Failure of a Modular Hip Implant at the Stem-Sleeve Interface

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abstract

In the current era of total hip arthroplasty (THA), orthopedic surgeons have several fixation options at their disposal. The modern monoblock prosthesis, introduced by Dr. Sir John Charnley, has seen many modifications since its inception in the 1970s and continues to be the most commonly used prosthesis style for primary and revision THA. Proximal modular sleeve technology was introduced in 1967 by Konstantin Sivash, modifying his original 1956 Sivash Stem design. The design is now known as the S-ROM, and although design modifications continue to date, the fundamental structure of the S-ROM remains essentially unchanged. Several other proximal modular prostheses are now currently available for use in THA. Although this similarity in design enables considerable surgical flexibility, it also links their potential for catastrophic failure.

This aim of this article was to present a brief history of proximal modularity in THA and to add to the small body of literature regarding catastrophic failure in modular hip implants, including its proposed etiologies including micromotion, fretting and corrosion.
Several fixation options exist for total hip arthroplasty (THA). The modern monoblock prosthesis, introduced by Dr Sir John Charnley, has seen many modifications since its inception in the 1970s and continues to be the most commonly used style of prosthesis for primary and revision THA.\(^1\) Proximal modular sleeve technology was introduced in 1967 by Konstantin Sivash, modifying his original 1956 Sivash Stem design.\(^2\) The design was acquired by US Surgical Corporation (Norwalk, Connecticut) in 1971. By 1974, Doug Noiles and Fred DeCarlo, 2 US Surgical Corporation engineers, had built on the original design to include a distal coronal slot and 8 distal flutes.\(^1\) In 1982, Joint Medical Products (New Brunswick, New Jersey) acquired the rights to US Surgical Corporation’s orthopedic devices, and this prosthesis was given its modern name: S-ROM (Sivash-Range of Motion). During the next 3 years, the S-ROM continued its evolution, with the addition of the calcar spout and steps to the modular ZTT metaphyseal sleeve, and the polished stem finish distal to the sleeve. Now, the S-ROM is marketed by DePuy Orthopaedics, Inc (Warsaw, Indiana), and although design modifications continue to date, the fundamental structure of the S-ROM remains essentially unchanged. Several other proximal modular prostheses are now currently available for use in THA. Although this similarity in design enables considerable surgical flexibility, it also links their potential for catastrophic failure.

One modern example of failure in modular hip implants was seen with the Profemur-Z (Wright Medical Technology, Inc, Arlington, Tennessee). This proximally seating modular hip implant uses a Morse taper configuration to adjust leg length, offset, and femoral version. This system has been used extensively in the Australasian market with unfavorable results secondary to an unacceptably high rate of catastrophic failure at the modular junction. In 2009, the Australian Orthopaedic Association identified an alarming trend of Profemur-Z failures.\(^3\) Their national implant registry revealed an 11.2% failure rate within 3 years, with all implant failures occurring within the modular stem-body tapered junction.\(^3\)

The occurrence of femoral stem failure has also been reported for the ZMR (Zimmer, Warsaw, Indiana), a similarly designed modular implant. This hip system offers 3 stem designs (taper, porous, and splined) and a variety of modular body shapes and sizes. This allows for versatility in the restoration of hip kinematics by adjusting anteversion, leg length, and horizontal offset. Lakstein et al\(^4\) reported a series of failures of the ZMR system at the proximal modular interface. Macroscopic imaging following implant retrieval demonstrated that all stem fractures were located 1 to 2 mm proximal to the visible body-stem junction. It was concluded that a repetitive bending moment led to crack initiation, propagation, and ultimate implant failure.\(^4\) Furthermore, chemical analysis of the implants also demonstrated that the failure was associated with wear between the stem and the body.\(^5\)

The overall literature on modular implant failure is sparse. The current article presents a case of modular implant failure and offers an expanded discussion of the cause of failure in modular implants.

**Case Report**

A 61-year-old man with a medical history limited to hypertension underwent right THA for advanced osteoarthritis using a Kocher-Langenbeck incision. A Howmedica (Mahwah, New Jersey) 54-mm Outer-diameter acetabular component with a 32-mm polyethylene liner were implanted. On the femoral side, a 36+8L S-ROM stem with the dimensions \(18 \times 13 \times 160\) mm and a 18F-Large ZTT sleeve were used. No complications occurred intra- or postoperatively. Approximately 8.5 years after insertion of the construct, the patient developed acute lateral thigh pain while standing from a seated position, associated with novel sensations described as “grinding” and “snapping” within the groin. On presentation to the authors’ institution, he was completely asymptomatic, with a painless range of motion through a 105° flexion-extension arc, internal and external rotation of 25° and 30°, respectively, and 40° of abduction. Radiographs demonstrated no evidence of loosening, subsidence, or fracture of the components (Figure 1), and a serologic workup was within normal limits. His symptoms abruptly reemerged
1 month later, now with an inability to ambulate or bear weight secondary to pain. Radiographs demonstrated a failure of the S-ROM femoral component at the stem-sleeve interface (Figure 2). At revision, a modified Kocher-Langenbeck approach with an extended trochanteric osteotomy was used. It was noted that the S-ROM stem failed catastrophically along the superior margin of the metaphyseal sleeve. The macroscopic appearance of corrosion, as denoted by blackened areas of the stem and stem-sleeve marginal junction, was visualized. A Zimmer ZMR 16 ×185-mm revision taper stem, size C cone body, with 35-mm buildup and 40-mm neck offset, and a 0+32-mm 12/14 taper head were inserted. The acetabular component was maintained, given its stability, with the polyethylene liner exchanged for a Stryker T4 (Stryker Orthopaedics, Runnemede, New Jersey) with a 32-mm internal diameter. Two years after revision surgery, the patient continues to do well with a painless 110° flexion-extension arc, 45° of abduction, and internal and external rotation of 25° and 35°, respectively.

