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Case study

Fractography of a neck failure in a double-modular hip implant

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ABSTRACT

The tapered joints of modular hip implants are prone to fretting and crevice-corrosion. This can lead to total failure in under a year, especially for heavier, more active implant recipients. In this study, fractography of a failed Profemur Z implant showed that a life limiting fatigue crack was nucleated on the anterolateral surface of the implant's neck. The fatigue crack nucleation area appeared to have both more fretting damage and a higher corrosion rate than on other surfaces of the neck.

1. Introduction

Double-modular hip implants consist of a neck that is separate from both the stem and the head – the three parts fit together via tapered joints. Several necks and heads of different geometries are available, allowing the surgeon to optimize the hip angle, hip offset and leg length during surgery. However, concerns exist about the stability of the tapered joints used to connect the neck to the head and stem [1,2]. Specifically, tapered joints are susceptible to fretting and crevice-corrosion, which may lead to loosening, release of toxic metal ions and mechanical failure.

A study that followed 5000 double-modular hip implants (Metha Short Hip Stem Prosthesis) between 2004 and 2008 found that 1.4% of the titanium necks failed after approximately two years [3]. Most of the failures were attributed to the formation of microcracks on the anterolateral surface (i.e., toward the front and outside of the body) of the neck due to fretting and corrosion inside the tapered joint between the neck and stem. This damage led to the formation of a fatigue crack, and ultimately, complete fracture of the neck. According to Ref. [3], risk factors for neck failure included being male, heavier, more active, and having a sharper hip angle.

Three additional case reports of neck failures have been published on the same model of hip implant as this study's (Wright Medical Technology's Profemur® Z) [4–6]. All three reports found neck fracture to be caused by a fatigue crack which originated inside the tapered joint on the anterolateral surface of the neck, identical to those of Ref. [3]. All three reports also suggest fretting and/or corrosion played a role in the neck failures. However, no clear fatigue crack nucleation site was shown, possibly because of damage incurred after neck failure. This study does show a clear nucleation site, and comes to similar conclusions for failure as these aforementioned studies.

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2. Experimental

The implant recipient was described as an active 47-year-old male, weighing 84 kg. The implant consisted of a size 3 Profemur® Z stem, 8 degree varus neck, and a −3.5 mm × 50 mm Conserve® Total Class-A head. Both the neck and stem were made of Ti–6Al–4V, and the head was made of a cobalt-chrome alloy. The neck of this implant failed after three years (implanted in 2006, failed and removed in 2009). Due to legal reasons, the parts were examined in the as-received condition (no cleaning, cutting, etc.) using a scanning electron microscope (JEOL 6100) in 2011.

3. Results

Fig. 1 shows optical photographs of both fracture surfaces, as well as a model of where fracture occurred in relation to the modular hip implant. After fracture, one piece of the neck remained inside the stem's female taper; the other piece remained

