crack initiation.

Previously published cases all bear resemblance to the present study in that mechanical micromotion between tapered components leads to damage of the surfaces causing a fatigue fracture of the stem. Patel et al. reported three cases of S-ROM® hip system failure at the stem-sleeve junction [26]. No retrieval analysis was performed on the failed stem; however, they concluded that the failures were likely a result of fretting surface damage due to the micromotion at the stem-sleeve interface. Similarly, Mehran et al. reported a case of failure at the stem-sleeve interface [25]. Their microscopic analysis of the retrieved stem concluded that a fatigue fracture, secondary to cyclical loading and micromotion at the stem-sleeve interface, ultimately resulted in catastrophic component failure, but no detailed retrieval analysis was published with their study. Carlson et al. [18, 30] in their series examined 78 retrieved S-ROM® hip stems for fretting and corrosion. Seven of the devices were removed due to femoral stem fracture occurring proximally in the stem-sleeve tapered region. These fractured stems had been implanted longer than the non-fractured cohort, were under increased stress due to small stem diameter and large offset distances, and were found to have severe corrosion. However, the effects of implant positioning and proper sizing were not evaluated in this study.

Despite these reported catastrophic failures, clinical studies have thus far demonstrated the S-ROM®'s excellent outcomes and survivorship [26]. In the current literature, there does not appear to be a detectable increase in the rate of osteolysis judged radiographically because of the implant's modularity after intermediate follow-up [7].

The present case study confirms previous theories that mechanically assisted crevice corrosion at the stem-sleeve interface appears to be responsible for this catastrophic failure. Improving the modular taper junction is crucial to preventing micromotion at the stem-sleeve interface that

accelerates fretting corrosion mechanisms that can weaken the femoral stem causing subsequent implant failure. It is commonly known that perfect drying of the tapered surfaces before assembly is recommended to limit the risk of fretting and corrosion [42]. The present report is based on a detailed retrieval analysis.

In conclusion, we have found that modular stem failure is multifactorial. These factors can include the effect of mechanical micromotion and associated crevice corrosion at the stem-sleeve interface, the use of a longer neck for higher offset, varus implant alignment and a small cross-sectional area of the stem, in an obese and very active patient. We recommend a national implant retrieval registry to determine precisely the incidence of implant-related complications and examine the root causes of failure. This will help surgeons to identify trends of implant failure that are a direct result of implant design or materials and assist the manufacturers in improving future products.

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Disclosures

Conflict of Interest: Feras Waly, MBBS; Fahad H. Abduljabbar, MBBS, FRCSC; Trevor Gascoyne, MSc; and Olga Huk, MD, MSc, FRCSC, have declared that they have no conflict of interest. Thomas R. Turgeon, MD, FRCSC, reports grants from DePuy and Zimmer and non-financial support from Smith and Nephew, outside the present work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was waived from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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