According to microscopic analysis performed by DePuy Orthopaedics, Inc, a fatigue fracture, secondary to cyclical loading and micromotion at the stem-sleeve interface, ultimately resulted in catastrophic component failure.

**Figure 2:** Anteroposterior (A) and frog-leg lateral (B) radiographs identifying the failure.

**D**iscussion

Modularity in THA has become an increasingly popular option for complex primary and revision cases.1-3,6 Since its inception, the overwhelming majority of design permutations have resulted in clinical success. However, such successes are balanced by the additional risk of modularity because abnormal stress distribution can lead to catastrophic failure secondary to corrosion, wear, fretting, and fatigue of mating surfaces.5-7,10 Of these, fretting is the most common and unavoidable danger.

Fretting is a wear mechanism resulting from low-amplitude oscillating, sliding movement between 2 mechanically joined parts under loads. It occurs at a magnitude of motion that is so minute that all modular THAs are susceptible.11 It is possible that the constant cyclical loading on the modular interface forms microcracks that lead to greater stress and debris particles. Microscopic relative movement between mating surfaces of levels, as low as 0.125 to 3 µm, has been found sufficient to produce fretting debris.12,13 Abdullah’s11 biomechanical study demonstrated that a high assembly load reduces the magnitude of stress and micromotion fluctuations during ambulation, predicting lower fretting and fretting fatigue damage resulting in an increased lifetime of the prosthesis. Therefore, intraoperatively, orthopedic surgeons should aim for an assembly load of 6000 N or higher, which is higher than the largest anticipated ambulatory load.

Multiple authors have identified a link between the particles generated from fretting surfaces and an inflammatory response.14-16 Particles containing titanium can get trapped between articulating surfaces, causing a cytokine release and leading to a cascade ending in third-body wear and osteolysis.10 In the largest prospective study to date on stem-sleeve survivorship in S-ROMs, Le et al17 demonstrated that 54% of their cases had femoral osteolysis. No cases of osteolysis were isolated to, or arose from, the stem-sleeve junction. The authors were uncertain whether the femoral osteolysis was influenced by stem-sleeve fretting debris. Although the S-ROM has proven to be successful, it seems that any location that can allow micromotion is vulnerable to fretting and wear due to titanium particle release into the adjacent tissue with a consequent inflammatory cascade.

Bobyn et al14 reported that to gain the advantage of modularity, fretting would be inevitable due to normal physiological loading and unloading. However, if these cases of stem-sleeve interface failure continue, the goal must be to make fretting obsolete, which may be impossible with modularity.

Corrosion is another possible cause of catastrophic failure in modular hip implants. Collier et al17 reported that the geometry of the taper, the surface area ratio, and mixed metal implants can affect the rate of corrosion in the implants. Schutz and Thomas18 reported that titanium alloys can lead to the formation of titanium chlorides within the crevice. This chemical is unstable, and metal chlorides can react with water, leading to the formation of hydrochloric acid and titanium oxide/hydroxide. Consequently, the crevice would have an acidic pH level resulting in the titanium losing its passive film and becoming thermodynamically unstable.19 This reaction leads to corrosion and irregularly shaped pits in the modular junction, creating a
point of vulnerability. This acidic solution can form in both mixed and same-metal constructs. However, corrosion can be decreased by same-metal constructs because it will decrease the surface area ratio of cathode to anode. Collier et al. also reported that the larger the ratio between the cathode and anode, the more destruction that can occur at the anodic area. Thus, by using a single alloy throughout the prosthesis, one could expect to reduce the described corrosive force.

Cold fusion at the stem-sleeve interface may pose an obstacle during revision, and, more importantly, it may allow for vulnerability to prosthetic fracture. In the current case, fretting and corrosion led to failure. However, some studies have shown that corrosion may also lead to failure of disengagement. Fraitzl et al. performed a study on 22 S-ROM implants using macroscopic light and scanning electron microscopes, as well as energy dispersive radiograph analysis, to determine the role of corrosion in failure to disengage at the stem-sleeve interface. The study demonstrated that 13 of 22 implants had moderate to severe corrosion with discoloration and black debris consistent with titanium oxide at the stem-sleeve interface. Six of the 13 corroded implants needed a significant mechanical load or to be cut to be removed. They also demonstrated no correlation between the length of time after implant and damage severity. Thus, factors other than implantation time and, by implication, the number of cycles of loading that could contribute to fretting damage must be responsible for the formation of the cold weld at the stem-sleeve interface. Is it then possible that fretting and corrosion lead to a cold weld of the stem-sleeve interface, which decreases the motion, creating a more brittle construct and thereby allowing the forces applied on the construct to cause a fracture?

**CONCLUSION**

Design and functionality of modular hip prostheses have evolved over the past several decades, giving modern orthopedic surgeons a valuable tool with which they can customize leg length, offset, and version to improve patient outcomes. Despite their overall success, modularity adds an inherent mechanical weakness, leading to fretting and corrosion, with the potential for catastrophic failure. Several case examples have identified this complication; however, because no national joint registry exists, no reliable way exists to precisely measure the frequency with which this complication occurs. It is important for the orthopedic community to identify causes of failure and to investigate the potential for a national joint registry to aid in early identification of such complications. Furthermore, biochemical studies could be used to elucidate specific targets within the inflammatory cascade to prevent early corrosion and catastrophic failure.

**REFERENCES**