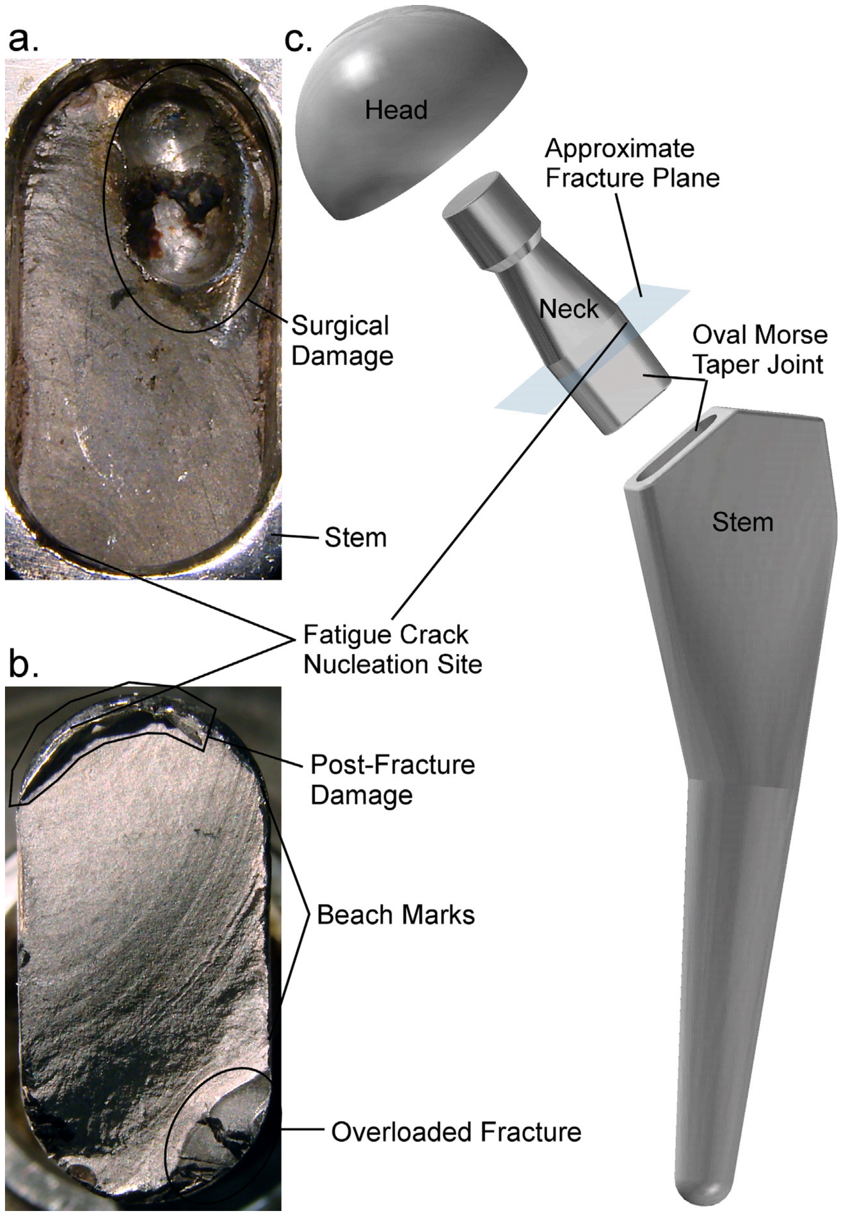

Fig. 1. (a) Optical photograph of the fracture surface of the neck that remained in the stem. The surgical damage was created by a tool used to remove the implant from the body. (b) Optical photograph of the fracture surface of the neck that remained attached to the head. Post-fracture damage occurred when the fractured neck slid across the inside of the stem's taper surface. (c) Exploded model of the modular hip implant, showing where neck fracture occurred. Both the neck and stem were made of Ti–6Al–4V.

attached to the head. The piece of the neck that remained in the stem was damaged by the surgeon during removal of the implant from the body. This surgical damage occurred near the overloaded portion of the fracture surface – the fatigue crack nucleation site remained pristine. In contrast, the piece of the neck that remained connected to the head was not damaged during surgery, but it was damaged when the fractured neck slid out of the stem's female taper after overload. Unfortunately, this post-fracture damaged ruined the areas of the taper surface and fracture surface that coincided with fatigue crack nucleation. Thus, only the stem-side neck was examined further for crack nucleation causes. The head-side neck was used to assess the extent of fretting and corrosion between the surfaces of the Morse taper joint.

Visually, the neck surfaces that remained outside of the tapered joint were shiny, with no obvious signs of corrosion. The neck surfaces inside the Morse taper, however, were darkened and appeared corroded. SEM images of these surfaces are shown in Fig. 2 and confirmed the visual inspection. Outside the tapered joint, the surfaces were uniform with original

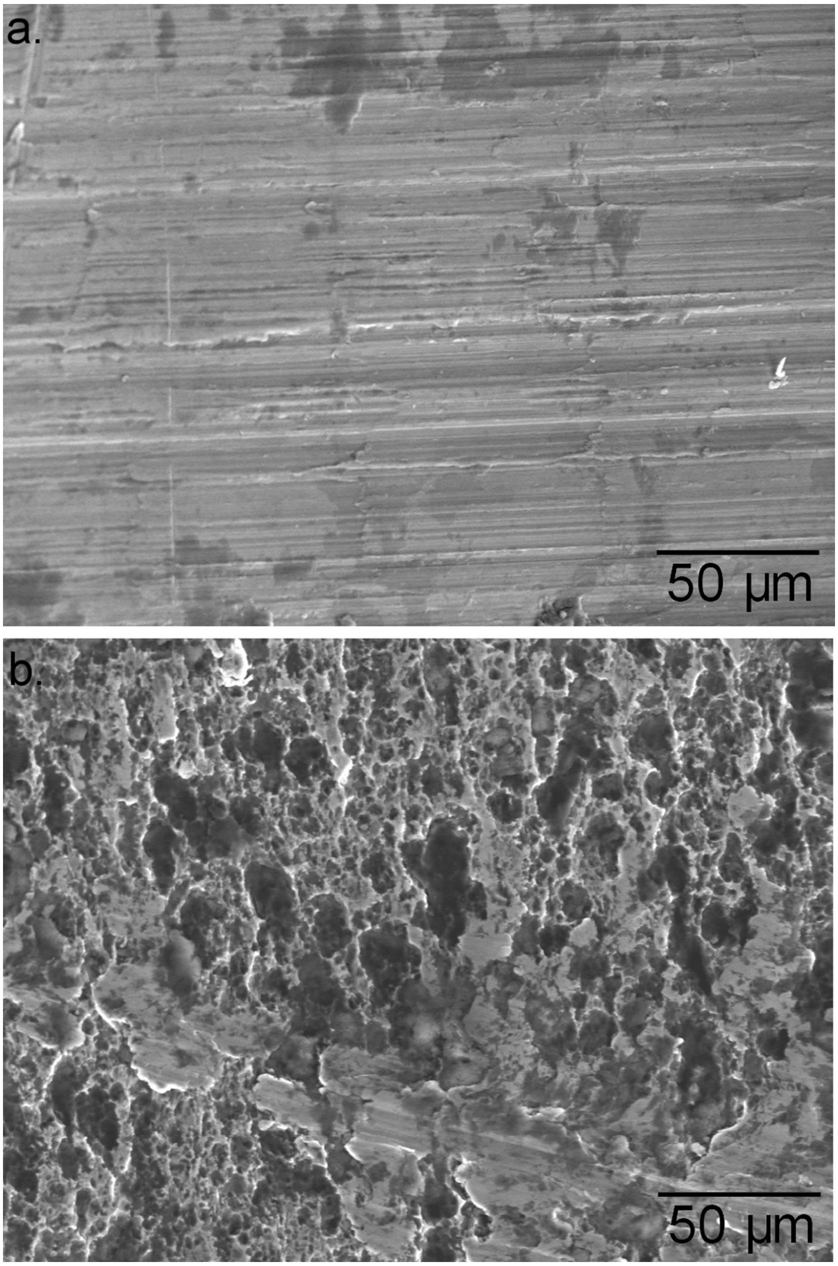

Fig. 2. (a) Secondary electron image of the surface of the neck's Morse taper located outside the joint's contact area. This surface was uniform and showed original machining marks, which run perpendicular to the long axis of the neck (the long axis of neck runs from top to bottom in this image, with the head side at top). (b) Secondary electron image of the surface of the neck's Morse taper located inside the joint's contact area. Most of the surface was corroded and fretted. (Orientation is same as in (a).)

machine marks evident. Inside the joint, the surfaces were extremely non-uniform and roughened, indicative of crevice-corrosion. Areas of fretting were also observed, somewhat less frequently than corroded areas. As mentioned earlier, however, the anterolateral portion of the taper surface that was expected to contain the highest degree of fretting was damaged after fracture as the neck slid out of the stem. Only a very small fraction of the tapered surface that was inside the joint was free of fretting or corrosion.

Signs of corrosion were also observed while imaging the fracture surface. Fig. 3 shows secondary and backscattered electron images of the fracture surface, taken at the interface between the neck and the stem. The brightest phase in the backscattered image is the titanium alloy. It is unclear whether the darker phase at the joint interface is a solid corrosion product or residue left after desiccation of body fluids. No EDS was performed because the fracture surface of the neck was recessed too far into the stem to yield quality X-ray spectra at this joint interface. Regardless, the jagged edge of the titanium neck and the gap between the neck and stem is indicative of corrosion. The entire circumference of the fracture surface was separated from the stem by 10–80 μm, giving an average corrosion rate of about 15 μm/yr.

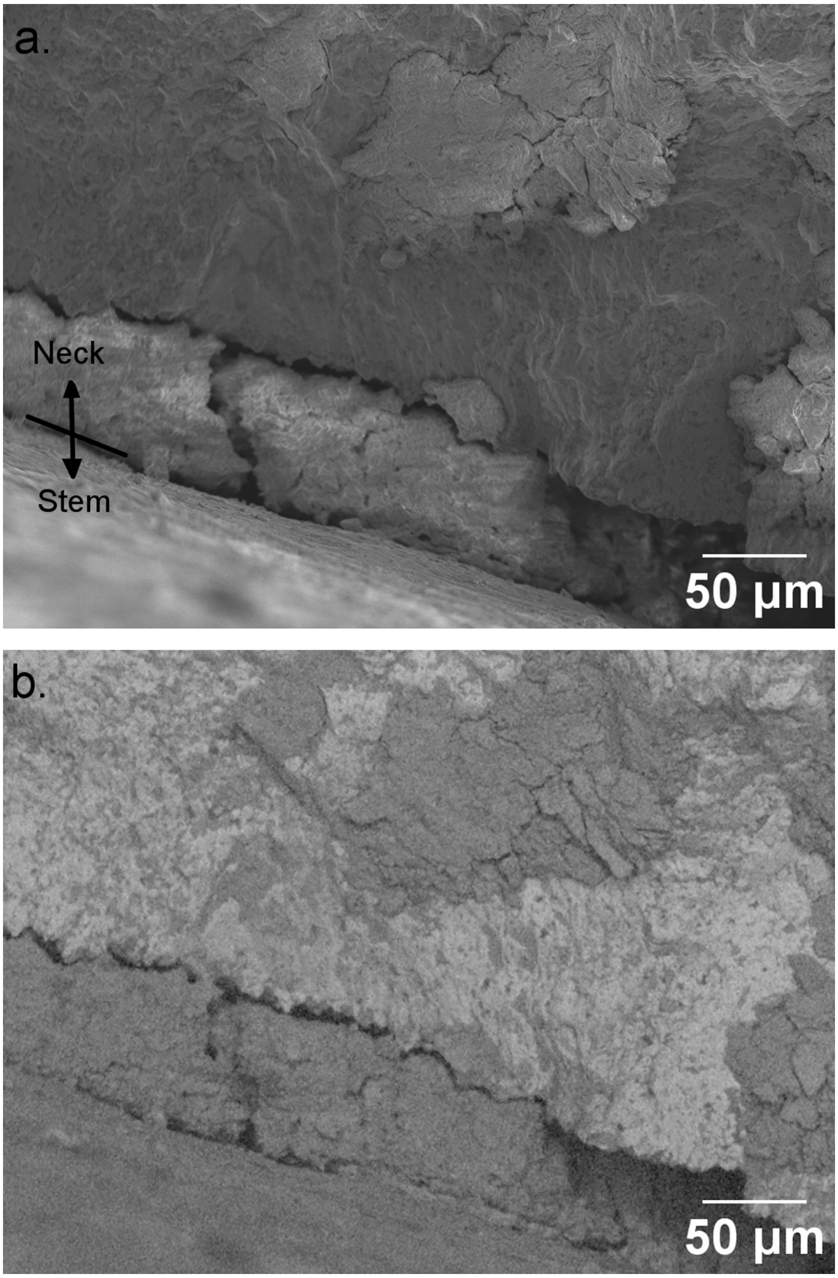

Fig. 3. (a) Secondary electron image of the stem–neck joint interface at the fatigue-fracture plane. (b) Backscattered electron image of the same area. The entire circumference of the neck along the fatigue-fracture plane was corroded.

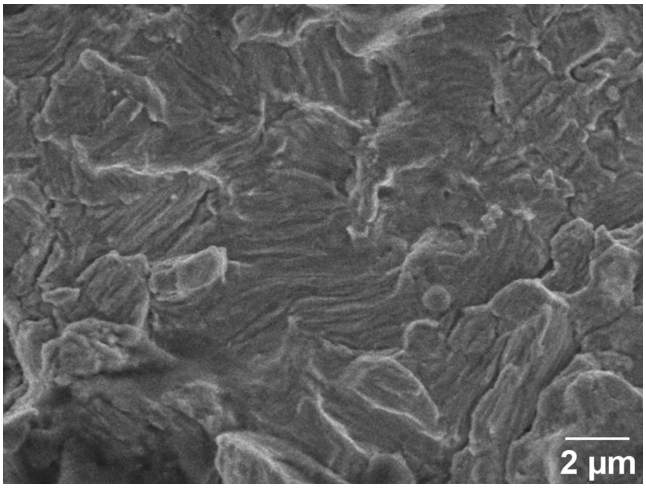

Fig. 4. Secondary electron image of the fatigue-fracture plane showing fatigue striations. The striations were present throughout the beach-marked area shown in Fig. 1b.

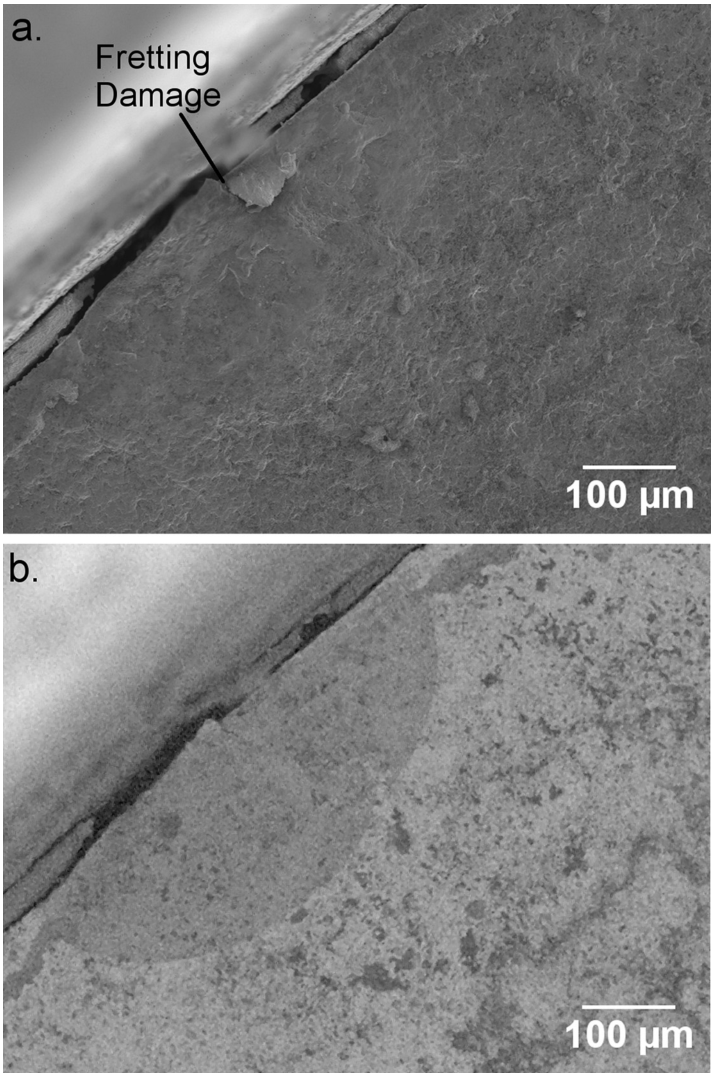

Fig. 5. (a) Secondary electron image of the fatigue crack nucleation site. (b) Backscattered electron image of the same area. The site includes fretting damage at the anterolateral surface of the neck and corrosion which has penetrated more than twice as deeply as other areas of the stem–neck joint interface.

Based on the optical photographs (Fig. 1), approximately 94% of the fracture surface area consisted of beach marks indicative of fatigue crack growth. Only 6% of the area was from the final overloaded fracture. SEM images confirmed the presence of a fatigue crack. In secondary electron images (Fig. 4), fatigue striations were clearly seen throughout the beach-marked area of Fig. 1b. Also, a distinct crack nucleation site was found (Fig. 5). The site appears to be a crack oriented perpendicularly to the fatigue crack and surrounded by a region different in chemical composition to that of the base alloy. Although it may have been a pre-existing flaw, the crack was likely created by fretting; and the zone surrounding it appears to be the result of corrosion that was enhanced by the presence of this crack. If it were a preexisting flaw, one would expect to find similar flaws on the surface of the taper outside the joint or on central areas of the fracture surface – neither was observed during this study. The penetration depth of corrosion at this nucleation site is more than twice that of all other areas along the circumference of the fracture surface. Tapered joints in a variety of common engineering applications are never considered leak tight without the use of an additional sealing mechanism (o-ring, grease, etc.). Given that no sealant is used in hip implants, some degree of fluid penetration into the joint is inevitable.

4. Conclusions

Based on the findings of this study and others, Ti–6Al–4V implants are susceptible to crevice-corrosion because of fluid penetration. Furthermore, the load used during surgery to press-fit the tapered joint together appears to be inadequate, since fretting damage has also been commonly observed. The combination of fretting and crevice-corrosion significantly reduces the fatigue strength of the Ti–6Al–4V neck in double-modular hip implants.

References

[1] Bobyn JD, Tanzer M, Krygier JJ, Dujovne AR, Brooks CE. Concerns with modularity in total hip arthroplasty. Clin Orthop Relat Res 1994;298:27–36.
[2] Kop AM, Swarts E. Corrosion of a hip stem with a modular neck taper junction: a retrieval study of 16 cases. J Arthroplasty 2009;24(7):1019–23.
[3] Grupp TM, Weik T, Bloemer W, Knaebel H. Modular titanium alloy neck adapter failures in hip replacement – failure mode analysis and influence of implant material. BMC Musculoskelet Disord 2010;11:3.
[4] Wilson DAJ, Dunbar MJ, Amirault JD, Farhat Z. Early failure of a modular femoral neck total hip arthroplasty component. J Bone Joint Surg 2010;92(6):1514–7.
[5] Dangles CJ, Altstetter CJ. Failure of the modular neck in a total hip arthroplasty. J Arthroplasty 2010;25(7):1169e5–9e7.
[6] Wright G, Sporer S, Urban R, Jacobs J. Fracture of a modular femoral neck after total hip arthroplasty. J Bone Joint Surg 2010;92(6):1518–21.